Abstract

Stratocumulus clouds are ubiquitous around the globe. On average, they cover around 20 % of the Earth's surface. Wide-spread presence, persistence and high albedo makes them important for the energy balance of the planet. Because only minor variations in coverage or optical thickness can impact the surface radiation budget, the feedback of stratocumulus clouds to global warming remains one of the major sources of uncertainty in model-based climate predictions.

Marine stratocumulus clouds typically occupy upper few hundred meters of the atmospheric boundary layer. Circulation and turbulence in such a stratocumulus-topped boundary layer (STBL) is driven primarily by the cloud top radiative cooling which can be supported by evaporative cooling, latent heat release, surface heating and wind shear. The transport of moisture from the ocean surface maintains the cloud against entrainment drying. The efficiency of vertical transport, hence the properties of stratocumulus cloud and its evolution, is dependent on the thermodynamic and dynamic structure of the STBL. When the STBL grows in depth, the drivers of the circulation weaken or the subcloud layer stabilizes, then the mixing of air volumes across the entire STBL depth may become impossible to sustain. The boundary layer decouples, i.e. the stratocumulus cloud is disconnected from the moisture supply from the surface.

Within the present study, the stratification, turbulence and aerosol properties in coupled and decoupled marine STBLs are compared using high resolution in situ measurements performed by the helicopter-borne platform ACTOS in the region of the Eastern North Atlantic. Particular attention is given to small-scale turbulence.

The thermodynamically well-mixed (i.e. coupled) STBL was characterized by a comparable latent heat flux at the surface and in the cloud top region, and substantially smaller sensible heat flux in the entire depth. Turbulence kinetic energy (TKE) was efficiently generated by buoyancy in the cloud and at the surface, and dissipated with comparable rate across the entire depth. Structure functions and power spectra of velocity fluctuations in the inertial range were reasonably consistent with the predictions of Kolmogorov theory. The turbulence was close to isotropic.

In the decoupled STBL, decoupling was most obvious in humidity profiles. Heat fluxes and buoyant TKE production at the surface were similar to the coupled case. Around the transition level, latent heat flux decreased to zero and TKE was consumed by weak static stability. In the cloud top region, heat fluxes almost vanished and buoyancy production was significantly smaller than for the coupled case. TKE dissipation rate inside the decoupled STBL varied between its sublayers. Structure functions and power spectra in the inertial range deviated from Kolmogorov scaling. This was more pronounced in the cloud and subcloud layer in comparison to the surface mixed layer. The turbulence was more anisotropic than in the coupled STBL, with horizontal fluctuations dominating. The degree of anisotropy was largest in the cloud and subcloud layer of the decoupled STBL.

Integral length scales, of the order of 100 m in both cases, indicate turbulent eddies smaller than the depth of the coupled STBL or of the sublayers of the decoupled STBL. It is hypothesized that turbulence produced in the cloud or close to the surface is redistributed across the entire coupled STBL but rather only inside the sublayers where it was generated in the case of the decoupled STBL. Scattered cumulus convection, developed below the stratocumulus base, may play an important role in the transport between those sublayers.

In both cases, the size distribution of aerosol particles did not change significantly with height, except for the influence of activation inside the cloud. Three principal modes were identified in the aerosol size distributions: Aitken, accumulation and larger accumulation. The sources of the observed aerosol particles were likely sea spray emission and long-range transport of continental aerosol combined with the entrainment into the STBL. The total concentration of aerosol particles and the concentration of cloud condensation nuclei were constant below the coupled stratocumulus. In the decoupled STBL, the concentrations in the subcloud layer were smaller than in the surface mixed layer.

Most of the results concerning the coupled case are consistent with the previous studies of stratocumulus dynamics. The observations of TKE production, heat fluxes and turbulent fluctuations in the decoupled STBL fit well into the range of conditions reported in the literature. The important novelty of this work are the results on small-scale turbulence because the parameters like local dissipation rate, intertial range scaling, anisotropy and length scales were not addressed in the context of STBL coupling before.