Ultra-high resolution modeling of the tropical air sea interaction: Demonstration of Oceanic part

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1.Backgrounds

Importance of cumulus convection in the energy and hydrological cycle of the earth's atmosphere can never be over-emphasized. But its smallnesses in temporal and spatial scales compared to the scale of the global atmosphere as a whole prevent it from explicitly calculated in current generation of GCM's. Thus every GCM includes cumulus parameterization, which have many uncertainties that arise from our poor understandings on the interaction between large scale motions and the cumulus clouds. To examine the interaction explicitly, so called 'cumulus ensemble models'(CEM) had been used since early 1980's. They are large domain (O(100km)) cloud convection models, where one imposes an 'observed' large-scale forcing and analyzes the results in a statistical manner. There remains, however, a critical defect in this approach; in the real atmosphere the interaction between cumulus clouds and large-scale motion is two-way, whereas in CEM it is forced to be one-way (large-scale motion causes cumulus convection).

Similar concern also applies to the tropical air sea interation (TASI). Usually, the TASI is thought of as a large-scale problem; typical example is El Nino and Souther Oscillation, whose spatial and temporal scales are O(10,000 km) and O(2 years), respectively. Such treatment can partially be justifiable on the ground that (1) tropical wind system that controls the air-sea exchange processes has great horizontal scale, and (2) thermal adjustment time of ocean mixed layer as a whole is long. However, atmospheric forcing to the ocean undoubtedly contains considerable smaller scale signals which is produced by cumulus convection. The significance of the small scale components to the TASI problem as a whole is still unclarified.

As documented in Nakajima(1994), I constructed a two-dimensional cloud model that covers a domain of 16384km. Its high spatial resolution (2km) and incorporation of cloud microphysical processes allows cumulus convection to be represented explicitly. At the same time, the domain is as large as the longitudinal size of the pacific. As remarked in Nakajima(1995), if we make an ocean numerical model whose resolution and domain size is similar to the cloud model and conduct a coupled experiments, lots of informations on the TASI in the wide range of resolution will be collected.

In this report, some preliminary results of the numerical study using such a high resolution ocean model is presented. Currently, the interaction between the atmospheric model is under construction; the ocean model is run independent of the atmosphere. Moreover, the phenomena corresponding to the present calculation, oceanic deep convection, occurs mainly in extra–tropics. Thus the contents of this reports should rather be taken as a demonstration of such high resolution ocean modelings in general. The results concerning the TASI, the main theme of this study, will be reported in the next year.

2. *Deep convection in the ocean*

The widespread homogeniety of the water temperature in the deeper half of the global ocean is an evidence of its common origin. In fact there are only two the places where the sea water sinks from the surface layer into the deep ocean: one is high latitude Atlantic ocean, and the other is Weddel sea near the Antarctic continent. One of the important procecess of the deep water formation is deep gravitational convection resulting from strong surface cooling by the atmosphere in wintertime. [For more details, see Killworth(1983).]

Such deep convection has small intrinsic scale both in time and in space, and can presumably respond to small scale inhomogeniety of the atmospheric cooling. Sea ice can also modulate the atmospheric forcings in various ways even if it could be more or less homogeneous. Nevertheless the sensitivity of oceanic deep convection to the spatial or temporal inhogomeniety of surface forcing is has not be considered in the past. [For past theoretical or numerical studies, see Jones and Marshall(1993)] Thus, I will examine these points by a series of numerical experiments with systematic variations of surface forcings.

3. Design of Experiments

The numerical ocean model is based on non-hydrostatic, Bousinesq system. The effect of the earth's roation is included ($f = 10^{-4}$). The domain is two–dimensional and extends horizontally 32 km and vertically 2000m. The spatial resolution is vertically 100m and horizontally 250m . The effect of salinity is currently not included. Non–linear viscosity and diffusivity are employed, and their intensities are set to be minimal that can maintain stable numerical integrations.

Four serieses of experiments are performed. Different variation of surface flux is considered in each series. Serieses TA and TB examine the temporal inhomogenieties, whereas serieses XA and XB examine the spatial inhomogenieties.

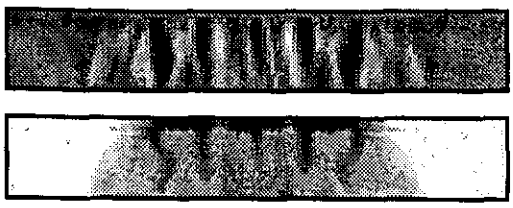

Figure 1: The snap-shots of vertical velocity field(upper panel) and temperature(lower panel) in case XA2. Light(Dark) color means positive(negative) deviation.

The series TA examines the sensitivity to the degree of temporal concentration of the surface cooling. In series TA, i.e., experiments TAi, i=1,2,...,8, the intensity of the cooling is spatially homogeneous. In time, it is specified as $2^{(i-1)} \times 100[W/m^2]$ for $8/2^{(i-1)}[days]$ from the beginning of each experiment, and is zero for the rest of each time integration.

The series TB examines the sensitivity to the wavelike change of the surface coooling with various period. In series TB, i.e., experiments TBi, i=1,2,...,8, the intensity of the cooling varies in time t as $(1+sin[2^i \times 2\pi t/(8days)]) \times 100[W/m^2]$. Again, it is spatially homogeneous.

The series XA examines the sensitivity to the degree of spatial concentration of the surface cooling. In series XA, i.e., experiments XAi, i=1,2,...,7, the intensity of the cooling is temporaly constant. In space, it is specified as $2^{(i-1)} \times 100[W/m^2]$ in an area whose width is $32/2^{(i-1)}[km]$ and is zero elsewhere.

The series XB examines the sensitivity to the degree of spatial concentration of the surface cooling, in a way that is different from the series XA. In series XB, i.e., experiments XBi, i=1,2,...,8, the intensity of the cooling is temporaly constant. In space, it is specified as $2^{(i-1)} \times 100[W/m^2]$ at every $2^{(i-1)}$ grid points.

All experiments continue for 8 days from the initial condition of rest and newtrally stratified state. Note that the total amount of surface cooling during the time integration is the same in all cases in spite of the exsistence of temporal or spatial inhomogenieties.

4.Results

Before examining the sensitivity experiments, the qualitative feature of the simulated deep convection is shown. Fig.1 shows the snap-shots of the vertical velocity and temperature in the experiment XA2, in which half of the domain is cooled. In the cooled region, the vertical motion is characterized with the horizontally alternating upward and downward motions. The downward moving plumes are cooler than the surrounding upward moving water. In collective sense, the water in the cooled region is cooler than the water in the region not

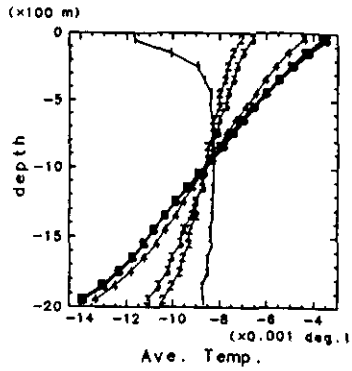

Figure 2: The vertical profiles of horizontally averaged temperature at t=8day in cases in the series TA. The numbers on each line represents the index in the series.

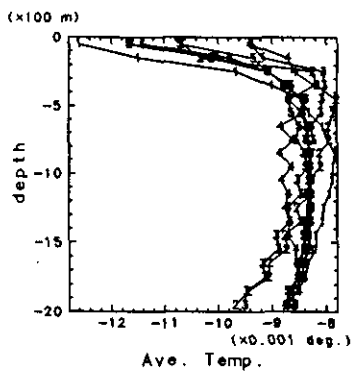

Figure 3: Same as Fig.2 but for the series TB.

cooled. The horizontal pressure gradient associated with this temperature difference is balanced by the Coriolis force induced by the transverse flow (i.e., flow in the direction perpendicular to the paper). Transverse flow is also associated with individual plumes (not shown).

We proceed to the examinations on the sensitivity experiments. As the pages are limitted, we focus exclusively on the vertical profiles of the horizontally averaged temperature at the end of the each experiments.

Fig.2 shows the final vertical profiles of mean temperature for series TA. It is clearly seen that shorter and more intense cooling produces colder bottom water. But also noted is that, when the time interval of cooling is shorter than 1 days, the temperature profile is insensitive to the degree of temporal concentration of cooling. Close examination of the time evolution of each cases in series TA (not shown here) reviels that the threshold timescale, 1 day, is the characteristic onset time scale of convection after the start of the cooling. In other words, convection does not 'feel' the time variability of the forcing if its time scale is shorter than that of the growth of convection itself.

Fig.3 shows the final vertical profiles of mean

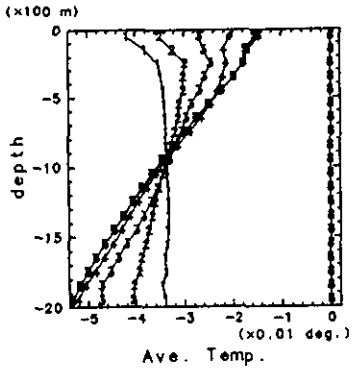

Figure 4: Same as Fig.2 but for the series XA. (Neglect the line with index 8.)

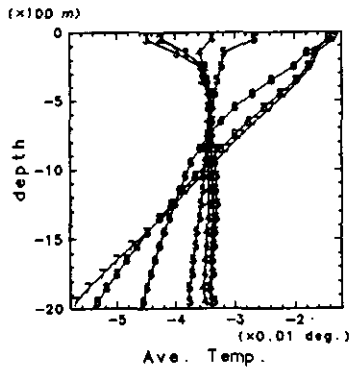

Figure 5: Same as Fig.2 but for the series XB.

temperature for series TB. The differences among the experiments is smaller than those in series TA. Namely, the profiles for experiments TB5 ~ TB8 is almost the same; the insensitivity to variation in one day or smaller appeared also in this series.

Fig.4 shows the final vertical profiles of mean temperature for series XA. It is clear that more spatially concentrated cooling produces colder bottom water. However, like the threshold time scale for 'sensible' time variation, there seems to be a threshold spatial scale that can be felt by the convection; the vertical profile for case XA5 ~ XA8 is almost the same, indicating that the convection can not 'resolve' the scale smaller than 2 km. This scale is almost the same as those of the sinking plumes (see Fig.1).

Fig.5, which shows the final vertical profiles of mean temperature for series XB, also implies the insensitivity to the spatial imhomogeniety with horizontal scale smaller than 2 km.

Finally, it should be noted that the effect of spatial imhomogeniety is much more significant than that of temporal variability. The temperature differences among the series TA or TB is ~ 0.01 K, which is much smaller than those in series XA or XB, ~ 0.05 K.

5.Concluding remarks

The results briefly summerized above shows the existence of threshold temporal or spatial scales in the response of the convection to the external forcings, which is related to the characteristic scales of the convection itself. This type of connection between the sensitivity of certain system to external forces and the characteristic scale of the system may also exsists in the TASI problem. In other words, the interaction between the air and sea may be different in models with different resolution, because the scale of dynamical systems in air or sea sometimes is affected by the model's resolution. This point is the original aim of this study, and will be reported in the future.

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