P1.2 THE RELATIONSHIP BETWEEN THE INITIAL TRIGGER AND THE FINAL STATE FOR THE CONVECTIVELY UNSTABLE ATMOSPHERE

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Abstract

This paper uses new generation meso-scale model—Weather Research and Forecasting (WRF) model to simulate the convection in the convectively unstable atmosphere and to study the relationship between the final state of the air and the initial trigger that activates the convection. The results show the well-developed cells. At final state the air is balanced between the lifting, instability and moisture of the air. Lacking of anyone of these three ingredients necessary for convection is not going to have convection any more. At final state, the total CAPE released is proportional to the strength of the initial bubble. The kinetic energy, the vertical distribution patterns of moisture and moist static energy (MSE) also show their coherent relationship with the strength of the initial bubble. When the strength of the initial bubble reaches a particular point, the final state varies near an equilibrium state, i.e. no linear relationship exits between the strength of the initial bubble and the released CAPE, the left moisture and the kinetic energy. Over the disturbed area, the differences at final state or during the evolution between different cases are much smaller than those over the whole domain. The cases with surface moisture flux show different results from the cases without surface heat and moisture flux. They have more CAPE left, more moisture hold in the air and more latent heating happen at mid-layer. Comparing the case with surface flux over ocean to the case over land, the results show similar results.

1. INTRODUCTION

Of the many subgrid-scale processes that must be represented in the numerical models of the atmosphere, cumulus convection is perhaps the most complex and perplexing. Cloud-scale convections are driven by latent heating from condensing water vapor. But most of these convections are subgrid-scale processes for the conventional grid size of the general circulation and numerical weather prediction models. As we all know these processes have strong impacts on the larger-scale circulation. To measure their collective effects, we have to parameterize these small convections. But the simulation of many individual phenomena is sensitive to the way convection is parameterized. The cumulus parameterization is based on the correct understanding of the effects convection processes have on the larger-scale circulation. The collective effects of convection on background will be different in terms of the different initial triggers. The objective of this paper is to investigate the relationship between the initial conditions trigging the convection and the final equilibrium states after the convection to qualitatively propose in some aspect the effects of convection on background field.

2. EXPERIMENTS

a. Experimental designs

The experiments are idealized two-dimensional single cell simulations in x and z direction. The background profile is based on the Ooyama input profile (Ooyama 2001). It is a slightly humidified version of Jordan's (Jordan 1958) mean tropical atmosphere for the hurricane season. The background field is set to be uniform in x direction and initially the air is at rest. No shear is added and the air will have an air mass type of convection. From the initial moist static energy profile in figure 3, it shows the air is convectively unstable.

To trig the convection, we put warm bubbles at the surface at initial time. The original bubble is the same as that in Ooyama (Ooyama 2001) as following:

$$T' = \Delta T_{\max}[1+\cos(\pi r)]/2 ,$$

where, for |x| $\le a$ and 0 $\le z \le (b+c)$,

$$r \equiv [(\frac{x}{a})^2 + (\frac{z-c}{b})^2]^{1/2} ,$$

and a=16, b=3, c=0.75, all in km. Set #1 experiment includes 4 cases with different values of $\Delta T_{\max}$ but at no surface moisture flux (=0). $\Delta T_{\max}$ = 1.5*K*, 3*K*, 6*K* and *9K respectively*. Set #2 experiment includes one case with $\Delta T_{\max}$ = 6*K* and with surface moisture and heat flux over land. Set #3 experiment also include one case with $\Delta T_{\max}$ = 6*K* and with surface heat and moisture flux but over ocean. We call these 6 experiments as half, one, double, triple, land and ocean respectively. All the bubbles are located at the middle of the domain. So now we have three sets of experiments. Set #1 experiment has no surface moisture source. The objective of set one experiment is to see the effects of the strength of the initial bubbles on the final states. Set

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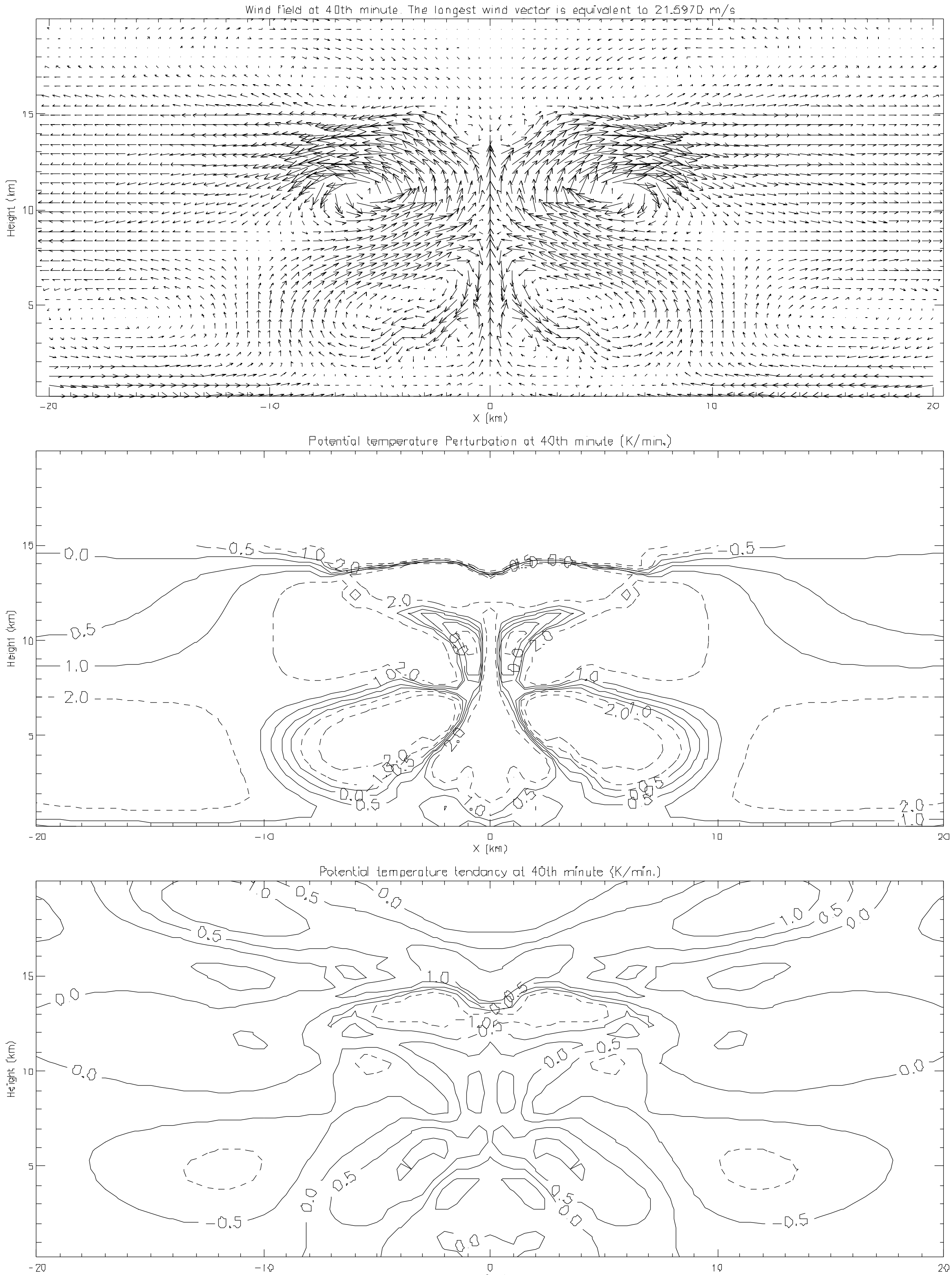

Figure 1: Wind (Top), Potential Temperature Perturbation (Middle), Potential Temperature Perturbation Tendency (Bottom)

#2 experiment has surface moisture source over land. Set #3 experiment has surface moisture source over ocean. Through these three sets of experiments, we can compare the different results between cases without surface moisture flux, with surface flux over different type surface.

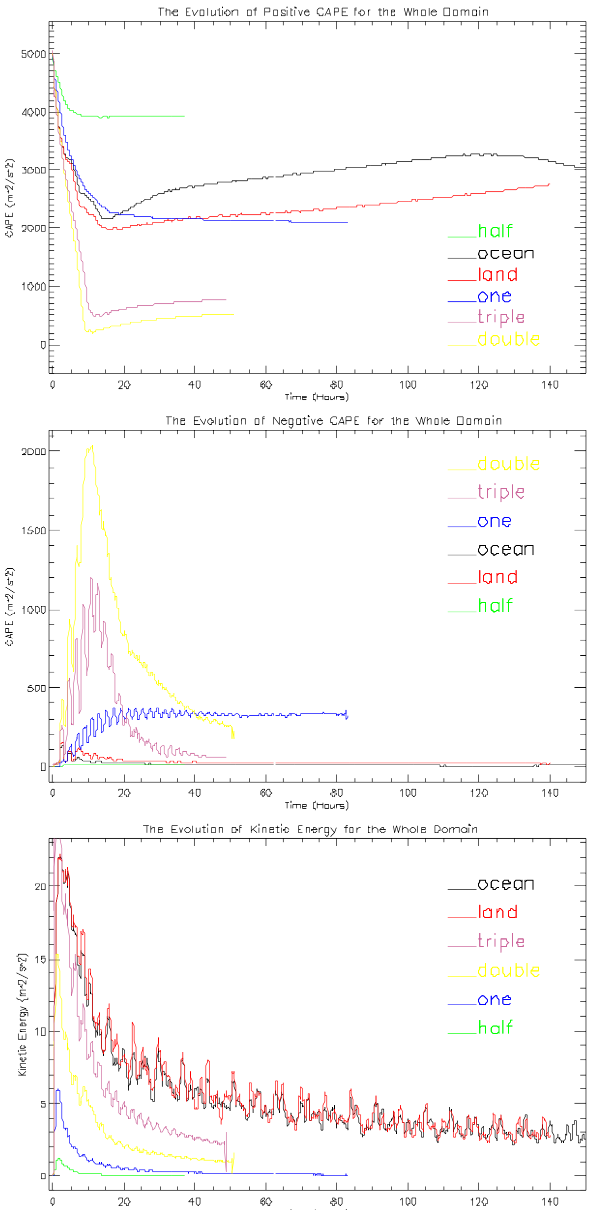

Figure 2: Evolution of positive cape (Top), negative cape (Middle) and kinetic energy (Bottom) of the whole domain

b. The model

For these idealized simulations we set the f=0, which means we don't consider the rotation of the earth. This is acceptable because most of the convection occurs in topical region where f is very small or near 0. Also our attention is focused on the small-scale motions. The surface is flat with no terrain.

The domain is as large as 350 km in x and 21.25 km in z. The boundary condition is periodical in x direction. The resolution in x is 500m and about 500m in z. The vertical coordinate is sort of height coordinate but slightly different. It has vertical stretching coefficient that is designed for the terrain based height coordinate.

For the physics processes we turned off the radiation processes. For the microphysics process, we use Kessler scheme that includes rain, water vapor and cloud water.

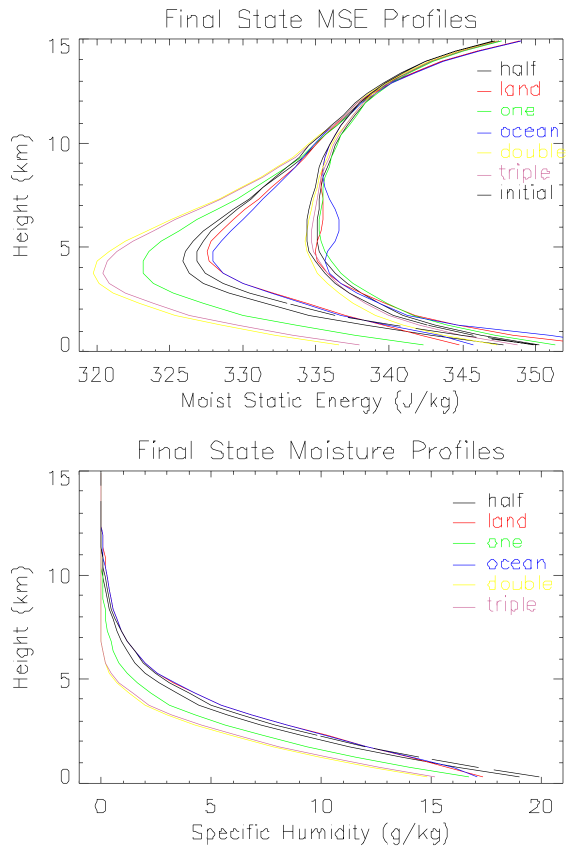

Figure 3: Final and initial state moist static energy profiles (Top) and Final state moisture profiles (Bottom) of the whole domain

3. RESULTS

Figure 1 is the wind field, potential temperature perturbation field and potential temperature perturbation tendency at 40 minutes for the one case. We can see the well-developed cell very clearly. Its life cycle is less than 1 hour. It developed one main precipitation shower. It has the characteristic of the single-cell thunderstorm (Houze 1993). Comparing the wind field and the θ perturbation tendency field, we can see that outside of the middle column, corresponding to those cell motions, the θ perturbation is more related with the adiabatic cooling by upward motion and adiabatic warming by the downward motion. For the middle column, it is upward motion all the way from the bottom up to the top of the troposphere. The surface bubble drives this upward motion thermodynamically. In this region, the θ perturbation and its tendency is positive due to the latent heating.

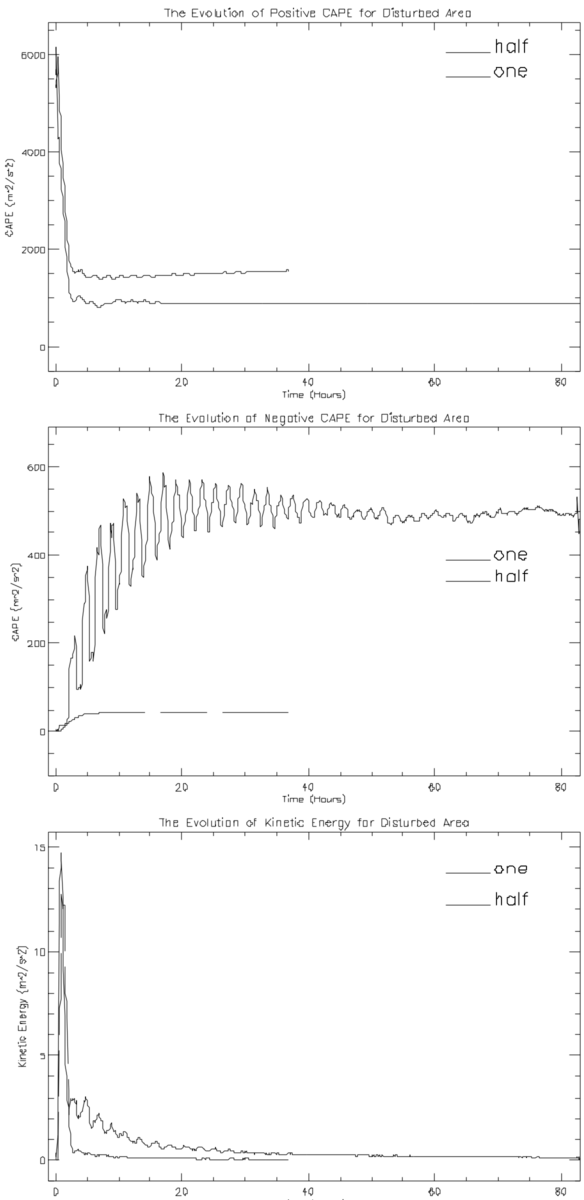

Figure 4: Evolution of positive cape (Top), negative cape (Middle) and kinetic energy (Bottom) of the disturbed area

In order to investigate the relationship between the strength of the initial bubble and the final state, first we need to define what is the final state. In our experiments, we use variable moist static energy (MSE, normalized by a value of g=9.8 m/s^2) and take the difference between the surface moist static energy and the minimum value of the saturated MSE vertical profile. If the change of the maximum difference in between one hour is less than 0.01 for 12 times at 5 minutes interval, we take the 12th state as the final state. For the cases with surface moisture flux, we relax this condition to 0.04 instead of 0.01.

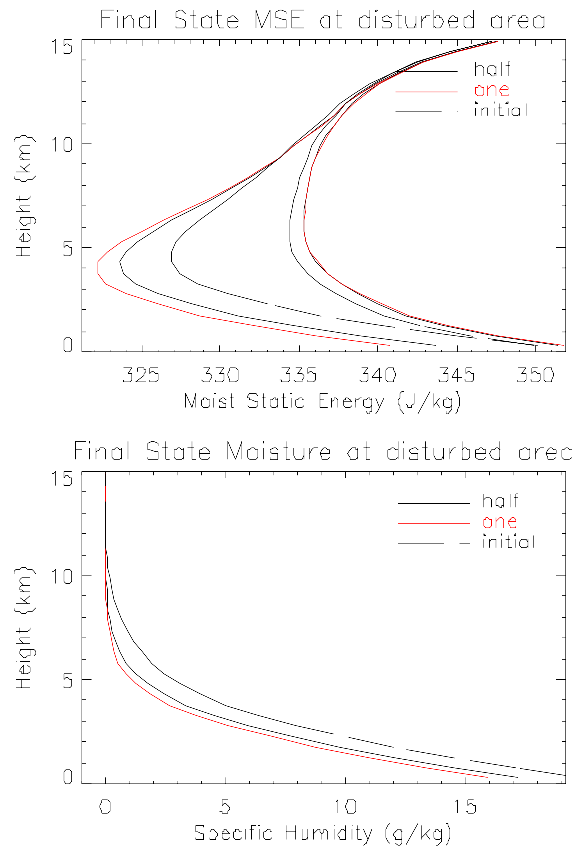

Figure 5: Final and initial state moist static energy profiles (Top) and Final state moisture profiles (Bottom) of disturbed area

Figure 2 shows the domain-averaged CAPE, low-level cap (where the parcel T is less than the environmental T in parcel method) and KE evolution curves for all cases. Fig.3 shows the final state MSE profiles, and moisture profiles for all cases. First, we will look at cases from set #1 experiment. The curves in fig. 2 show the amount of the released CAPE is proportional to the strength of the initial bubbles. The MSE profiles and the moisture profiles in fig.3 show coherent relationship with the strength of the initial bubbles. We notice that when the strength of the initial bubble reaches a particular point the MSE profiles, the moisture profiles and the remain CAPE curve vary near an equilibrium state, i.e. they are not going to decrease any more with the increasing strength of the initial bubbles, which implies that the air has an equilibrium state. The linear relationship doesn't exit any more. Comparing the double and triple cases can see this. From fig.2, it is obvious that the KE is balanced with the CAPE and moisture. We have to have enough KE to lift the parcel to break the cap at low level to release the CAPE and condense the water vapor in the air. For example, looking at the half case, although there is a lot of CAPE and moisture left and the low level cap is small for the air comparing with the one or double case, the KE is too low to break the cap. This is consistent with what are well known, i.e. the 3 necessary conditions for deep convection to happen: lifting, instability and moisture (Schultz et al, 1999; Doswell, 1987).

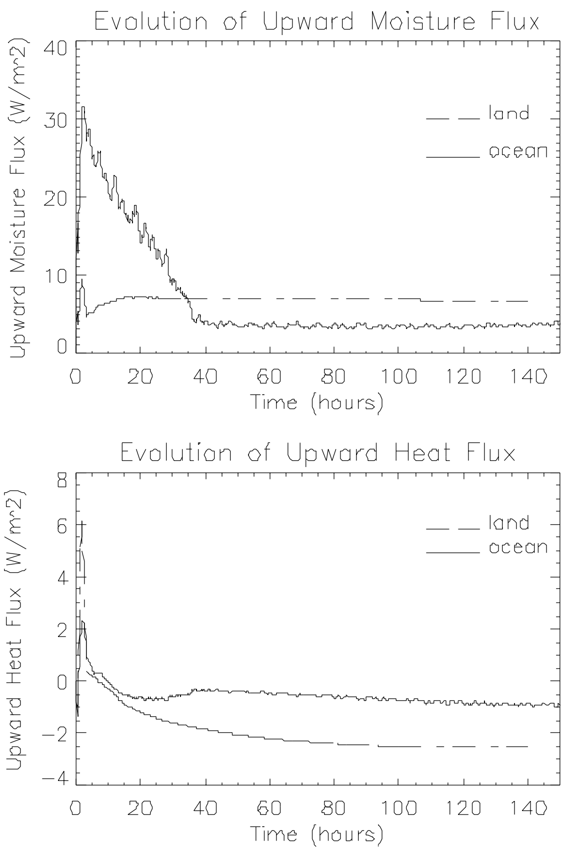

Figure 6: Evolution of upward moisture flux (Top) and upward sensible heat flux (Bottom)

For different cases with different strength of the initial bubbles, the horizontal disturbed areas are different. We define the disturbed area as all the points with cap greater than 0. For the half and the one cases, even at final state only part of the whole domain are disturbed. But for the double and the triple cases, the whole domains are disturbed. For this reason, in addition to looking at the whole domain averaged final profiles, we will look at the disturbed area averaged final profiles for the half and the one cases. Fig. 4 shows the CAPE, low-level cap, KE evolution curves for the half and one cases' disturbed area. Fig. 5 shows the final state MSE profiles, and moisture profiles for the half and the one cases' disturbed area. From the figures we can see that for the disturbed area, the differences between different cases are much smaller than those of the whole domain. The large KE at beginning lead to the less CAPE left. They are in other balance states between the lifting, instability and moisture.

Both of the land and the ocean cases show large differences in moisture profiles from the double case due to the surface moisture flux. The moisture source at the surface keeps the moisture profiles of the air very similar to the initial one. Looking at the final saturated MSE profiles, we notice that the mid-layer is much warmer comparing the set #1 experiment results. This may be explained by the more latent heating at the mid-layer due to the surface moisture flux. Fig. 6 is the surface upward heat flux and moisture flux for the land and ocean cases. The moisture flux variable has been multiplied by latent heat of vaporization. It is equivalent to latent heat flux at the surface. The averaged total upward heat flux (latent heat flux pluses sensible heat flux) during the evolution is 6.16 W/m^2 for ocean and 4.88 W/m^2 for land. This may explain the difference in the final saturated MSE profiles at the mid-level between the ocean and the land cases.

4. CONCLUSION

Based on our simple experiments on the relationship between the initial triggers and the final states, we found that there is coherent correlated relationship between the strength of the initial bubble and total amount of the CAPE released, the eddy kinetic energy, the final state moisture profile and the MSE profile. But for a particular convectively unstable air, it has it's own up limit equilibrium state which is not a function of the strength of the initial bubble. The total amount of potential energy released is not unique in terms of different initial triggers. Instead it is determined among three ingredients necessary for deep moist convection, i.e. instability, moisture and lifting. In terms of the surface moisture flux, it makes big difference between the cases with and without it. But it produces similar results between the cases over ocean surface and over land surface.

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