Three modes of cloud-boundary layer coupling over the Southern Ocean: Performance of conventional and mass-flux PBL schemes

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Abstract

While the continental planetary boundary layer (PBL) structure and model capability to simulate it are relatively well understood, its structure and the ability of models to simulate it over the Southern Ocean (SO), especially in the presence of clouds, are less known. In this study, in situ soundings and remote sensing data collected from ships during two field campaigns over the SO, the Measurements of Aerosols, Radiation and Clouds over the Southern Ocean (MARCUS) and the Clouds Aerosols Precipitation Radiation and atmospheric Composition over the Southern Ocean (CAPRICORN) campaigns, and WRF simulations with different PBL schemes are examined to study the boundary layer structure over the SO, focusing particularly on the coupling status between the surface-based boundary layer and the single cloud layer above.

Ten single cloud layer cases, including Dec. 1, 2017, Mar. 21-22, 2018, Mar. 23, 2018, Jan. 10, 2018 detected during MARCUS, and Feb. 17-18, 2018 detected during CAPRICORN, are examined. The **cloud-boundary layer coupling over the SO** for these cases can be classified into **three modes:**

1. Coupled cloud-boundary layer in the presence of weak surface positive flux;

2. Decoupled cloud-boundary layer in the presence of surface negative flux, with a very shallow surface-based PBL; and

3. Decoupled cloud-boundary layer in the presence of single-layer high clouds and stronger surface positive flux, with thicker surface-based PBL.

WRF simulations were conducted for these selected cases using different PBL schemes, including the Yonsei University (YSU) scheme with and without extra mixing and entrainment induced by cloud-top cooling (referred to as YSUtop-down when the cloud-top cooling treatment is included), the Mellor–Yamada Nakanishi and Niino (MYNN) scheme, and the MYNN scheme with the eddy-diffusivity (ED) local closure and mass flux (MF) nonlocal approach (referred to as MYNN-EDMF). For cases with the different cloud-boundary layer coupling modes, different PBL schemes provided the best consistency with obser-

vations. The MYNN-EDMF scheme is more consistent with observations than the conventional PBL schemes for the type 3 coupling mode because of the different vertical extent of local mixing and nonlocal mass flux in presence of sufficient surface flux. The YSUtopdown scheme has more consistency with observations than the YSU scheme for the type 1 coupling mode to simulate higher cloud-topped boundary layer. For the type 2 coupling mode, the different PBL schemes perform similarly.