Impact of Dynamics and Atmospheric State on Cloud Vertical Overlap

Contributors

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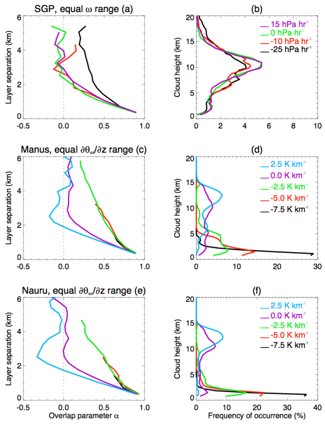
Research Highlight

The observation and representation of cloud vertical overlap in general circulation models (GCMs) is the object of active research due to its impact on the Earth radiative budget. It has been proposed that cloudy layers that are contiguous have a maximum overlap and cloudy layers separated by clear air have a random overlap, which is the assumption used in many GCMs. However, radar observations from a European site revealed that vertically contiguous cloudy layers show a maximum overlap between layers up to several kilometers apart but tend towards a random overlap as separations increase. The decorrelation length-scale that characterizes the progressive transition from maximum to random overlap changes was found to depend on model resolution. A similar study performed using radar data from the ARM Climate Research Facility (ACRF) Southern Great Plains (SGP), North Slope of Alaska (NSA) and Tropical Western Pacific (TWP) sites revealed that this decorrelation length changed between locations and between season and thus may be influenced by environmental conditions. Furthermore, cloud resolving model simulations suggest a connection between wind shear and convection and overlap type.

We used midlatitude winter and tropical radar derived active remote sensing of cloud locations (ARSCL) cloud observations at the ACRF SGP and TWP sites respectively, in conjunction with meteorological reanalysis fields, to investigate the impact of the atmospheric state and dynamics on cloud overlap. The overlap between two cloudy layers is characterized by a parameter α, obtained as a function of layer separation from the respective cloud fractions of the two layers and their combined cloud fraction. If α=0, the overlap is random, α=1 indicates maximum overlap and α<0 when minimum overlap occurs some of the time. The decorrelation length is obtained from an exponential fit to the variations of the mean α (calculated over a large number of radar observed cloudy layer pairs) as a function of layer separation.

The overlap between non-contiguous cloudy layers was found to always be random, in agreement with previous studies, with no dependence on atmospheric state or dynamics. For contiguous cloudy layers, when all types of atmospheric state and dynamical regimes were undifferentiated, the results were somewhat different from the previous study at the ACRF sites. It was found that although the method used to process the radar reflectivities to extract cloud boundaries had little impact on the overlap characteristics, the way precipitation periods are discarded from the data set can have a large impact: if precipitating periods are kept, the overlap between cloudy layers is maximum more often at large separations than if they are discarded because the radar cannot easily differentiate between in-cloud hydrometeors and precipitating droplets. We used a more conservative method to remove these periods than in the previous study and found much smaller decorrelation



Mean overlap parameter α as a function of separation: (a,b) at SGP for all winter months of 2002-2004 and for 4 subsets of increasing 500 mb ω such as ω < 15 hPa hr-1, -15 < ω < -5 hPa hr-1, -5 < ω <5 hPa hr-1 and ω > 5 hPa hr-1; (c,d) at Manus for 5 subsets of increasing $\delta\theta es/\delta z$; (e,f) at Nauru, for the same 5 subsets as at Manus. The TWP $\delta\theta es/\delta z$ subsets are 2.5 K km-1 wide and centered on 2.5, 0, -2.5, -5 and -7.5 K km-1, the range defined by -7.5 K km-1 also includes all the points found below -8.75 K km-1. All curves stop at the separation where the number of points < 250 at SGP but the criterion was relaxed to 100 points at TWP. For each site, the right column shows the height distribution of all layers that were used to obtain the overlap parameter (no overcast cloud sub-layers).

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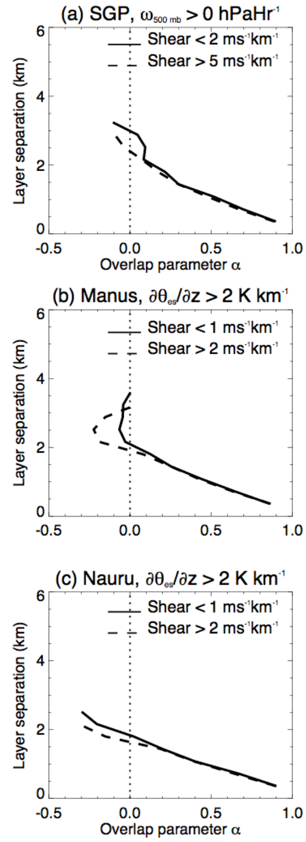
lengths. In addition, high level clouds (above 10.5 km) were found to favor random overlap, so when retained in the dataset, we found fewer differences in decorrelation length between the sites than previously observed. To study the overlap in specific atmospheric situations, all clouds were included up to the highest altitude reached with the radar observations (15 km at SGP and 20 km at TWP) but precipitating periods were ignored. For the midlatitude location, we found that strong synoptic scale upward motion, characterized with the reanalysis vertical velocities, maintains maximum overlap at large separations (Figure 1, a-b), while in the tropics, overlap becomes closer to maximum overlap as convective stability decreases, as characterized with the gradient in the saturated equivalent potential temperature (Figure 1, c-f). In midlatitude subsidence and tropical convectively stable situations, where a smooth transition from maximum to random overlap was found on average, large wind shears sometimes favored minimum overlap (Figure 2).

The results suggest that a straightforward modification of the existing GCM mixed maximum-random overlap parameterization approach that accounts for environmental conditions can capture much of the important variability and is more realistic than approaches only based on an exponential decay transition from maximum to random overlap. Since overlap is an inherently statistical property of cloud parameterizations, one approach might be to probabilistically switch the overlap of contiguous cloudy layers from maximum to random as a function of the large-scale vertical velocity, convective stability, or wind shear. This approach would allow for the possibility of cloud overlap feedback in a climate change simulation.



Mean overlap parameter α as a function of separation for the two subsets derived from the 25th (solid) and 75th (dashed) distribution of wind shear: (a) at SGP for all points in descending situations; (b) at Manus for $\delta\theta es/\delta z$ > 1.7 K km-1 (75th percentile of the $\delta\theta es/\delta z$ distribution); and (c) at Nauru for $\delta\theta es/\delta z > 2.1$ K km-1 (75th percentile of $\delta\theta es/\delta z$ distribution). All curves stop at the separation where the number of points < 250.

Reference(s)

Naud, C, A Del Genio, GG Mace, S Benson, EE Clothiaux, and P Kollias. "Impact of dynamics and atmospheric state on cloud vertical overlap." Journal of Climate 218: 1758–1770.

Working Group(s)

Cloud Modeling