Retrievals of backscatter coefficient and mass concentration of particles with coherent Doppler lidars

L. Thobois, R. Parmentier, J. P. Cariou, and J. Preissler – LEOSPHERE A Vaisala Compagny, Saclay, France
B. Shrestha – University at Albany, USA
E. Dieudonne, H. Delbarre – University of the Littoral Opal Coast (ULCO), Dunkerque, France

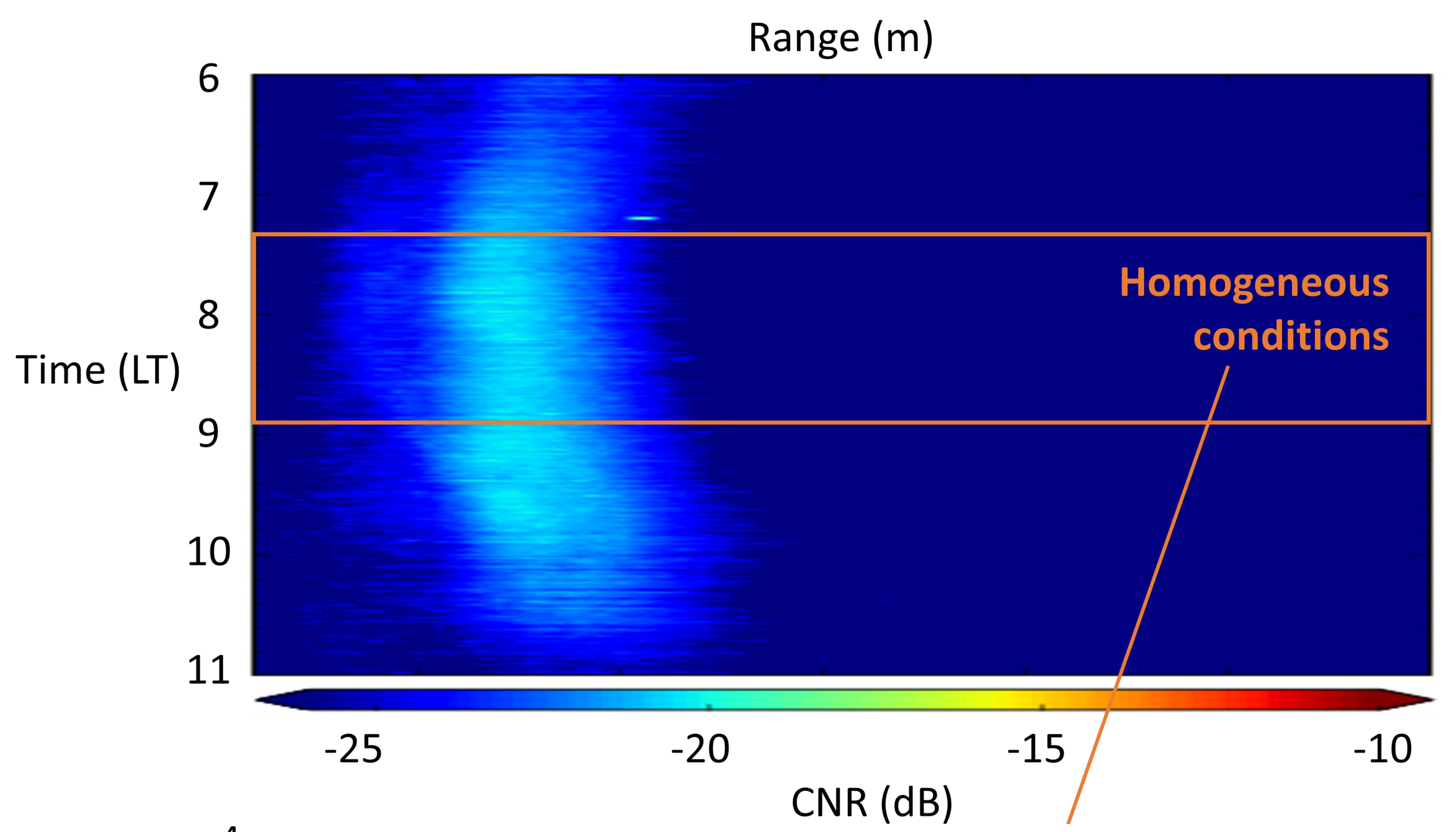
Motivation

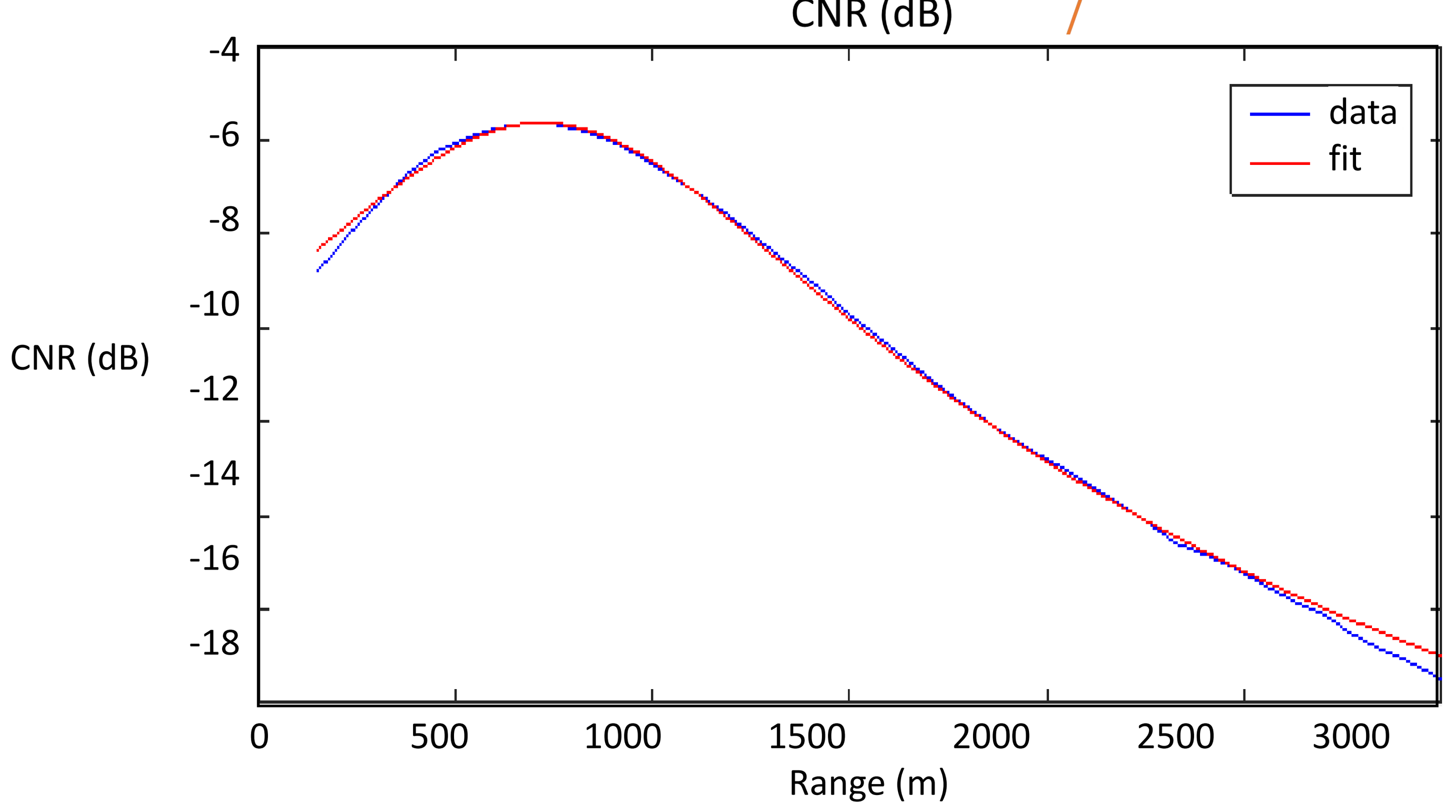
For both, air quality regulatory bodies and industries, it is crucial to understand spatial dispersion of aerosol. In-situ sensors provide accurate measurements of aerosol concentration with time, but only as point measurements. They do not allow a multi-dimensional view of the dispersion over an area of interest.

Coherent Doppler Lidars (CDL) have been developed to measure wind speed. However, their backscatter signal is also used to study aerosol and cloud properties, like backscatter coefficient, which is proportional to aerosol concentration. The big advantage of CDL is, that wind and aerosol are measured simultaneously with one single sensor. Scanning CDL can in addition be used for 4D monitoring of wind and aerosol concentration.

Calibration of telescope function

The CDL beam is slightly focused to maximize measurement range. This introduces a maximum in the detected signal intensity, or carrier-to-noise ratio (CNR), which is a direct output of CDL. This focal effect can be corrected for when the so-called telescope function is known. Here we show an experimental approach.

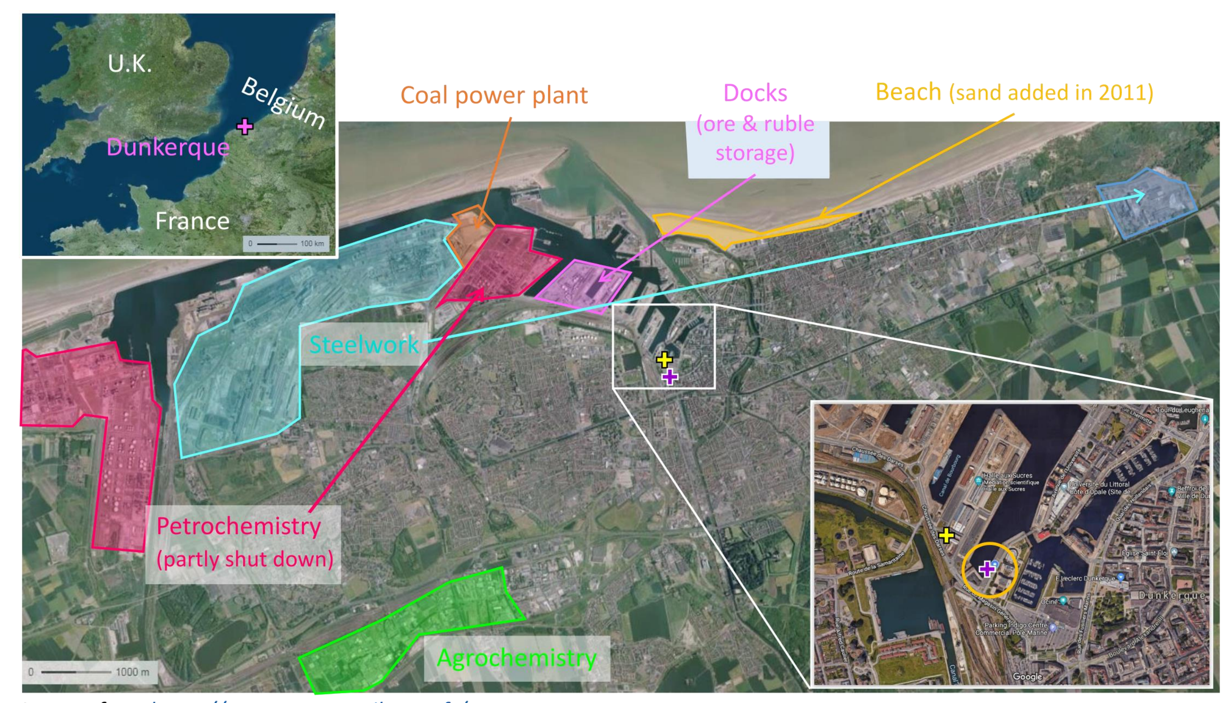




The gain is corrected by fitting CNR measured in homogeneous conditions (blue line above) to a Lorentzian function, and using the resulting curve (red line above) to weigh each profile. Variability of the telescope function is mainly due to turbulent changes in refractive index of the sampled air. Within intervals of 90 minutes, B. Shrestha found variability of about 20 % at different NY State Mesonet stations.

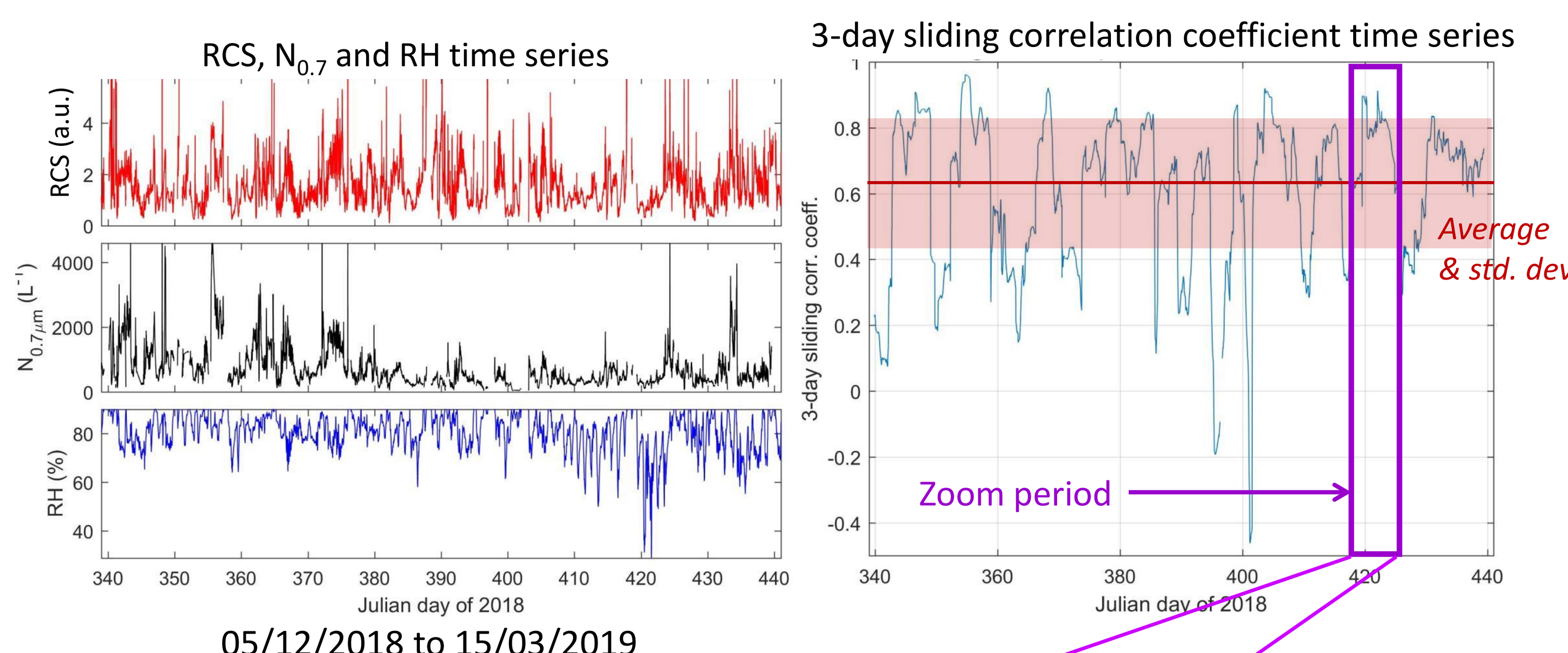
For well characterized CDL, the telescope function is expected constant and calibration can be done without atmospheric influence.

Horizontal mapping by ULCO in France

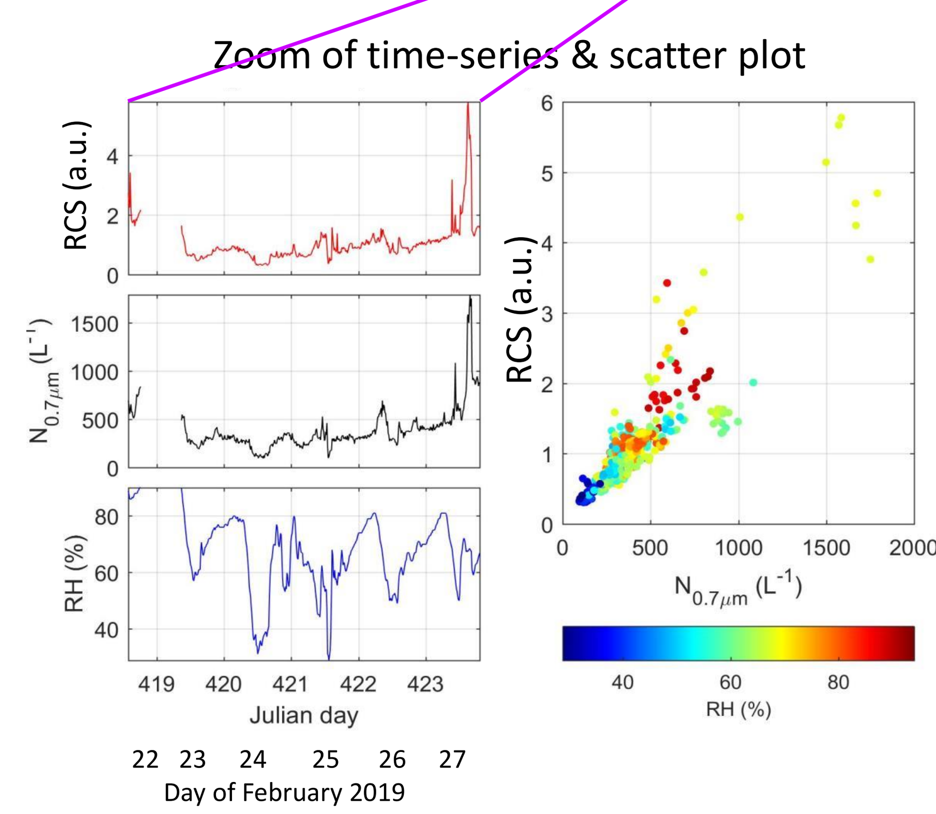


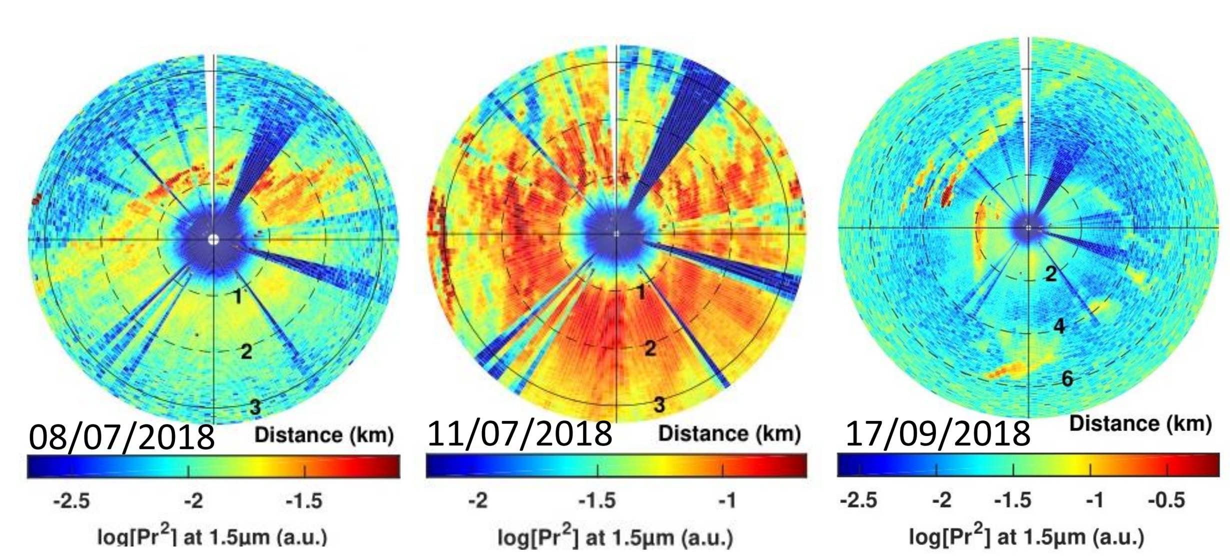
Images from https://www.geoportail.gouv.fr/

Study of local pollution in Dunkerque, France, by E. Dieudonne (at ULCO): Horizontal backscatter mapping at low elevation angle (2°) with CDL (WLS 100S). Comparing backscatter signal from CDL with data from particulate matter (PM) analyzer (ENVEA MP 101 M) and optical particle counter (GRIMM dust monitor).



Best correlation coefficient (R^2=0.64) was found between range corrected signal (RCS) and number concentration of particles at 0.7µm ($N_{0.7\mu m}$). R^2 of RCS vs measured PM2.5 and PM10 was 0.15. R^2 of RCS vs PM2 reconstructed from cumulative volume concentration (assumed density 1.7) was 0.62.

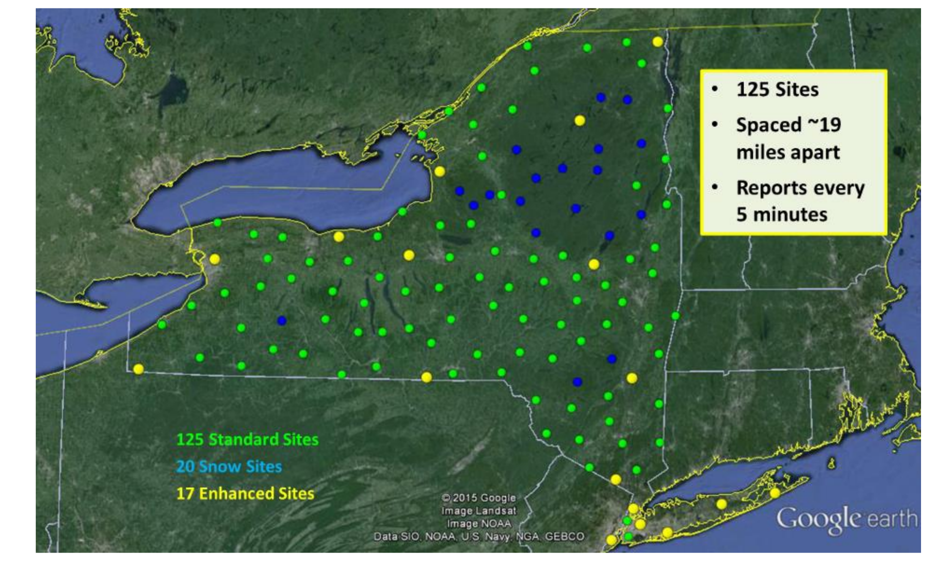


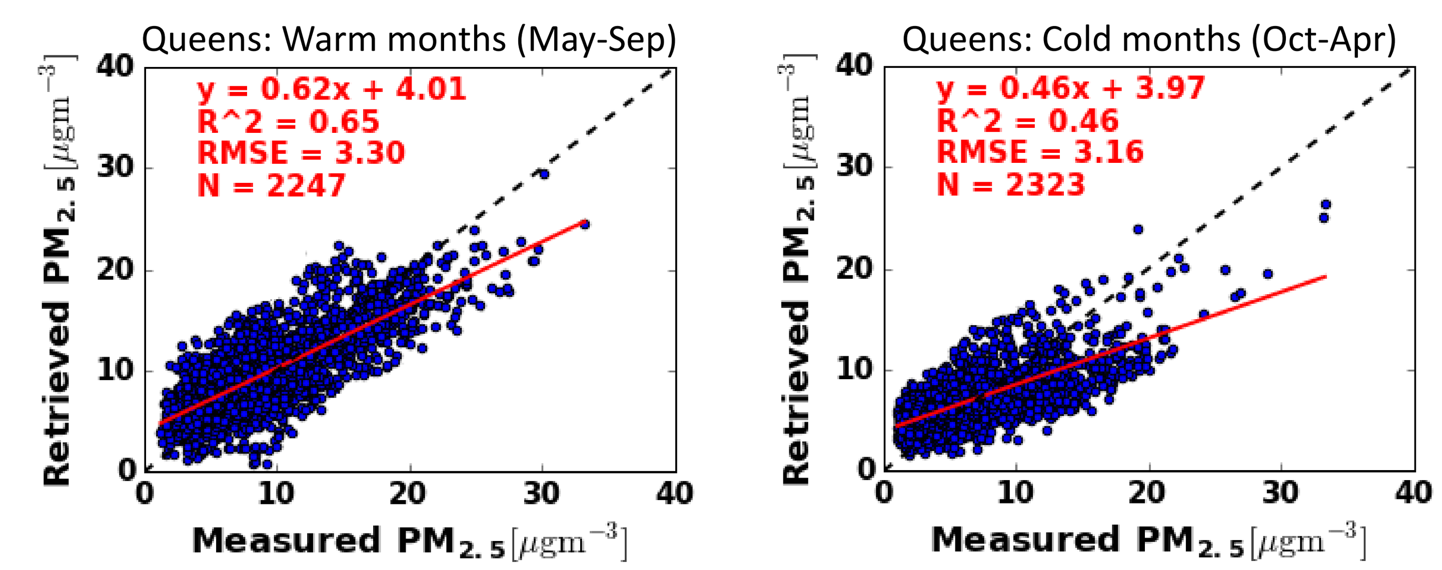


Examples of horizontal RCS maps illustrate inhomogeneous distribution of scatterers around the Dunkerque site

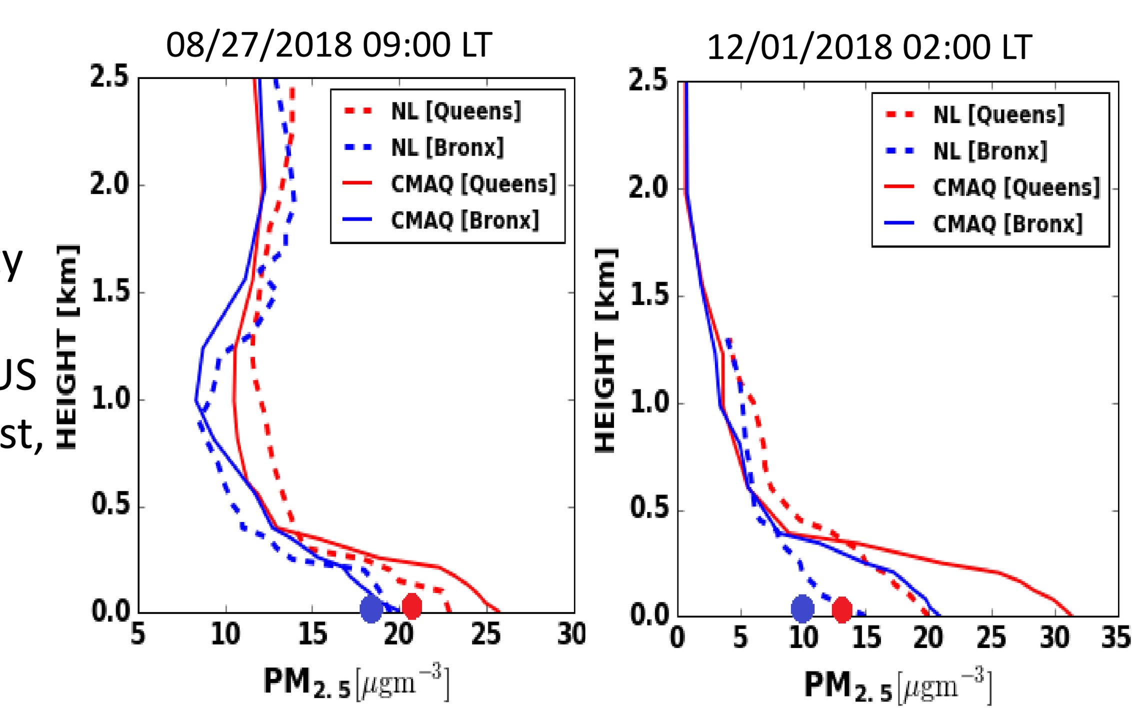
Vertical profiling in NY State Mesonet in US

Use of CDL in networks: Application of a nonlinear model to convert backscatter profiles from CDL (WLS 200S, operated in NY State Mesonet, US) to PM2.5. The model includes profiles of temperature, humidity (from microwave radiometer) and wind speed.





Comparison of PM2.5 profiles to CMAQ (Community Multiscale Air Quality Model of US EPA, hourly forecast, 12 km resolution).



Conclusions and outlook

We present ongoing work towards aerosol quantification, combined with wind information, using CDL as multi-purpose lidars. CDLs are sensible to particles from about 0.5 µm. PM2.5 includes particles smaller than 2.5 µm. If a large fraction of particles is smaller than 0.5 µm a negative impact on the correlation between CDL and in-situ data is expected.

Another challenge was the impact of inhomogeneous atmospheric conditions on the calibration of CNR and calculation of backscatter profiles. In case of vertical profiling, vertical gradients of aerosol load, as well as aerosol type, play an important role. Very clean conditions, as seen in NY Mesonet in cold months, also posed a problem. Nevertheless, this study shows the potential of calculating aerosol fluxes on a network scale thanks to the combined wind and aerosol detection.

For horizontal mapping of sources and aerosol dispersion, horizontal inhomogeneities are a challenge. We measure close to the ground, which means close to a variety of sources, especially for the site in Dunkerque. Due to the high variability there, matching lidar data to the location of in-situ sensors is difficult.

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Poster 418

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