Utilizing remote sensing instruments to evaluate WRF-CMAQ model in urban environment

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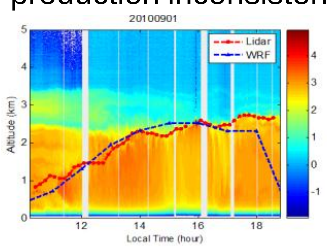
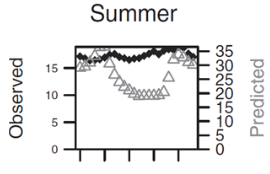
Motivation

- Air quality models (WRF-CMAQ) are commonly used in air quality applications.
- In urban environments, these models become more complex due to the inherent complexity of the land surface coupling and the enhanced pollutants emissions.
- Parameters that we are interested in assessing, include planetary boundary layer, particulate matter, and aerosol optical properties.
- Our goal is to assess and to improve the air quality model performance especially in urban area by using remote sensing instruments.

Overview

- We explored the usefulness of vertical sounding measurements on assessing meteorological and air quality forecast models.
- Particularly, we focused on assessing the WRF model (12km x 12km) coupled with the CMAQ model for the urban New York City area using multiple vertical profiling and column integrated remote sensing instruments.
- In addition, this study includes a mathematical method using a direct Mie scattering approach to convert aerosol microphysical properties from CMAQ model into optical parameters for direct comparisons with multi-wavelength (1064-532-355 nm) lidar and sunphotometer measurements, located in CCNY.
- This multispectral information may provide better insight into aerosol speciation and production inconsistencies within the model.





Doraiswamy et al. (2010).

Physics Options	2007 WRF Run 1	2007 WRF Run 2	2010 WRF Run
PBL	Modified Blackadar	ACM2	MYJ 2.5
Surface Layer	Pleim-Xiu	Pleim-Xiu	NOAH Unified 5-layer Land-surface
Microphysics	WSM6	Morrison II	Ferrier Gridscale
Cumulus Parameterization	Kain-Fritsch	Kain-Fritsch	Cumulus-Betts-Miller-Janjic
Shortwave Radiation	Dudhia	Dudhia	Lacis-Hansen
Longwave Radiation	RRTM	RRTM G	Fels-Schwartzkopf

Instruments

Lidar

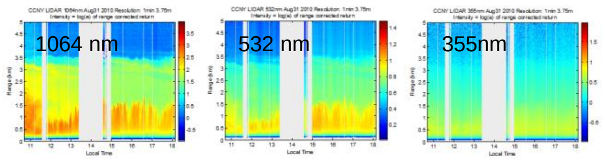
$$P(R,\lambda) = \left(P_0 \frac{c\tau}{2} A\eta\right)\left(\frac{O(R)}{R^2}\right)\left(\beta(R,\lambda)\right)\left(e^{\left(-2\int_0^R \alpha(r,\lambda)dr\right)}\right)$$

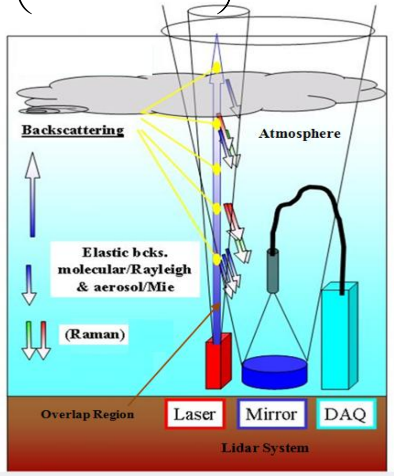
K - System constant

G(R) - Range-dependent measurement geometry

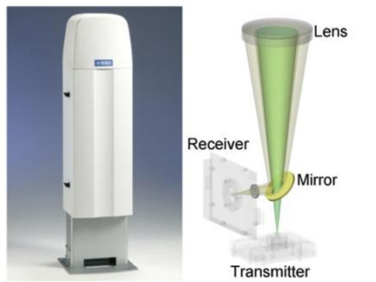
β(R) - backscatter coefficient

T(R) - Transmission term





Ceilometer



Vaisala CL31 model

- Original designed for cloud detection, but also can be used for aerosol observation at low range (surface ~ 1km) using 910 nm channel.
- Eyesafe diode laser and light weight.

Sunphotometer

$$T = \frac{I_{out}}{I_{in}} = e^{-\int \alpha dz} = e^{-\sigma \int N dz}$$

α - absorption coefficient

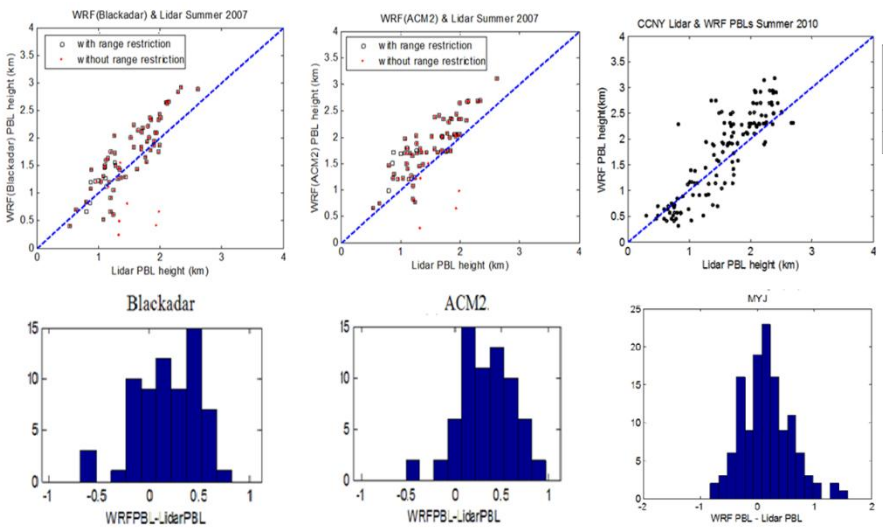
σ - absorption cross section

N - density of absorbers

CIMEL Electronique 318A

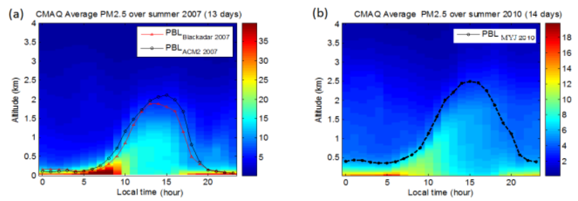
- The measured radiant flux is due to a combination of what is emitted by the Sun and the effect of the atmosphere; the link between these quantities - Beer's law.
- This instrument is part of the AERONET and the wavelengths of interested are 1640 nm, 1020 nm, 532 nm, 500 nm, 440 nm, 380 nm and 340 nm.

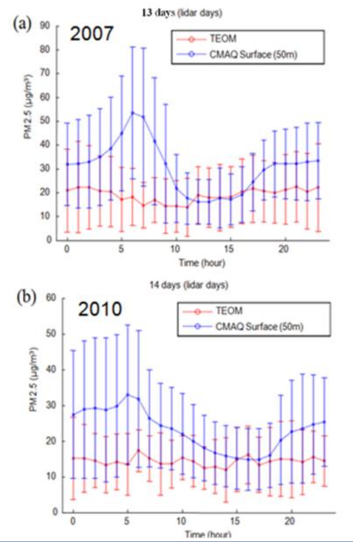
Results and Discussion

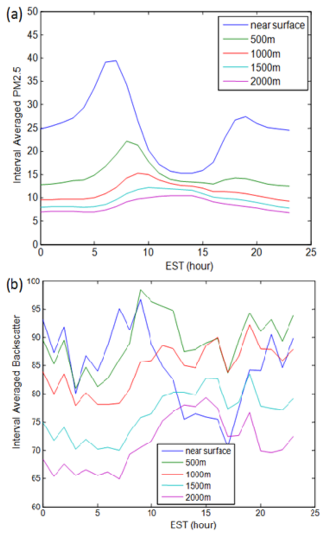


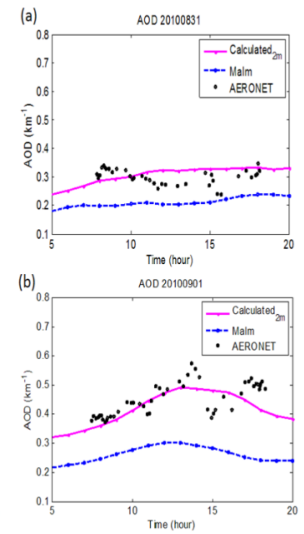
WRF schemes / Lidar PBL Methods	Blackadar (2007) 13 days, 67 data points			ACM2 (2007) 13 days, 67 data points			MYJ (2010) 14 days, 83 data points		
	R	Mean	Std	R	Mean	Std	R	Mean	Std
Wavelet (with height limit)	0.87	0.19	0.30	0.84	0.34	0.28	0.84	0.23	0.40
Wavelet (without height limit)	0.72	0.10	0.46	0.71	0.25	0.40	0.60	0.06	0.61

- The $PM_{2.5}$ spike is less intense in the observation of summer 2010.
- The summer 2010 PBL heights are significantly larger on average for summer 2010 during the sunrise / sunset periods, in comparison to the more compressed PBL height of summer 2007.









Summary

- The observed biases are reasonable within the errors (nonlinear vertical grid, forecast uncertainties) are expected .
- The strong surface emission behavior in the diurnal pattern predicted by CMAQ are not seen in the ceilometer observation as these actual emissions are evenly distributed in the PBL.
- The CMAQ extinction parameter has the same near surface behavior with the $PM_{2.5}$ mass so it is reasonable to diagnose the CMAQ $PM_{2.5}$ with the lidar and ceilometer backscatter.
- It is clear that CMAQ primary emissions are not properly distributed vertically which may caused by the very low PBL of the model during predawn and post-sunset period.
- On the other hand, for summer 2010, the expansion of the PBL height seems to allow at least partial venting of the pollutants, which is more in line with ceilometers based observations.
- We calculate the extinction from CMAQ outputs (particulate mass) base on Mie Scattering approach and the results match well with AERONET data.