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Large-scale marine atmospheric boundary layer depth variability during VOCALS

Over the subtropical southeast Pacific (SSEP) subsidence dominates and results in a strong inversion above the well-mixed marine atmospheric boundary layer (MBL). The MBL generally deepens offshore, but the actual height can vary considerably in both time and space (Wood and Bretherton, 2004). Depth of the MBL is related to both large scale (e.g., variations in synoptic subsidence) and also small scale (e.g., turbulence) phenomena. Understanding the variability is important since the large scale variability of the MBL influences the local environment that contains the stratocumulus clouds and the other associated physical processes. Examination of the individual processes occurring within the MBL (i.e., generation of turbulent kinetic energy from cloud top radiative cooling, air-sea transfer, decoupling, etc) are largely ignored in favor of characterizing the basic terms impacting changes in the local MBL depth that are contained within the four terms of the prognostic MBL depth equation: horizontal MBL advection, large scale vertical velocity at the top of the MBL, and entrainment velocity.

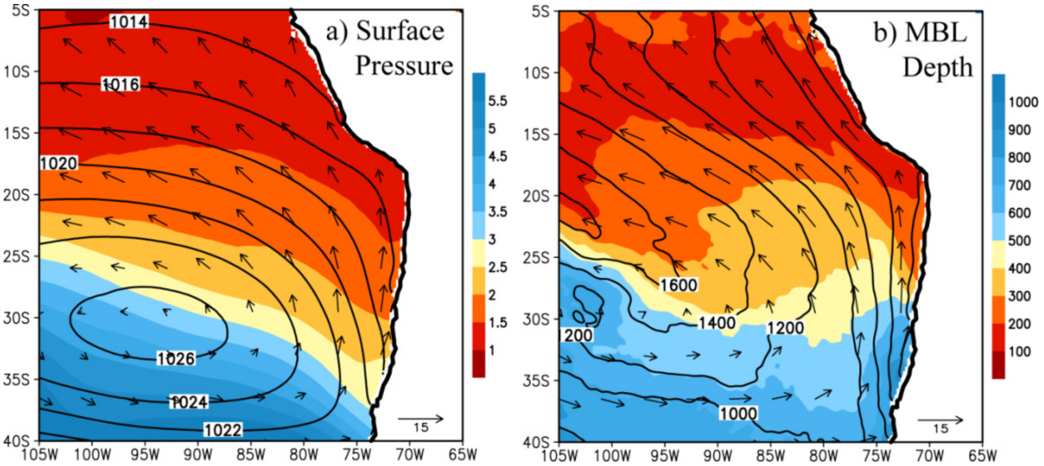

Figure 1. (a) Mean surface pressure (hPa, contours), standard deviation of surface pressure (hPa, color), and mean 10-m wind (m s^{-1}, vectors). (b) Mean MBL depth (m, contours), standard deviation of MBL height (m, color), and mean wind at top of MBL (vectors, m s^{-1}) during October and November 2008.

Variability of the MBL over the SSEP is assessed primarily by using data from the Advanced Weather Research and Forecasting model (WRF, Skamarock et al. 2005) for the period of October and November 2008 during the VOCALS field campaign. Comparison with observations at 20°S, 80°W demonstrates that during October the MBL variation agrees well but the simulation is on average 200 m lower while in November the simulation does not perform as well. Observations along 20°S reveal the variability of the MLB depth, which on average increases from about 1000 m at the coast and to about 1500 m offshore at 86°W, but there can be significant variability. The WRF underestimates the MBL depth more near the coast than offshore, which is a common modeling problem in the SSEP (Wynat et al. 2009). Because the variability is the focus of this study, the offset in the average is not as crucial. Average and standard deviation of the sea level pressure and MBL depth during October and November 2008 are shown in Fig. 1. An anticyclone dominates the region with surface winds consistent with the pressure distribution. The MBL deepens offshore with similar anticyclonic wind. Large variations in both surface pressure and MBL depth are clear in the mid-latitudes and diminish towards the subtropics. It also appears as if off the coast, the variation is advected by the wind at the top of the MBL creating a swath of slightly higher variability.

To understand the variability of the MBL using WRF output, each term in the prognostic local MBL height equation is calculated explicitly except the entrainment velocity which is calculated from the other terms in the equation. While the majority of this term can be regarded as the entrainment velocity, it is acknowledged that errors from the other terms also enter into this term. For this reason it is referred to as the residual term to remind the reader that this is the case. As shown in other studies (e.g., Wood and Bretherton 2004) on average the vertical velocity and residual term are the greatest in magnitude with opposing signs while the average advection is generally less. An important aspect of these terms with respect to changes in the MBL is their variability and how that relates to the variability of the MBL. This is explored initially by calculating the standard deviation of each term over the SSEP. While the variation of vertical velocity is greatest north of 20°S with enhanced variation in the Peruvian Bight due to the daily upsidence wave (Garreaud and Muñoz 2004), advection dominates to the south mainly as a consequence of the synoptic variation at mid-latitudes being translated to the north into the subtropics. Along 25°S the variability of the vertical velocity and advection is about the same. The ratio of vertical velocity to advection along 20°S, where many VOCALs observations took place, is between 1.25 and 2. An important finding was that the variability in advection and the rate of change of MBL depth was close over most of the domain with advection being just under twice as large. This suggested a relationship between variability in advection and the rate of change of MBL depth and is explored further.

Relative contributions of each of the terms to changes in MBL depth at individual times over the SSEP during periods of rising, steady, and falling MBL height near 20°S, 80°W demonstrates the scale of the features (spanning more than 5° at times) as well as their instantaneous magnitude and collocation with changes in the MBL depth. During events of large changes around 20°S, 80°W, fairly pronounced links are present between the advection of MBL depth and the local MBL depth change while the vertical velocity and residual play a less significant role during the large changes in MBL depth. During more quiescent periods, the advection is significantly reduced and there is more of a balance between the vertical velocity and residual.

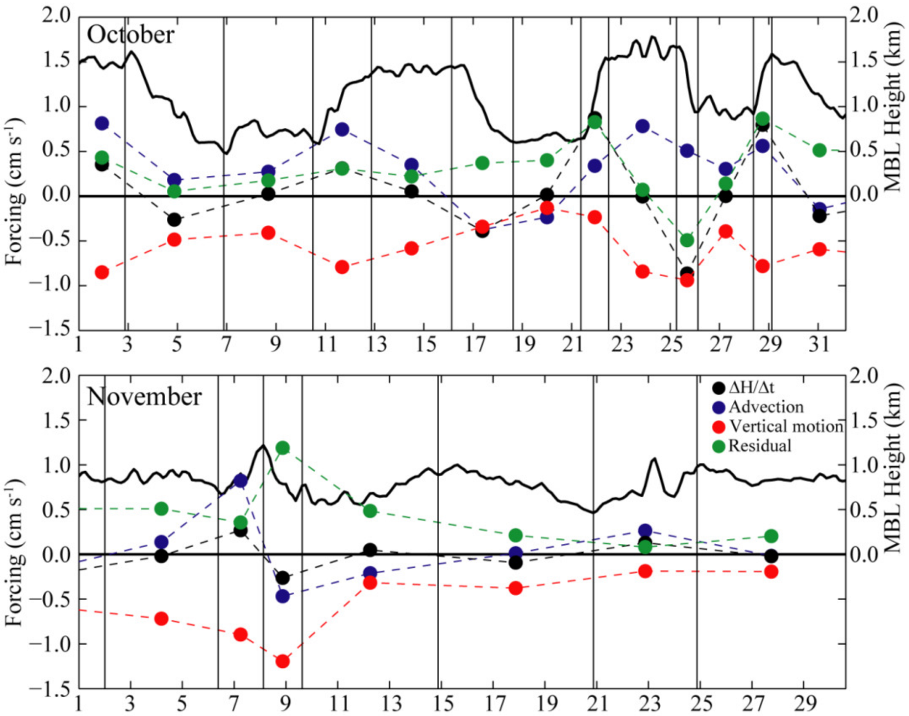

Figure 2. Time series of MBL height (m, solid contour), and averages of three-hour change of height (cm s^{-1}, black), advection (cm s^{-1}, blue), vertical motion at MBL top (cm s^{-1}, red), and residual (cm s^{-1}, green). Time range of averages indicated by vertical lines.

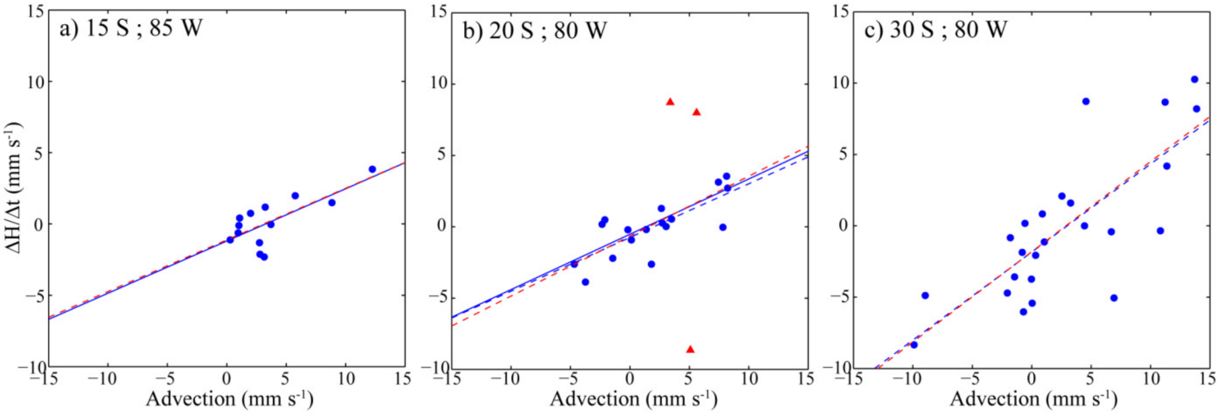

Figure 3. Comparison between the advective and change in depth terms (mm s^{-1}) averaged over distinct periods. Locations are at (a) 15°S, 85°W, (b) 20°S, 80°W, and (c) 30°S, 80°W. Outliers in (b) indicated by red triangles. Best fit lines are from standard linear regression using all the data (solid), standard linear regression without outliers (blue dashed), and robust fit (red dashed).

A time series at 20°S, 80°W illustrates the change of terms over time (Fig. 2). Here again there is an indication that the MBL depth depends greatly on the variability in advection while the vertical velocity and residual tend to always oppose each other at the largest magnitudes, but have less variability and impact on the change of MBL height. With the exception of some outliers during short periods of intense change in MBL height, relationship between advection and change of MBL height is fairly strong (Fig. 2). Analysis to the northwest and to the south also revealed a similar relationship, but greater (less) variability to the south (north), consistent with the analysis from the simple standard deviation plots.

While the vertical velocity and residual tend to be the terms with the greatest magnitudes in the MBL height equation, it appears that the advection is an important factor for controlling the change in MBL height especially south of 20°S. Advection is not the greatest in magnitude on average, but the variability of MBL height appears to be directly linked to the variability in advection. The variability of advection is in turn tied to mid-latitude synoptic variability such that these are translated to the north and impact the adjacent SSEP. When diagnosing local MBL change in the VOCALS region, it is important to accurately represent the advective component. It is recognized that while advection is not a fundamental process that modifies column MBL depth in a Lagrangian sense(e.g., vertical velocity, sea surface temperature, or surface wind velocity), it is an important factor in explaining local MBL variability and must be considered when examining the local rate of change in MBL depth.

References

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