Lecture 14. General features and climatology of marine boundary layers

Differences between marine and continental atmospheric boundary layers (Garratt 6.3)

Marine boundary layers (MBLs) typically differ from boundary layers over land surfaces in the following ways:

(a) Near-surface air is always moist, with a typical relative humidity (RH) of 75-100%

(b) The diurnal cycle tends to be weak (though not negligible), since surface energy fluxes get distributed over a considerable depth (10-100+ m) of water, which has a heat capacity as much as hundreds of times as large as the atmospheric boundary layer.

(c) Air-sea temperature differences tend to be small, except near coasts. The air tends to be 0-2 K cooler than the water due to radiative cooling and advection, except where there are strong winds or large sea-surface temperature (SST) gradients. The MBL air is usually radiatively cooling at 1-2 K/day, and some of this heat is supplied by sensible heat fluxes off the ocean surface. If the air is much colder than the SST, vigorous convection will quickly reduce the temperature difference.

(d) Due to the small air-sea temperature difference, the 'Bowen ratio' of sensible to latent heat flux tends to be small (typically 0.1 in the tropical oceans, and more variable in midlatitudes); latent heat fluxes are 50-200 W m^{-2}, while (except in cold air outbreaks off cold land-masses) sensible heat fluxes are 0-30 W m^{-2} (slide 1)

(e) Over 95% of marine boundary layers contain cloud (slides 3-4). The exceptions are near coasts, where warm, dry continental air is advected over a colder ocean, and in some regions (such as over the cold water upwelled along the equator in the eastern Pacific cold tongue) in which air is advecting from warmer to colder SST, tending to produce a more stable shear-driven BL which does not deepen to the LCL of surface air. Cloud can greatly affect MBL dynamics, as we discuss throughout this class. It also affects the surface and top-of-atmosphere energy balance and the SST.

MBL cloud types

Commonly seen types of cloudy MBL types (photographic examples in slide 2) include:

(i) Stratus (St) and stratocumulus (Sc)-capped BLs, typically found in anticyclonic flow over the subtropical and midlatitude oceans, and often seen during the cool season over moister landmasses or in cold air outbreaks. These BLs may include Cu below or rising into the Sc.

(ii) Shallow cumulus (Cu) boundary layers, ubiquitous over oceanic trade-wind regimes, and often seen over land and midlatitude oceans as the later phase of cold air outbreaks

(iii) Boundary layers under deep convection, which have mesoscale variability associated with evaporating precipitation and downdrafts from cumulonimbus cloud systems

(iv) Fog and shallow stably-stratified stratus layers, often seen in midlatitudes in warm advection over cold water or in the Arctic over sea ice.

Slide 4 shows roughly how MBL cloud types correlate with SST.

The global distribution of low cloud (at heights of 2 km or less above the surface) is documented in routine synoptic observations of cloud type and cover by untrained surface observers using a simple visual classification scheme from the World Meteorological Organization (WMO). Over the oceans, these have been archived over the past 50 years, and were compiled by Warren et al. (1988) and made into maps by Norris (1998b). Slide 5 shows that more than 100-200 km offshore, a complete lack of BL cloud is rare, occuring 1-2% of the time in most ocean locations. It also shows that fog is common in summer on the cold side of 'oceanic fronts' separating warm and cold SST, e. g. north of the Kuroshio Current and Gulf Stream.

Slide 6 (left) shows the frequency (FQ) which observers report the dominant cloud type is stratus. This tends to form under high pressure without strong surface heating. It favor cold oceans during the summer. The right side of slide 6 shows bad-weather stratus reflecting precipitation. It tends to reflect the rainfall distribution, and occurs relatively infrequently over the summer midlatitude oceans when normal stratus is maximum.

Slide 7 shows cloud types that indicate cold advection over cool SSTs (Sc) and warmer SSTs (cumulus under stratus). These cloud types correspond to convective boundary layers with upward surface heat fluxes. Here 'cool' and 'warm' are relative to the overlying troposphere, so in a cold air outbreak, the ocean may be relatively warm compared to the air aloft and favor a Cu-under-Sc boundary layer. Slide 8 shows the various cumulus cloud types, which favor warm SSTs.

Slide 9 shows the annually averaged cloud cover (frequency of occurrence multiplied by fractional sky cover when cloud type is present) for `stratus' (stratus+stratocumulus+fog), which encompasses the most radiatively important cloud types, since cumulus cloud only has a typical sky cover of 20%. Stratus cloud layers are typically 100-500 m thick, with a cloud base anywhere from the surface to 1500 m, and mostly do not precipitate much. Over much of the midlatitude oceans and parts of the eastern subtropical oceans, stratus cloud cover exceeds 50%. In some parts of the Aleutian Islands, the average stratus cloud cover in June, July and August is 90%. Over land, there is much less stratus cloud due to the lesser availability of surface water. In most of the tropical and subtropical oceans, stratus clouds are rare, as we saw in previous slides.

Slide 9 also shows 'net cloud radiative effect', the change to the net downward radiation at the top of the atmosphere induced by clouds. For boundary layer cloud, net CRE is mainly due to the reflection of sunlight by the cloud, which reduced net downward radiation at TOA and causes negative CRE. The net CRE is highly anticorrelated with stratus cloud amount because stratus clouds are reflective, having a typical albedo of 0.3-0.7. The longwave cloud radiative effect is small since being low clouds, stratus emit radiation at a similar temperature as the underlying surface. About 50% of the radiative cooling is realized in the ocean and 50% in the atmosphere. The atmosphere cools because of the longwave cooling of the clouds. The surface cools because the clouds shade the sunlight. The clouds emit longwave radiation downward that partly compensates for the shortwave cooling of the surface.

BL structure of subtropical convective CTBLs and lower tropospheric stability

Slide 10 shows composite soundings from four field experiments that studied marine subtropical and tropical CTBLs (Albrecht et al. 1995). The experiments were conducted over locations with very different sea-surface temperature (SST).The typical observed boundary layer cloud structure and circulations are sketched.

The deeper BLs tend to have less cloud cover, a weaker inversion, and a less well-mixed structure in the total water mixing ratio w = vapor+liquid (which is conserved following fluid motions in the absence of mixing). The stratification of the virtual potential temperature θ_v is roughly dry-adiabatic below cloud base. In the cloud layer, it is moist-adiabatic within the shallow FIRE stratocumulus cloud layer and conditionally unstable in the other cases.

The lower tropospheric stability (LTS) = θ(700 hPa) –θ(1000 hPa) (Klein and Hartmann 1993) correlates well with how shallow and strong the inversion is, as seen at the top of the figure in slide 10. Hence it also correlates well with stratus cloud cover and net CRE in low latitudes, as seen in Slide 11. This strong correlation between how cool the SST is compared to the free troposphere, the vertical structure of the boundary layer, its cloud cover, and its effect on the radiation budget is very important for climate, yet difficult for climate models to quantitatively reproduce.

Over midlatitudes, when stratocumulus or cumulus cloud is observed the soundings again fall into the above categories (Norris 1998a). However, the RH of surface air may be lower and hence the depth of the subcloud layer may exceed 1 km.

References

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