A study of the microphysical mechanism for correlation patterns between droplet radius and optical thickness of warm clouds off the coast of California as simulated by a downscaling spectral bin microphysical model.

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1, Introduction

Warm liquid clouds are of fundamental importance in the earth's climate for their significant effects on the hydrological cycle and radiation budget. The optical and microphysical properties are characterized by cloud radiative properties such as optical thickness (τ) and effective radius (R_{eff}).

Nakajima et al. (1991), and Nakajima and Nakajima (1995) found positive and negative correlation patterns between R_{eff} and τ from aircraft observation (Figure 1), and satellite observation (Figure 2) respectively. Suzuki et al. (2010) interpreted these correlation patterns using two-dimensional idealized model with a spectral-bin microphysical scheme (Figure 3). In this study, we conduct a three-dimensional downscaling simulation to represent stratocumulus off the coast of California and interpret microphysical mechanisms for the correlation patterns.

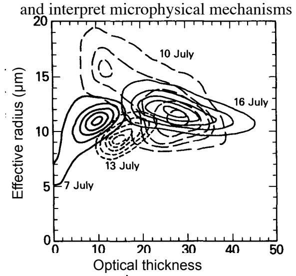


Figure 1. Scatter plot between optical thickness (τ) and effective radius (R_{eff}) observed from aircraft observation (Nakajima et al., 1991).

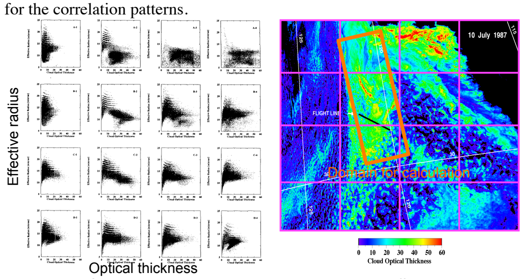


Figure 2. Scatter plots between optical thickness (τ) and effective radius (R_{eff}) observed from satellite observation (left), and spatial distribution of optical thickness observed from satellite (right) (Nakajima and Nakajima, 1995).

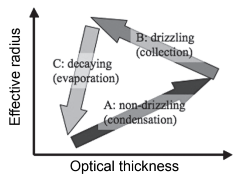


Figure 3. Schematic diagram to interpret the tendency of optical thickness and effective radius at each growth stage of cloud (Suzuki et al., 2010) .

2, Model description and experimental set

Model description (Iguchi et al., 2008)

Dynamics : JMANHM (Saito et al., 2006)

Cloud physics : Bin (Khain and Sednev, 1995), Bulk (Ikawa and Saito, 1991)

–Warm cloud process only

–Add regeneration of aerosol for bin model (Feingold, 1996)

Radiation : MSTRN-X (Sekiguchi and Nakajima, 2008)

Aerosol : Downscaled from SPRINTARS (Takemura et al., 2005)

Date : 1987/7/10 (FIRE period, Figure 4)

Domain : Off the coast of California (Figure 4)

Sensitivity experiment : Aerosol (×1, ×3, ×5), Inversion height (H_i) (+0 m, +300 m, +500 m)

Experimental set

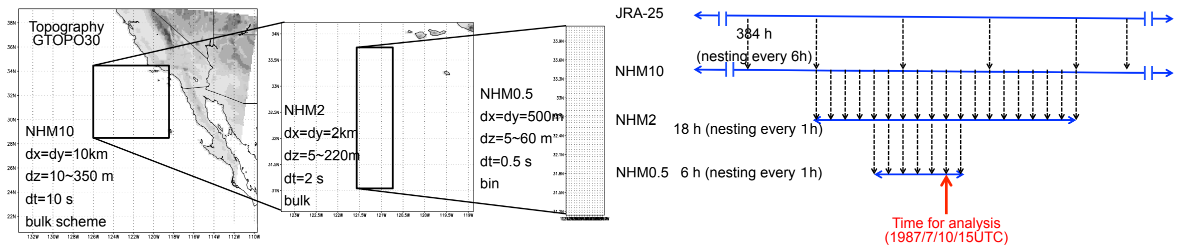


Figure 4. Experimental design of downscaling simulation. The term "bulk" and "bin" means microphysical scheme used in each domain calculation.

3, Result

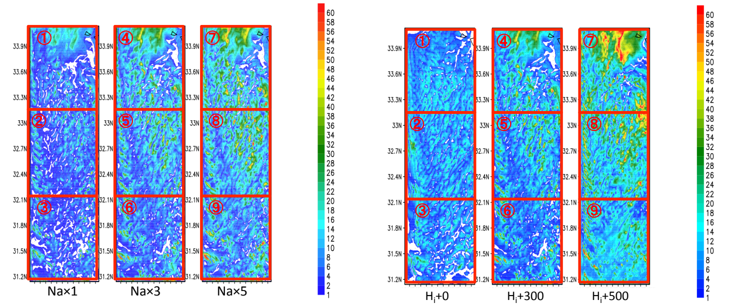


Figure 5. Optical thickness at 1987/07/10/15UTC calculated by the model through sensitivity experiment changing aerosol amount (left), and inversion height (right).

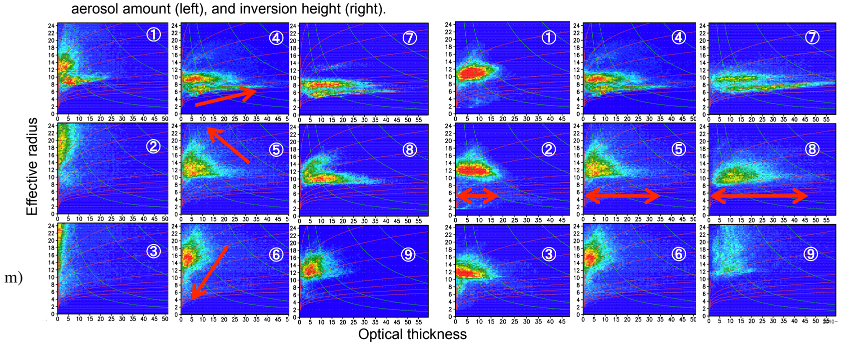
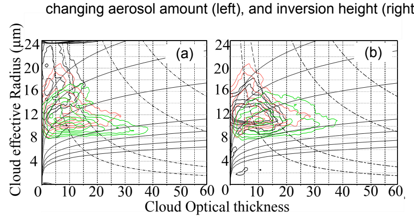


Figure 6. Scatter plots between cloud optical thickness and effective radius obtained from sensitivity experiment changing aerosol amount (left), and inversion height (right). Numbers in each plot correspond to domain in Fig.5.



← Figure 7. Scatter plots over the central part of computational domain obtained by sensitivity experiment changing aerosol amount (a), and inversion height (b). Black, red, and green contour correspond to the plot of domain ②, ⑤, and ⑧ respectively. Solid and dash curves are isolines for cloud number concentration and liquid water path given by adiabatic model (Brenguier et al. 2001)

4, Discussion

1. According to the adiabatic model, liquid water path is determined by cloud top height, which is equivalent with inversion height in this simulation.
2. The bi-modal feature seen in scatter plot ⑧ of fig.6 (left) is associated with a difference of aerosol characteristics of airmass.

⇒ The scatter plot does not show the growth stage of clouds like Fig. 3, but it shows characteristics of air mass in each of the three domains.

1, Adiabatic model (Brenguier et al. 2001)

$$(\text{Cloud water mixing ratio}) = q = \lambda h$$

$$(\text{Liquid water path}) = \int_0^H q\,dz = \frac{1}{2}\lambda H^2$$

H : cloud top height, λ : const.

2, Aerosol distribution

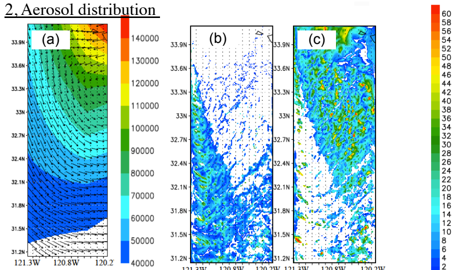


Figure 8 Column aerosol number concentration (shaded) and horizontal wind component (arrow) of Na×5 experiment at initial times (a), and optical thickness of Na×5 experiment of fig 5., but cloud number concentration is smaller, (b) and larger (c) than 100 cc^{-1} →

5, Conclusion

1. A three dimensional downscaling simulation succeeded in representing positive and negative correlation patterns such as seen in previous studies (fig. 1, 2, and 3).
2. Aerosols amounts can change the cloud number concentration without changing liquid water path in accordance as a previous study (Suzuki et al., 2010).
3. Inversion height, which corresponds to cloud top height, change the liquid water path, without changing number concentration as also seen in Suzuki et al. (2010).
4. Scatter plots do not show the growth stage of clouds as in Fig.3, but shows characteristics of air mass in each of the three domains.

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