VERTICAL STRUCTURE OF THE MARINE ATMOSPHERIC BOUNDARY LAYER

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ABSTRACT

The marine atmospheric boundary layer (MABL) is the lowest layer of the atmosphere over the ocean. Along the California coast it is about 400 m thick in the summer. It is cooled and moistened by the ocean below and separated from warm, dry free troposphere above by a region of rapidly increasing temperature, known as the inversion layer. In June 1996, 377 vertical profiles of the MABL were recorded by an instrumented aircraft during the Coastal Waves 96 project. The speed and virtual potential temperature measured by the plane were shown to have a consistent form during the project, which covered 200 km across-shore and 800 km alongshore and took place over 11 days. The averaged dimensionless profiles show a wind jet located within the strongly statically stable inversion layer at the top of the slightly stable MABL. Different height scales for virtual potential temperature and wind speed gave the most effective scaling.

Keywords: Marine atmospheric boundary layer, coastal meteorology, California, vertical profiles.

INTRODUCTION

In summertime along the west coast, the marine atmospheric boundary layer (MABL) consists of a cool, moist layer of air about 400 m deep which is denser than the warm, dry air above (Figure 1). This vertical structure is well established and has been studied during several field experiments. Shipboard releases of instrumented balloons were the basis of a climatology showing an inversion-topped MABL with a jet in wind speed that extended far offshore (Neiburger et al. 1961). A. Miller described the strong inversion and jet in the MABL off of San Francisco (Lester 1985). During the Coastal Ocean Dynamics Experiment, the dynamics of the wind jet at the top of the MABL were investigated by Zemba and Friehe (1987) and Beardsley et al. (1987). The jet has been modeled by Holt (1996) and Burke and Thompson (1996).

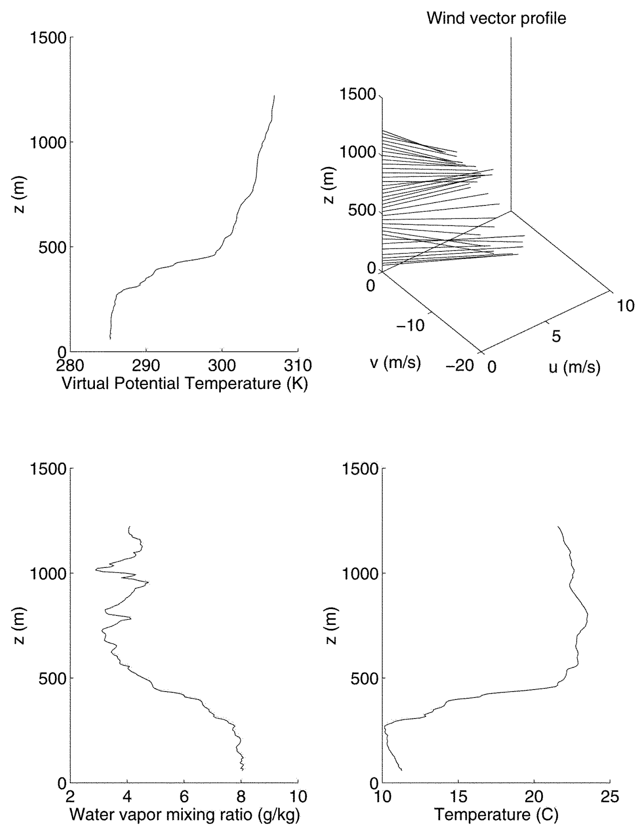

Figure 1. A typical profile of the MABL during summer taken by an instrument aircraft during Coastal Waves 96. Top left: Virtual potential temperature profile; Top right: Wind vector profile. Lower left: Water vapor mixing ratio profile; Lower right: Air temperature profile.

During June 1996, the Coastal Waves 96 field project studied the MABL within 200 km of the west coast. For 11 days of June 1996 an instrumented aircraft surveyed the MABL, recording standard meteorological variables such as temperature, humidity, and wind speed. Each survey included vertical profiles of the MABL from about 1500 m to the 30 m above the sea surface, as well as runs at level altitudes. Data was recorded at 25 Hz, rapid enough for the direct calculation of fluxes from covariances. The location of the profiles flown during all flights (Figure 2) shows that the survey region extended to about 200 km offshore and 800 km alongshore, from Cape Blanco in Oregon to Point Conception, California.

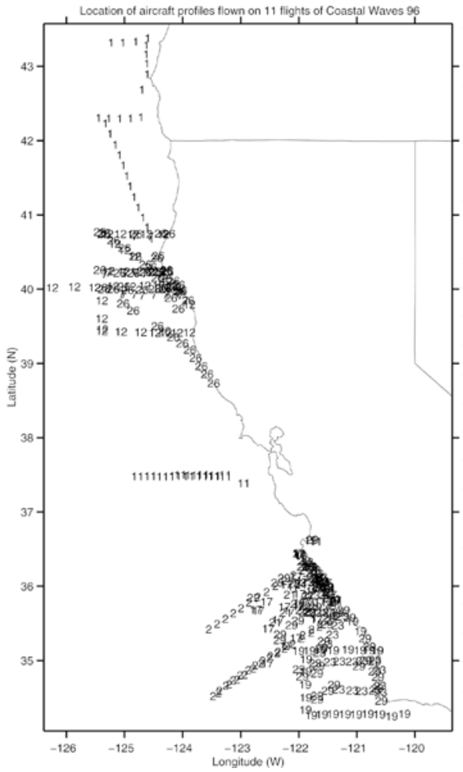

Figure 2. Profile locations indicated by the flight number. The survey region covered approximately 800 km alongshore and 200 km across shore.

METHODS

The vertical boundaries defining the MABL are the sea surface below and the inversion layer above. Exchanges across these boundaries affect the vertical structure of the MABL. Fluxes calculated from runs at 30 m can be taken as representing fluxes across the ocean surface, since this altitude is within the surface layer. The fluxes were directly estimated from averaged covariances of the high-rate data. A histogram of fluxes from all 30 m runs (Figure 3) shows that most surface heat flux estimates were downward (negative) and most moisture fluxes were upwards (positive), indicating that the MABL was cooled and moistened by the ocean. Few runs were flown within the inversion layer, so the exchanges at the top of the MABL are not estimated here. Zemba and Friehe (1987) calculated a vertical profile of the exchange of momentum and found that it was highest near the sea surface where the drag of the sea surface slows the wind.

These exchanges of heat, moisture, and momentum give the MABL its vertical profile. The 377 vertical profiles flown during the Coastal Waves project were used to evaluate how persistent this vertical structure was during the project. Without scaling, the profiles of virtual potential temperature (Figure 4) and speed (Figure 5) appear variable. Altitude, speed, and virtual potential temperature scales were chosen by their success in collapsing the profiles onto a single shape. Speed (U) was scaled by the mean speed (U_{mean}) beneath the jet height (H_{jet}), giving $U(z)' = U(z)/U_{mean}$, where

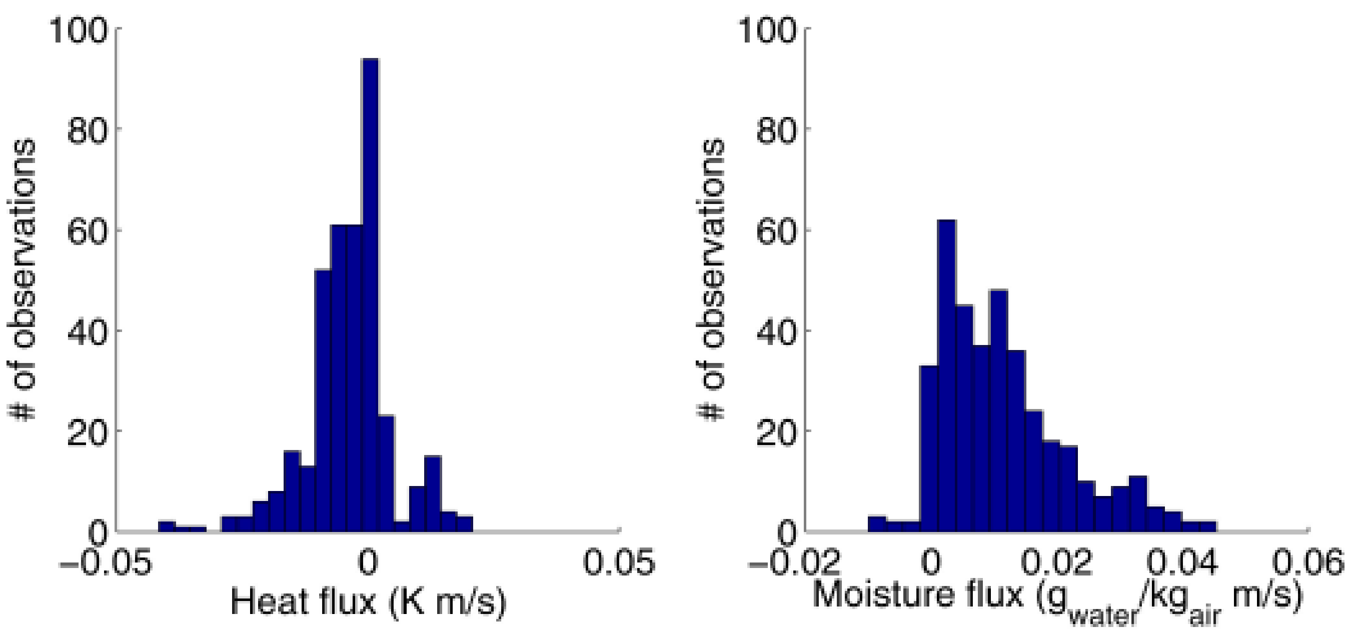

Figure 3. Histograms of fluxes calculated directly from high rate data at 30 m. Each 2 minute average counts as 1 observation. Left: Heat flux; Right: Moisture flux. Positive values are fluxes from the ocean to the atmosphere.

primes indicate dimensionless quantities. Altitude for the wind profiles was scaled with the height of the jet ($z' = z/H_{jet}$), following Forrer (1997). Virtual potential temperature (T) was scaled by the difference in temperature between the surface and the inversion base (dT), after subtracting out the mean temperature (T_{mean}) beneath the inversion base, giving $T(z)' = (T(z) - T_{mean})/dT$. The bottom of the inversion layer (H_{inv}) was chosen as the height scale for the virtual potential temperature profiles ($z' = z/H_{inv}$). Using the same height scale for the wind and virtual potential temperature profiles reduced the success of the scaling.

RESULTS

The majority the speed profiles scaled successfully (Figure 4). The mean dimensionless speed profile shows the wind jet maximum was about 25% greater than the mean speed, and the surface minimum was 25% less than the mean speed, an approximation used in Winant et al. (1988). The mean dimensionless virtual potential temperature profile shows the strongly statically stable inversion layer lying above the less stable MABL (Figure 5), with most profiles fitting into the scaling. Fedorovich (1997) scaled buoyancy profiles by the jump in buoyancy across the inversion layer and the thickness of the inversion. However, the fact that many of the profiles did not extend through the top of the inversion layer prevented use of this possibly more successful set of scales.

The height scales used for the virtual potential temperature and speed profiles were different. The success of the scaling decreased when the same height scale was used for both. A comparison of the two height scales (Figure 6) shows that when the MABL was fairly shallow, the jet height was just above the inversion base, and that the height scales were comparable. A deep boundary layer (above 500 m) seems likely to have a jet beneath the top of the inversion base, but scatter is high. Some of the scatter may be attributed to the convective regime of the layer: when the layer was undergoing forced convection, the speed and virtual

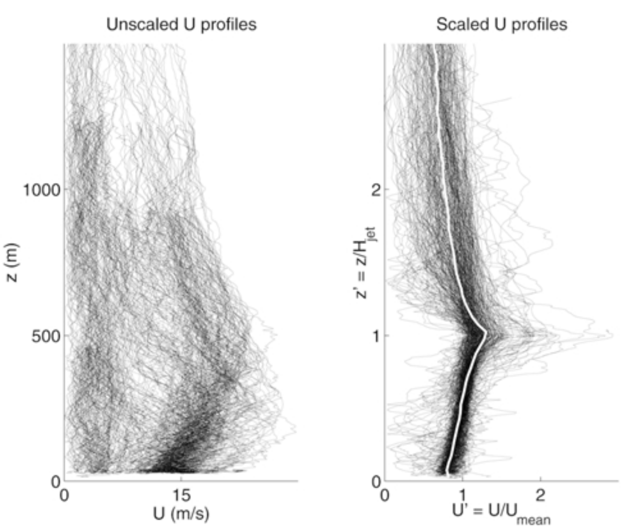

Figure 4. Left: Vertical profiles of wind speed. Right: The dimensionless speed profiles, with altitude (z) scaled by the height of the wind jet (Hjet) and speed scaled by the mean speed below the jet (Umean). The mean profile (white) is averaged over dimensionless altitude bins.

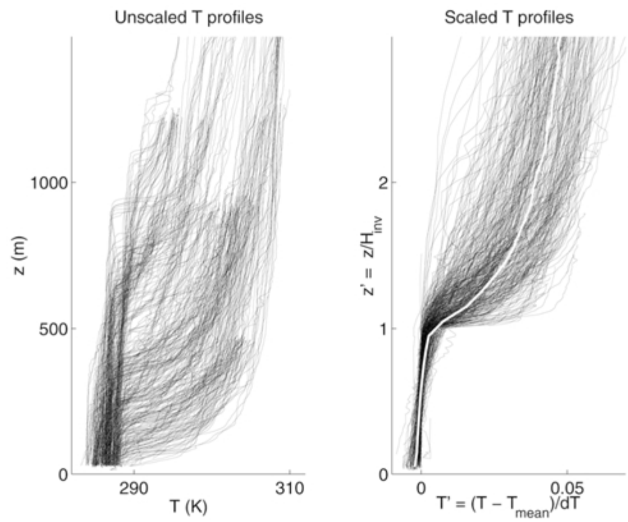

Figure 5. Left: Vertical profiles of virtual potential temperature. Right: The dimensionless virtual potential temperature profiles. Altitude was scaled with the height of the inversion base (Hinv). After the mean virtual potential temperature beneath the inversion base (Tmean) was removed, the profiles were scaled by the difference in temperature between the top and bottom of the marine atmospheric boundary layer (dT). The mean profile (white) is averaged over dimensionless altitude bins.

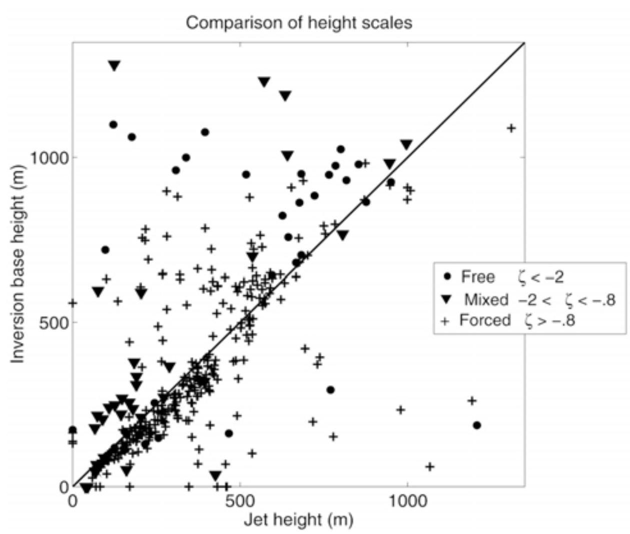

Figure 6. The height scale used in the speed profiles (Hjet) vs the height scale used in the virtual potential temperature profiles (Hinv). If the scales were the same they would lie along the strait line. The convective regime is given by z/L, where L is the Monin-Obukhov length scale calculated from the fluxes at 30 m: free convection (solid circles), mixed (triangles), or forced convection (crosses).

potential temperature scales were more likely to be close than in a free convective regime.

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