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USE OF GROUND BASED SENSORS TO EXPLORE MIXING HEIGHT DYNAMICS IN URBAN AREAS AND ASSESS WRF MODEL ESTIMATES

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ABSTRACT

Aerosols are in general distributed in a well mixed manner throughout the turbulent mixing layer and therefore accurate modeling of the atmosphere boundary layer is important in improving air quality forecasts. However, most of the recent air quality models run operationally at the state level (i.e. New York State) do not take into account the details of the urban layer (i.e. No Urban Canyon Model) and this can be expected to result in significant modifications in the mixing height dynamics. For instance, it is expected that large scale urban cover can reduce the turbulent kinetic energy (TKE) and thus reduce buoyant flux thereby inhibiting the start of the convective growth and limiting the extent of the mixing layer height. It is also expected that the behavior of the mixing height (MH) in urban areas will decay more slowly due to urban heat island mechanisms. The main goal of this paper is using active instrumentation with emphasis on high signal to noise (SNR) lidar system to obtain accurate measures of MH for comparison to Weather Research and Forecasting (WRF) model estimates.

1. INTRODUCTION

Urban areas often encounter high aerosol pollution episodes so it is important for air quality forecast models to calculate aerosol emissions and transport. Since aerosols are often dynamically driven by convective boundary layer dynamics during daytime heating, it is useful to assess the performance of MH estimates and parameterizations from the Metrological Models. Lidar is an active remote sensing instrument which can be used to investigate the behavior of the MH dynamics. However, due to the high power laser, lidar cannot be operated 24/7. But we expect that by combining high power lidar for high PBL heights with 24/7 eye safe ceilometers, we can probe the full diurnal structure of the mixing layer dynamics. However, in this study, we mainly focus on validating and evaluating the performance of the WRF model with lidar measurements. Two study cases are chosen for discussion. [1]

2. INSTRUMENT LIDAR

Lidars can probe the turbulent mixing layer since in convective conditions, aerosol particulates are trapped in the layer. Lidars can see this instantaneous magnitude of the return signal is related to aerosol backscatter and time delay between the pulse and signal return provides the distance. Therefore the lidar system can determine the MH by using Mie scattering mechanism because it have a significant backscatter contrast between the mixing layer and free troposphere layer. While we have three channels (UV, VIS, NIR), the NIR channel is used since molecular effects on this channel are smallest

A wavelet based technique is used to estimate the MH. The wavelet transform with appropriate parameters chosen is capable to find the global maxima where the backscatter signal is the strongest (e.g. dramatic signal change between mixing layer and free atmosphere) and is the indicator of the mixing height. [2]

3. WEATHER RESEARCH AND FORECASTING MODEL

WRF Model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3-dimensional variational data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands

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of kilometers. In this study, the WRF/CMAQ model data for entire year 2007 is generated using the following schemes:-

a) WRF-NMM - NCEP 0Z forecast data
  - Mellor-Yamada-Janjic (MYJ) 2.5 a local TKE PBL scheme
  - NOAH Land Surface Module (Bulk Parameterization)

b) CMAQ version 4.6
  – Nested 12km x 12km
  – Eddy Vertical Diffusion “K-coefficient”
  – aero3 aerosol mechanism

4. RESULT

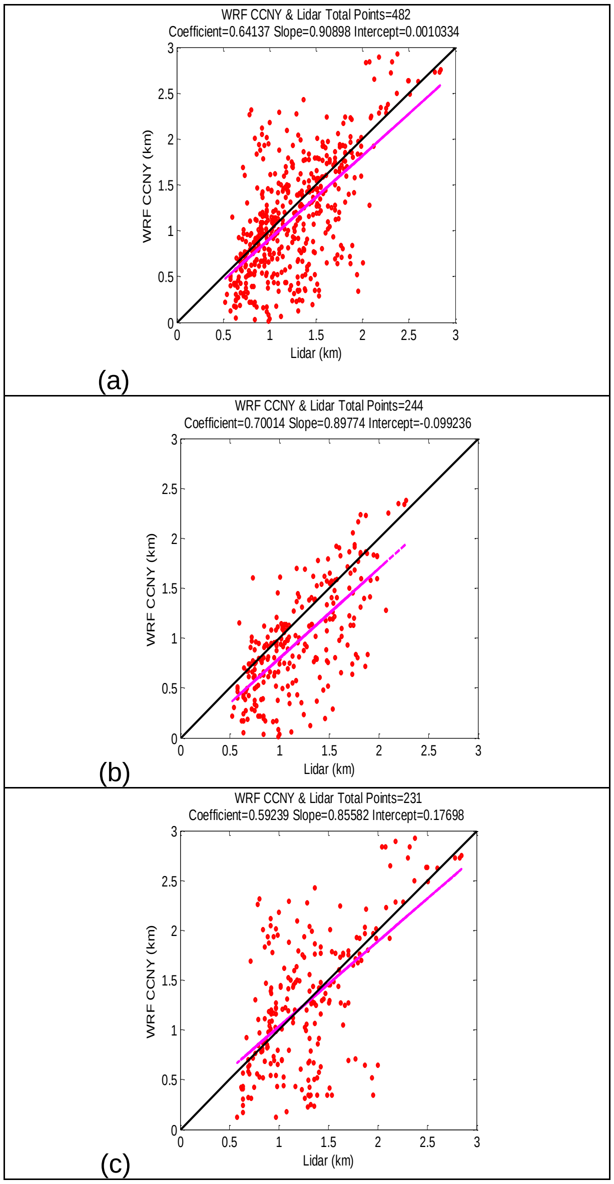
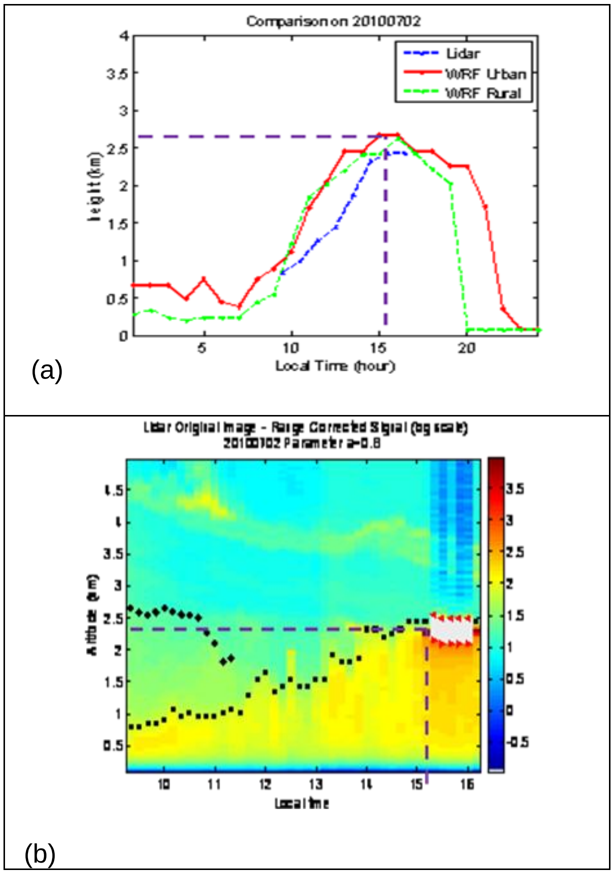


Figure 1 (a) WRF estimate MH versus Lidar estimate MH over year 2007 (b) WRF estimate MH versus Lidar MH estimate over months 1, 2, 3, 4, 10, 11 and 12 (c) WRF estimate MH versus Lidar MH estimate over months 5, 6, 7, 8 and 9

We first explore the accuracy of the model by validating them with lidar measurements. In Figure 1 (a) we note strong correlation (0.64) in the general data over year 2007. In Figure 1 (b) we found that for winter – fall, the correlation (0.7) is slightly higher but we see a strong tendency for WRF to underestimate. In Figure 1 (c), spring-summer correlation is lower (0.59) and is more spread as expected due to more complex structure in the mixing layer. We note in particular that WRF tends to overestimate the mixing layer height and those cases where WRF underestimates is mainly due to Lidar picking up the residual layer as the mixing height. Future wavelet based analysis techniques are being developed ignore the residual layer which will allow a better analysis data set for comparison. In addition, Lidar overlap area occurs below 500 meters and in general mixing height during winter period are lower than 500 meters so this region needs to be discounted.

4.1 Case Study 1



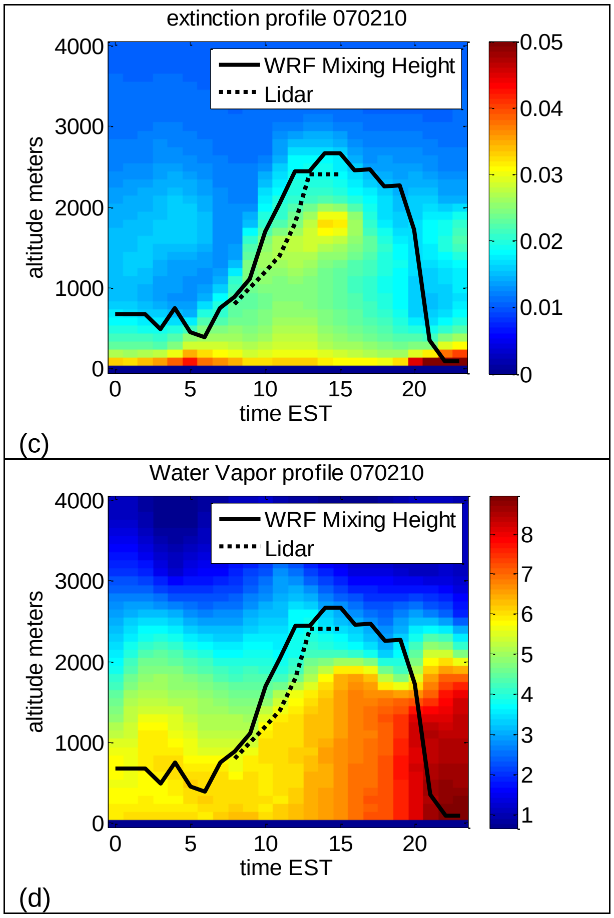


Figure 2 (a) Mixing height in New York City area on July 2, 2010 (b) CCNY lidar measurement on July 2, 2010 (c) WRF/CMAQ extinction on July 2, 2010 (d) WRF/CMAQ water vapor mixing ratio on July 2, 2010

Since air quality issues are most crucial in summer where the surface heating is dominant and UCM modeling is most important, we are particularly focused on summer months where effects are strongest. In addition, it is important that minimal background synoptic conditions (wind speed < 10m/h) are present that would introduce significant shear components.

As an example of a general trend we observe in summer, we see In Figure 2 (a), that the lidar estimate of MH is slightly suppressed and delayed from that of WRF estimate urban mixing height. This may be due to overestimates of heat flux based on surface parameterization of WRF model. Moreover, there is a significant increase in MH persistence during night over urban. We also note that the CMAQ particulates are accurately following the turbulent mixing layer reinforcing the use of lidar backscatter as the MH. Figure 3 (d) shows the water vapor mixing ratio as function of height. In particular, we observe strong correlation during the convective growth period although the particulates and water vapor do not follow the same mixing. Multiple comparisons tend to illustrate a significant urban suppression of the convective growth which is qualitatively consistent with a reduction of TKE from the urban canopy which is not accounted for in the operational models. However, due to the coarse 12 km resolution, we cannot easily take out coastal factors but since coastal mixing layer heights are always suppressed in comparison to urban, such contamination would lessen further the mixing layer. Therefore, we would expect an even larger mismatch if higher resolution models were used. To address these issues, we therefore look to include urban boundary and high resolution to see improvements. [3]

4.2 Case Study 2

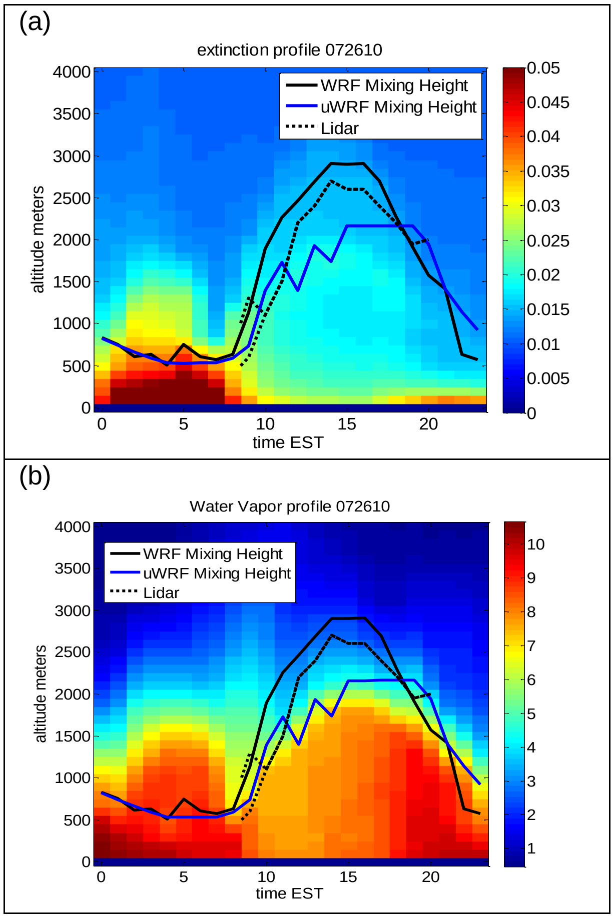


Figure 3 (a) WRF/CMAQ extinction on July 27, 2010 (b) WRF/CMAQ extinction on July 27, 2010

The urbanized WRF (uWRF) model we used in the comparison is a multilayer urban model [4] that accounts for impacts from horizon (canyon floors, roofs) and vertical (walls) surfaces in the momentum, heat and turbulent kinetic energy equations. In modeling an urban areas, the model ingests a statistical distribution of buildings of same width at same distance from each other, but with different heights governed by a distribution function based urban databases. A 24-h simulation was performed (12-h spin up) was used and 4 two-way nested domains with a grid spacing of 9, 3, 1 and 0.333 km were defined. Initial and boundary conditions from NAM (resolution: 12 km). Vertical resolution of 51 terrain following sigma levels (33 levels in the lowest 1.5 km, first level ~10m. In this case, the PBL Parameterization follows that of Bougeault and Lacarrère [5] and Urban classes were derived from the National Land Cover Data (NLCD). Once the classes were defined, Urban canopy parameters from National Urban Database and Access Portal Tool (NUDAPT) were defined and assimilated in WRF on a GRIDDED basis. In Figure 3 (a-b) we note very significant modifications seen between WRF and uWRF bringing the mixing height down dramatically and delaying the onset of convective growth. Note that uWRF weakens the decay of the mixing height in agreement with observations. [6]

5. CONCLUSION

Lidar is by the far the most reliable instrument for MH observation due to the accurate boundary based on aerosol optical scattering. This is validated by the close dynamics in the CMAQ extinction and the WRF MH as expected if only local emissions are accounted for and strong convection dominates. Lidar observations also seem to provide some evidence of WRF overestimation of MH at peak of convective growth which is reasonable due to urban roughness scales decreasing the turbulent kinetic energy. In addition, a slower decay of the mixing layer height occurs but difficulties in lidar observations give little statistical assessment. Efforts to correct lidar overlap region and improve wavelet technique for MH estimation are ongoing. Preliminary uWRF comparisons show that adding the UCM can explain the qualitative errors but seems to overcorrect.

6. REFERENCES

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