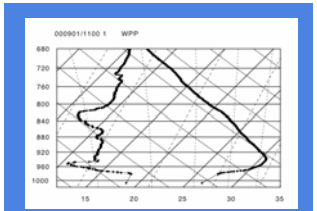
Multi-Sensor Estimation of Mixing Heights over Houston During TexAQS-2000

During the TexAQS-2000 field program, a wide variety of instruments were available to probe the planetary boundary layer (PBL). All were operating on September 1, 2000, including an airborne Microwave Temperature Profiler (MTP). This poster presents the first estimates of mixing height from an airborne MTP, compares mixing height estimates from other instruments, and integrates the measurements into a sequence of maps that depict the spatial and temporal evolution of mixing heights in the vicinity of Houston.

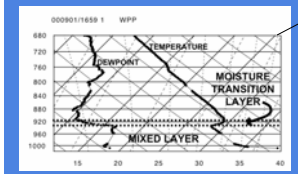
John W. Nielsen-Gammon (Texas A&M University); Christina L. Powell (Wright State University); M. J. Mahoney (Jet Propulsion Laboratory, CalTech); Wayne M. Angevine, Christoph Senff, and Allen White (CIRES, University of Colorado and NOAA Earth System Research Laboratory); Carl Berkowitz and Christopher Doran (Pacific Northwest National Laboratory); and Kevin Knupp (University of Alabama in Huntsville)

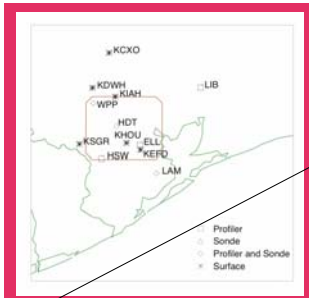


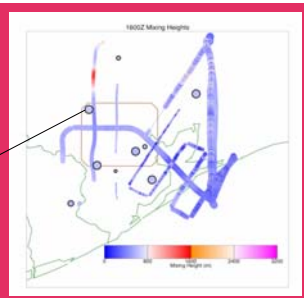
Rawinsondes

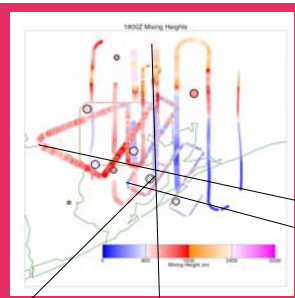
Mixing heights were estimated subjectively from rawinsonde profiles as the midpoint of the sudden decrease of water vapor mixing ratio (moisture transition layer) at the top of the apparent PBL. If no clear moisture transition layer was present, the base of the inversion was used.

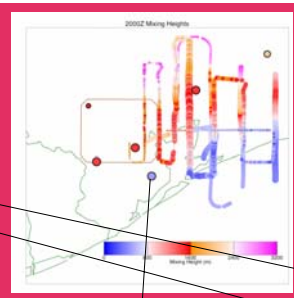
The sounding below is from 1700 UTC Sept. 1. Note the strong inversion near 900 hPa, a remnant of the elevated inversion present earlier that morning (see sounding above).

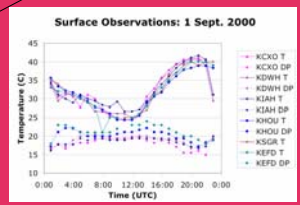










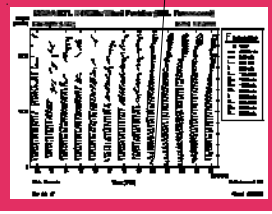


Mixing height estimates are shown above from all platforms at three different times: 1600 UTC (late morning), 1800 UTC (early afternoon), and 2000 UTC (mid-afternoon) from all profilers. Fixed sites are indicated by circles (locations of fixed sites are shown in far left), while measurements from mobile instruments are shown as colored dots or strings of dots. A thin black line denotes measurements from the airborne lidar, while no line denotes measurements from the airborne MTP. The size of the circles or dots indicates how close to the time of the map the measurement was taken. Only measurements made within 1.5 h of the map time are shown. The brown box delineates the core of the Houston metropolitan area.

In general, the highest mixing heights are observed north of Houston, with a fairly abrupt transition (see maps above and MTP measurements below). The larger mixing heights correspond to warmer surface temperatures and more rapid morning temperature rises. The surface temperatures and dewpoints plotted to the left are organized from north to south in the legend to the right of the figure.

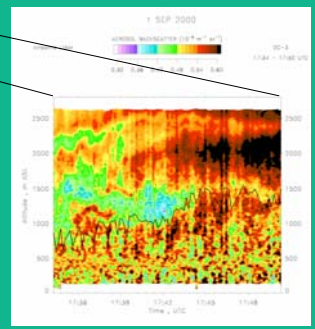
The predominant wind direction during the day was from west to east. As the mixing height deepens over land, it remains relatively shallow over water. Mixing heights are also relatively low downwind (east) of Galveston Bay.

Mixing heights drop suddenly in mid-afternoon at the Lamarque profiler site. The time-height section of winds from the profiler shows that a weak, shallow sea breeze developed between 1900 UTC and 2000 UTC, deepening and persisting through 2200 UTC.



Conclusions

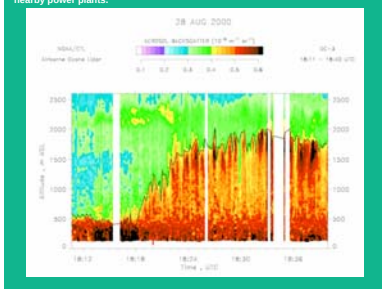
1. The airborne MTP, when flown within the boundary layer, produces data from which mixing heights can be determined objectively. The mixing heights estimates are comparable in accuracy to those from radiosondes, profilers, lidars, or in situ aircraft. Biases among all the instruments are small, and individual measurements have an RMS difference of around 200 m.
2. The mixing height pattern on Sept. 1, 2000 was unusually complex. An elevated inversion suppressed PBL growth until around 1700 UTC (noon local time). Growth was rapid north of Houston, and the slower growth of the PBL over Houston proper may have been due to the remnants of the previous day's sea breeze. There was no evidence of a larger mixing height over the inner urban area. Mixing heights were lower downwind (east) of Galveston Bay and along the Gulf coast as a weak sea breeze developed late in the day.

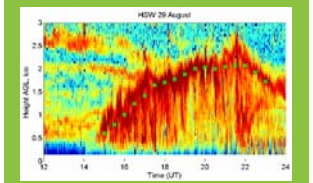


Airborne Aerosol Backscatter Lidar

The returned power from the backscatter lidar identifies layers with concentrated aerosols. Following a rough subjective estimate of maximum mixing height, the mixing height is determined objectively using the expected rapid decrease in aerosol concentration from the PBL to the free troposphere (Davis et al. 2000 JTech). An example is shown below for a flight track moving from water (left) to land (right) under onshore flow conditions.

Accurate mixing height estimates can be difficult when elevated aerosol layers are present. The time-height section above was taken on Sept. 1 and includes multiple aerosol layers aloft, possibly from dirty continental background air or nearby power plants.



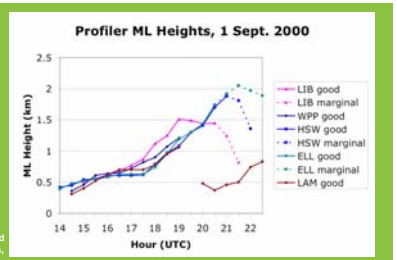


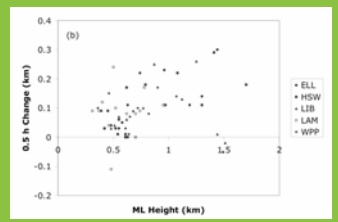
Radar Wind Profilers

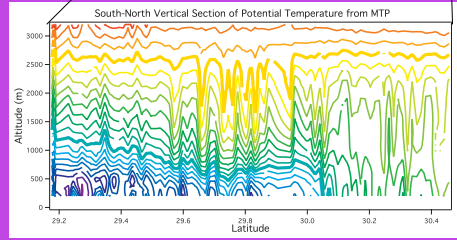
Mixing heights were estimated subjectively from reflectivity and spectral width patterns of each beam. Based on these patterns, the mixing height was assigned to the appropriate peak of reflectivity (above). Each discrete height estimate corresponds to a rough estimate over an hour of the average mixing height. Clear, unambiguous situations were assigned "good" quality flags, while other were assigned "marginal" quality flags.

The evolution shown above is typical: rapid mixing height increase in the morning, followed by slow increase in the afternoon. On Sept. 1 (upper right), despite sunny skies, the evolution was unusual: a slow rise in the morning, including a period of nearly constant mixing heights, followed by a rapid rise in early afternoon. The likely cause of this evolution was the strong elevated temperature inversion present in the morning (see radiosonde data, above).

Airborne instruments make essentially continuous measurements. To reduce these measurements to a common time, it is necessary to adjust for the likely change in mixing height during this interval. Here, the magnitude of the adjustment was determined based on the height itself, using the profiler estimates (right); slow increase for mixing heights below 0.5 km, almost no increase between 0.5 km and 0.7 km, and rapid increase above 0.7 km.





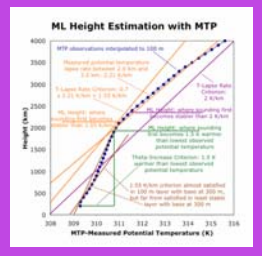


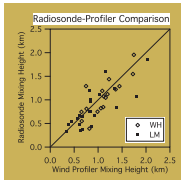
Microwave Temperature Profiler

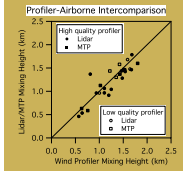
The MTP is a passive scanning instrument that measures thermal rotation-line emissions from oxygen molecules. The MTP instrument was flown on board the NCAR Electra aircraft during TexAQS-2000.

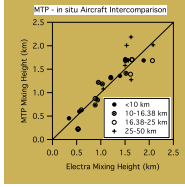
The radiances measured by the MTP at different forward scanning angles are converted to temperature profiles using a statistical retrieval technique based upon reference groups of observed or modeled profiles, and are then converted to potential temperatures (above, contour interval 0.5 K) for mixing height estimation.

Because the vertical resolution of the MTP measurements is 100-300 m in the PBL, capping inversions were not directly measurable by the MTP. To recover mixing heights, a variety of objective techniques (right) were tested against colocated profiler estimates. The smallest error was produced by the Theta-Increase method (Heffter 1980 ARL Tech Memo), shown in green.









Instrumental Comparison

Two of the radiosonde launch sites were colocated with radar wind profilers. Mixing heights from the two instruments closely agree, with biases of less than 80 m and standard deviations of less than 270 m. Using only good-quality radiosonde and profiler estimates, the bias is 10 m. No biases were statistically significant.

To compare profiler estimates with those from airborne instruments, all airborne measurements from within 10 km of a profiler site on a particular flight leg were averaged together. Both the lidar and MTP were essentially unbiased, although the MTP estimates were tuned to be unbiased against the profilers. Standard deviations were 200 m for the lidar and 130 m for the MTP. Comparisons against the coastal profilers, ELL and LAM (LM) (not shown) were not as good, apparently because strong spatial variations of mixing height were often found near the coastal sites.

To obtain an independent measure of the accuracy of the MTP mixing height estimates, those estimates were compared to estimates from Electra aircraft soundings. Because the MTP measurements were only valid when the Electra was flying in a straight line and soundings were made using spirals, no truly collocated estimates exist. However, for estimates within a reasonable distance of each other, the standard deviation of the differences was less than 200 m.

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