EFFECT OF SOIL MOISTURE ON SHALLOW CUMULUS CLOUD IN LARGE EDDY SIMULATION

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1. INTRODUCTION

Land atmosphere interaction is a one of the most important factor for precipitation. Study of soil moisture conducted by Trenberth and Guillemont (1996) showed that soil moisture helped to sustain the extreme condition during summer season in Midwestern U.S. Giorgi et al. (1996) and Paegle et al. (1996) proposed that there is negative feedback between soil moisture and drought of flood conditions. Importance of soil moisture to the precipitation is also investigated by modeling approach. Fischer et al (2007) decreased the soil moisture by 25% in spring and resulting in summer temperature to increase more than 2^0C. The study suggested that the decrease of soil moisture also reduce the surface latent heat flux, leading to more sensible heat flux creating warmer atmosphere temperature. Budyko (1974) implied that more soil moisture creates more surface latent heat fluxes, increasing more moisture contribution to the atmosphere.

The present works thus aim to estimate the amount of soil moisture in idealized simulation affecting the shallow cumulus convection. Homogeneous soil moisture and horizontally homogeneous atmosphere is adapted. Potential of precipitation to occur on wetter or drier soil is quantified by running the model. Large Eddy Simulation (LES) with fully coupled to land surface and radiation model is used with different initial soil moisture percentage. Section 2 describes the equation in the model and experiment setting can be seen in section 3. In section 4, result of simulation is discussed and summary is given in section 5.

2. MODEL FORMULATION

PALM LES (Maronga et al., 2015) with non-hydrostatic, filtered incompressible Navier-Stokes equations in Boussinesq approximated form is used for the study. Idea of LES is to categorize the turbulence eddies as large and small eddies by filtering process. Double prime in the following equations indicates the Sub Grid scale (SGS) variables. The over bar sign indicating the filtered quantity is omitted except for SGS flux. The governing equation can be seen as follows.

$$\frac{\partial u_i}{\partial t} = -\frac{\partial u_i u_j}{\partial t} - \varepsilon_{ijk} f_j u_k + \varepsilon_{i3k} f_3 u_{g,j} - \frac{1}{\rho_0}\frac{\partial \pi^*}{\partial x_i} + g\frac{\theta_v - \langle\theta_v\rangle}{\langle\theta_v\rangle}\delta_{i3} - \frac{\partial}{\partial x_j}\left(\overline{u_i^{"} u_j^{"}} - \frac{2}{3}e\delta_{ij}\right) \quad (1)$$

$$\frac{\partial u_j}{\partial x_j} = 0 \quad (2)$$

$$\frac{\partial \theta}{\partial t} = -\frac{\partial u_j \theta}{\partial x_j} - \frac{\partial}{\partial x_j}\left(\overline{u_j^{"}\theta^{"}}\right) - \frac{L_V}{C_p \Pi}\Psi_{qv} \quad (3)$$

$$\frac{\partial q_v}{\partial t} = -\frac{\partial u_j q_v}{\partial x_j} - \frac{\partial}{\partial x_j}\left(\overline{u_j^{"} q_v^{"}}\right) + \Psi_{qv} \quad (4)$$

3. EXPERIMENTAL SETTING

Radiosonde observation on ARM SGP site 36.5^{0}N, 97.5^{0}W at 05:30 LST July 24th from Zhang et al. (2017) is used as initial profiles. Model domain is set as 28.8 x 28.8 x 4 km with 100 m grid resolution. Simulation time is 18 hours. Initial wind velocity is given as 0 m/s for u and v wind velocity for no-wind experiment and u=7 m/s, v=0 m/s for the wind experiment. Initial mixing ratio at the surface level is 0.015 kg/kg with initial surface pressure 1000 hPa. Dirichlet condition is used as top and bottom boundary condition, while the lateral condition is cyclic condition. Bulk schemes microphysics with precipitation parameterization via Seifert-Beheng schemes is used (Seifert and Beheng, 2001, 2006). Soil type used in this model is medium soil with saturation moisture 0.439 m^3/m^3 and wilting point 0.151 m^3/m^3.

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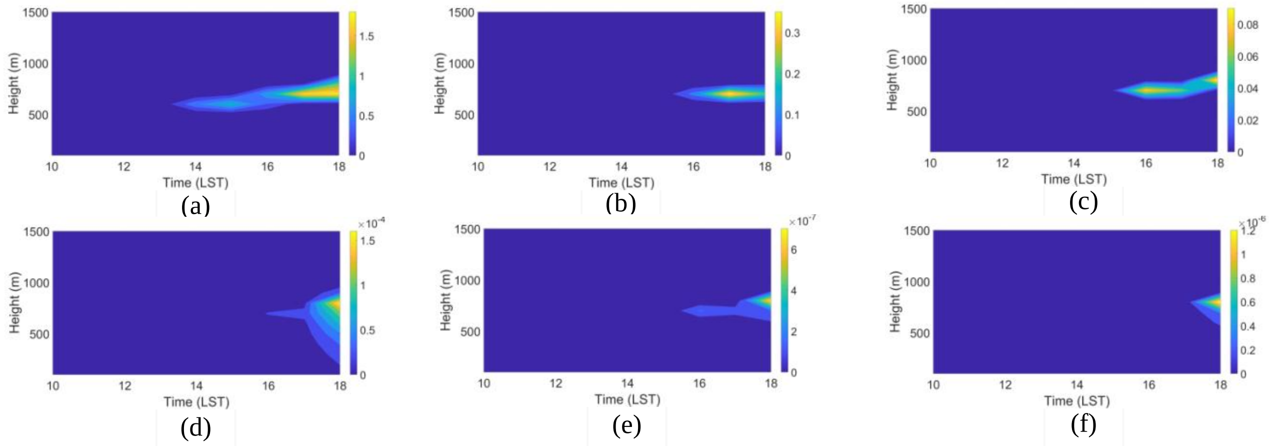

Figure 1. Profile of total domain quantities as function of time for the cloud and rain water mixing ratio on the wind on saturated soil moisture (a,d) and no wind with saturated soil moisture (b,e), 70% of saturated soil moisture (c,f). Color shading represent value of cloud water mixing ratio (kg/kg) and rain water mixing ratio (kg/kg). The y axis represents the height from the surface (km), while the x axis indicates the time of simulation (LST).

４． RESULTS

Shallow cumulus cloud and rain shows different response under different soil moisture and wind conditions as can be seen in Figure 1. Simulations with fully saturated soil moisture and wind implementation (u = 7m/s) shows lower cloud occurrence at 13 LST, but wider area and higher rainwater mixing ratio (a,d). On same experiment with no wind, cloud appearance start approximately 2 hours later compared with the wind case (b,e). Rain occurs on almost same time but the mixing ratio is not as high as that of the wind case. Meanwhile, at 70% of saturated soil moisture case with soil moisture of 0.3073 m^3/m^3, cloud occurs even less with smaller mixing ratio (c,f). These sensitivity experiments suggest that the availability of soil moisture is significant to the cloud and rain formation.

５． SUMMARY

Soil moisture plays important part in shallow cumulus cloud formation. To understand more of which soil moisture gives the most favorable situation for cloud formation, LES model is used. Our study has showed that rain and cloud is influenced by soil moisture and wind condition. Further study on how the soil moisture mechanism affects the rain and cloud formation will be conducted.

REFERENCES

Budyko, M., 1974: Climate and Life. International Geophysics Series, Vol. 18, Academic Press, 508 pp.

Fischer, E.M., S. Seneviratne, P. Vidale, D. Luthi, and C. Schar, 2007 : Soil moisture-atmosphere interactions during the 2003 European summer heat wave. J. Climate, 20, 5081-5099, doi:10.1175/JCLI4288.1.

Paegle, J., K. C. Mo, and J. Nougles-Paegle, 1996: Dependence of simulated precipitation on the surface evaporation during the 1993 United States summer floods. Mon. Wea. Rev.,124. 1786-1802.

Seifert A, Beheng K. D: 2001. A double-moment paramerization for simulating autoconversion, accretion and selfcollection. J.Atmos. Res. 59: 265-281

Seifert A, Beheng K. D: 2006. A two moment cloud microphysics parameterization for mixed phase cloud. Meteorol. J.Atmos. Phys. 92: 45-66.

Trenberth, K.E., and C. J. Guillemont, 1996: Physical processes involved in the 1988 drought and 1993 floods in North America. J.Climate,9, 1288-1298

Zhang, Yunyan, et al., 2017: Large Eddy Simulation of Shallow Cumulus over Land: A Composite Case Based on ARM Long-Term Observations as Its Southern Great Plains Site. J.Atmos. Sci, 74, 3229-3251, https://doi.org/10.1175/JAS-D-16-0317.1

LIST OF SYMBOLS

u_i	Velocity component $(u_1 = u, u_2 = v, u_3 = w)$	$u_{g,i}$	Geostrophic wind $(u_{g,1} = u_g, u_{g,2} = v_g)$	x_i	Coordinate on the cartesian grid $(x_1 = x, x_2 = y, x_3 = z)$
t	Time unit	ρ_0	Density of dry air	q_v	Specific humidity
ε_{ijk}	Levi-civita symbol	Cp	Heat capacity	g	Gravitational acceleration
δ_{13}	Kronecker delta	Θ	Potential temperature	Ω	Earth angular velocity
e	SGS total kinetic energy	L_v	Latent heat of vaporization	Φ	Geographical latitude