Boundary layer height measurements over Doha using Lidar

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Abstract

A Vaisala CL51 ceilometer, based on the Lidar technique, has been installed in Doha, at one building inside Qatar Foundation’s Education City, and is operating since December 2012. It is being used to perform backscatter profile measurements of the atmosphere in an attempt to study the effects of aerosols on solar radiation. Lidar observations give an estimate of the planetary Boundary Layer height at this location. The Boundary Layer height is determined by the Vaisala Boundary Layer View Software BL-VIEW using the gradient method based on the detection of strong changes in the vertical back-scattering aerosol profile. The scope of the present study is to present the measurements of the Boundary Layer height over Doha taken during several months using Lidar; a comparison of CL51 observations with solar radiation ground measurements is also included.

1. Introduction

The State of Qatar intends to build large-scale solar energy based projects by 2020 and much of this is expected to come from CSP plants. DNI is the relevant measure of solar resources for CSP. Ground measurements data of DNI are currently not available in Qatar, thus satellite data represents an alternative choice to evaluate DNI data and solar resource potential of a site. Nevertheless, satellite-derived data tends to give erroneous DNI values due to the fact that the used models do not account correctly for high aerosol loads [1], characteristic of the lower atmosphere over the desert area of Qatar.

Lidar ceilometer devices have been recognized as suitable instruments to detect the boundaries of atmospheric layers and to track and detect the aerosol concentration in the atmosphere [2]. Within the atmospheric boundary layer high aerosol concentrations can be found; therefore, analysis of the BL...
structure and evolution during the day is very important for the study of atmospheric aerosols and thus for solar resource assessment. The present study describes the use of a Vaisala CL51 ceilometer for continuous measurement and characterization of the BL height and structure for cloudless days over the city of Doha, based on the vertical backscatter profiles obtained with the ceilometer. Ground measurements of DNI and DHI at the same location are also displayed along with BL heights around local solar noon. This study is part of Qatar’s solar resource assessment project being performed at the Qatar Environment and Energy Research Institute.

**Nomenclature**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>BL</td>
<td>Boundary Layer.</td>
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<tr>
<td>BL-VIEW</td>
<td>Vaisala’s Boundary Layer View Software.</td>
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<tr>
<td>CSP</td>
<td>Concentrated Solar Power.</td>
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<tr>
<td>DHI</td>
<td>Diffuse Horizontal Irradiance.</td>
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<td>DNI</td>
<td>Direct Normal Irradiance.</td>
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<td>Lidar</td>
<td>Light Detection And Ranging.</td>
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**2. Methodology**

**2.1. Instrumentation**

The measurements shown in this study were taken by instruments installed on the roof of one building (Lat 25.33 °N, Long 51.43 °E) inside Education City:

- For measuring the vertical profile of the atmosphere, a Vaisala CL51 ceilometer is used, pointing vertically upwards. CL51 is the latest ceilometer model from Vaisala, based on Lidar Technology. CL51 has an eye-safe InGaAs pulsed diode laser with 910 nm wavelength, repetition rate of 6.5 kHz and energy of 3μWs and reports backscatter profiles up to 15 km with a resolution of 10 m. It employs second generation advanced single lens optics which allows reliable detection of very low stable layers and a powerful laser transmitter which provides an increased signal-to-noise ratio. More features about CL51 can be found in the CL51 Datasheet Brochure [3].

- DNI is measured with a Kipp & Zonen CHP1 pyrheliometer mounted on a Solys 2 two-axis sun tracker [4]. CHP1 is a “First Class” compliant instrument according to international standards, with a response time of 5 s, a spectral range of 200 to 4000 nm and daily uncertainty of +/- 1%.

- DHI is measured with a Kipp & Zonen CMP11 pyranometer [4], mounted on the same tracker as the CHP1 and shaded with a shading ball assembly.

**2.2. Analyzed data**

CL51 data is recorded every 36 s and pre-processed by the BL-VIEW software [5]. The results shown here are derived from backscatter profiles from ground level (height of the Lidar) up to 4 km, averaged in varying time and height intervals which depend on the conditions of the day under consideration in order to fine-tune the BL-VIEW Gradient Method algorithm implementation. BL-VIEW reports up to three boundary layer heights; the profile of each day is visually inspected to determine which height corresponds to the boundary layer according to the typical evolution of this layer [6]. DNI and DHI data
used in this study were recorded minute by minute in W/m².

This work includes data covering the period from January 2013 to May 2013; only data of cloudless days were considered in order to have a higher certainty in the determination of the BL height and minimal fluctuations of DNI. The following sections show, firstly, typical BL-VIEW backscatter profiles of clear days and dust event days in Doha, and then the BL height averaged around solar noon, between 11 am and 12 pm, together with the DNI and DHI profiles during the corresponding days.

3. Results and discussion

3.1. BL height determination

Figure 1 shows samples of backscatter profiles measured with CL51 over Doha between January and May 2013. Each plot displays the evolution of the backscatter signal during 1 full day. The colors represent the intensity of the signal (left side scale), from dark blue for the lowest and red for the highest intensities. The vertical axis on the right side indicates the height above ground level from 0 to 4000 m. The black squares are layer boundaries found by the gradient algorithm. On 12 January and 26 March, the BL is relatively well defined since a layer can be found with an evolution through the day from sunrise to sunset. On the 2nd of January, BL can still be found but other layers are also evident. On the 27th of May, the BL is being pushed down by the thick layer of dust on top of it. On the 12th and 22nd of May, the dust layer is so dense and dominant that the BL signal cannot be differentiated from other layers. Many days in May presented heavy dust events similar to the samples of May shown in this figure, with the dust layer extending above the maximum height analyzed by BL-VIEW.

Fig. 1. Backscatter profiles for cloudless days with varying degrees of dust in the atmosphere over Doha and its effects on the determination of BL height by BL-VIEW.
3.2. BL height and comparison with DNI & DHI

In order to study a possible relationship between the boundary layer height and solar irradiance at ground level, the BL height determined around solar noon (averaged between 11:00 am and 12:00 pm local Doha time) is shown in figure 2 (blue asterisks) along with DNI and DHI profiles for the same days. The irradiance values in W/m² can be read directly from the scale of the y axis of the plots; the heights in m are obtained by subtracting 1000 from the same axis. From these plots, no clear correlation between the height of BL and irradiance can be found especially in days with heavy dust events (see figure 1). For this reason, the height of the top layer containing the BL and all aerosol layers found was also determined and included in figure 2 (black asterisks); some days have missing entry for one of these reasons:

- The day was clear enough that no additional layers are found above the BL.
- BL-VIEW was not able to report the highest layer top because this layer goes beyond its maximum range.
- Three or more layers are found below the top one and BL-VIEW can only report up to three layer heights.

It can be noticed that, in general, higher altitudes of the top layer correspond to lower DNI and higher DHI, and vice versa. However, this is not always the case and the effect of these layers cannot be quantified given the high variability of the atmospheric conditions in Doha (e.g. dust storms, haze) which make the determination of the layer heights very difficult or, in some cases, impossible. As an example, on the 3rd and 4th of January the top layer heights were about equal, but DNI at noon on 4 January is noticeably lower because of higher intensity in the backscatter signal (not shown) on this day. The same effect was observed when comparing the 25th and 26th of May. The month of May had many dusty days like the examples shown in figure 1, where all layers were well mixed in a thick and dense layer extending above 4000 m, making the finding of the BL and maximum height impossible. A study including the backscatter intensity information or other parameters might provide a better insight of this effect.

4. Conclusion

Results of BL height measurements made over Doha are presented here, covering the months of January, March and May 2013. Cloud-free days were selected for determination of layer heights based on backscatter profiles of the atmosphere from ground level up to 4000 m. A comparison with ground measurements of solar radiation shows that BL height alone does not have a correlation with DNI values in this location; this is due to the fact that the boundary layer in Doha is often contained, mixed or dominated by higher layers of dust with varying but significant density. A qualitative inverse relation between the height of the top layer of aerosols and DNI values can be seen; however, a precise correlation could not be obtained because the high variability of atmospheric conditions and structure, with high aerosol loads, makes the determination of the top layer height an inconsistent process. The integrated backscatter signal along the vertical path might provide more insight into a possible quantitative correlation between ceilometer signals and irradiation; this idea is currently under study by the authors.
Fig. 2. Boundary layer and maximum layer heights in comparison with DNI and DHI for cloudless days in January, March and May 2013 over Doha.
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