All Mixed Up—Probing Large and Small Scale Turbulence Structures in Continental Stratocumulus Clouds

Research Highlight

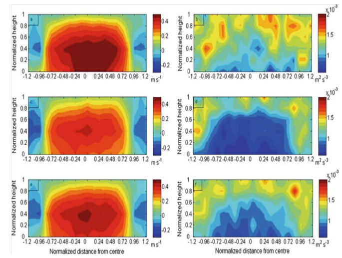
Continental stratocumulus clouds are frequently observed in the cold side of mid-latitude frontal systems or in association with anti-cyclones. They can affect the local surface temperature and the energy and water budget as well as the local climate. Observations from the ARM MMCR and other ancillary instruments combined with the flux fields from a radiative transfer model are used to examine the resolved and unresolved turbulence structures and forcing associated with 16 consecutive hours of stratocumulus clouds over the Southern Great Plains (SGP). The turbulence characterizations are compared and contrasted with those observed in marine stratocumulus clouds.

During the 16-hour observational period, the forcing processes that maintained the turbulence in the cloud varied substantially. The in-cloud turbulence during the day, in this case, is driven by both surface heating (characterized in this study by the convective velocity scale Ws*) and cloud-top cooling (characterized by a velocity scale Wr*). However, at night cloud-top cooling is the exclusive contributor to the in-cloud turbulence. In addition, during the case studied, mid-level clouds modulate the stratocumulus infrared cloud-top cooling that helps drive the turbulence in the cloud. The unique observations available from the ARM SGP site allow estimates of the surface fluxes and provide input for the calculation of the radiative fluxes in the boundary layer to calculate both the surface and the cloud-top forcing as a function of time. The combined Ws* and Wr*—the total velocity scale Wt*—provides a useful way to track the evolution of the turbulence structure in the cloud.

The variance of the in-cloud vertical velocity from the radar-measured radial velocity (the resolved turbulence) follows the diurnal cycle and is consistent with the total velocity scale Wt* variations. The Wt* values are lowest around sunset when the radiative cooling is also small due to upper-level clouds observed above the low-level stratus. The squared spectrum width or the unresolved turbulence follows the diurnal cycle too. Calculations show that the small-scale turbulence contributes 40% of the total velocity variance at cloud base, 50% at a normalized cloud depth of 0.8 and 70% at cloud top, which suggests that small-scale turbulence plays a critical role near the cloud top where the entrainment and cloud-top radiative cooling act. The 16-hour mean vertical integral length scale—a measure of the scale of the turbulence processes--decreases from about 160 m at cloud base to 60 m at cloud top, and this again signifies that the larger scale turbulence dominates near cloud base whereas the small-scale turbulence dominates near cloud top. Unlike marine stratocumulus clouds, there is no significant diurnal variation in cloud thickness or the inversion height.

The Eddy Dissipation Rate (EDR) estimates from Doppler spectrum width are obtained by applying revised equations and procedures. The EDR estimates from this technique agree well with those from the Doppler velocity power spectrum. In a normalized coordinate system, the averaged coherent structure of updrafts is characterized by low energy dissipation rates in the updraft core and higher energy dissipation rates surround the updraft core at the top and along the edges. In contrast, the energy dissipation rate is higher inside the downdraft core indicating that the downdraft core is more turbulent. The turbulence around the updraft is weaker at night and stronger during the day; the opposite is true around the downdraft. Both the resolved and unresolved turbulence are higher in the downdraft than in the updraft. The impact of the surface heating on the resolved turbulence in the updraft decreases with height and diminishes around the cloud top.

This study illustrates the utility of using Doppler spectrum width from the millimeter wavelength cloud radar to calculate EDR and investigate processes involved in the turbulence structure of stratocumulus clouds. The observed temporal variability can be used to examine the transient response of large eddy simulation (LES) to changes



Coherent structures of the vertical velocity (left panels) and the energy dissipation rate (right panels) in updraft region during the day (a, b), night (c, d), and for entire 16 hours (e, f) of continental stratocumulus.

in the surface and cloud-top forcing. Further, it allows for the possibility of comparing the simulated turbulence characteristics from LES with those obtained from the cloud-radar observations. Turbulence parameters inferred from these observations can be used to evaluate subgrid parameterizations used in numerical models operating on a variety of scales and aiding in the development of parameterizations of dissipation rates in some classes of numerical model. The methods developed for estimating the dissipation rates from the cloud radar spectrum width can be applied to other boundary layer cloud cases using ARM observations. Further, the EDR estimates from the radar spectrum have a strong potential for furthering our understanding of cloud-top entrainment processes and the development of drizzle.

Reference(s)

Fang M, BA Albrecht, VP Ghate, and P Kollias. 2013. "Turbulence in continental stratocumulus, Part I: External forcings and turbulence structures." Boundary-Layer Meteorology, 149(454), doi:10.1007/s10546-013-9873-3.

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Cloud Life Cycle