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Comparison of Temperature and Humidity Profiles with Elastic-Backscatter Lidar Data
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Abstract

This contribution analyzes elastic-backscatter lidar data and temperature and humidity profiles from radiosondes acquired in Barcelona in July, 1992. Elastic-backscatter lidar data reveal the distribution of aerosols within the volume of atmosphere scanned. By comparing this information with temperature and humidity profiles of the atmosphere at a similar time, we are able to assess the relationship among aerosol distribution and atmospheric stability or water content, respectively. Comparisons have shown how lidar’s revealed layers of aerosols correspond to atmospheric layers with different stability condition and water content.

1. Introduction

In July 1995, the Universitat Politècnica de Catalunya, Barcelona, SPAIN, and the Los Alamos National Laboratory (LANL), Los Alamos, New Mexico, USA, carried out the Barcelona Air Quality Initiative campaign (BAQI). The aim of this campaign was the investigation of circulatory patterns of air pollutants in an area with strong orographical and coastal influence. The campaign consisted in the continuous monitoring of the atmosphere above Barcelona with an elastic-backscatter lidar device developed at the LANL. Previous analysis of these data (Baldasano et al. [1]) revealed a multilayer vertical arrangement of aerosols within the atmosphere in Barcelona. The aerosol arrangement is believed to be caused by three main processes that take place in Barcelona in summertime because of the city sea-side location and complex surrounding orography. These processes are daytime convective vertical mixing, sea breeze circulation, and vertical circulations produced by mountain thermal and mechanical effects.
It has been reported in several works, e.g. Endlich et al. [2], Coulter [3], Sasano et al. [4], Van Pul et al. [5], how lidar's revealed aerosol distribution is strongly correlated with the temperature profile. Transport and diffusion of pollutants in the lower atmosphere is highly dependent on the structure of the Planetary Boundary Layer (PBL), one important feature of which is the height of the Mixed Layer (ML). Within the ML, passive quantities, such as particles, are mixed nearly uniformly. This layer is frequently characterized by the presence of a capping temperature inversion, or at least by a sudden stabilization of the atmosphere. This stabilization forces the pollutants emitted from the surface to remain trapped within this layer. Since aerosols are well mixed throughout the ML, it is revealed by the lidar as a layer of uniform range-corrected backscatter. That is the reason why we can identify the top of the ML from the data of aerosol distributions acquired with lidar. A sudden decrease in the lidar's signal is observed above de ML. This decrease coincides with the decreasing of the presence of aerosols and the pass from dirty to clean air.

On the other hand, the study of the humidity profiles, both, specific and relative, is also interested in comparison with the lidar data. As another scalar quantity as it is, the specific humidity, it is to say, the content of water per unit of mass of air, will be uniform if the atmosphere is well mixed, and show different water content as we change from the ML to a different mass of air. Finally, the study of the profiles of relative humidity is also interesting to assess the influence of humidity in the backscatter return, by modifying the aerosol size at high relative humidities because of its swelling. It may be possible to use this information to model the extinction and backscatter coefficients per unit volume with Mie Scattering Theory.

2. Data Acquisition and Processing

The lidar data were acquired by the LANL mini lidar, which is an elastic-backscatter lidar. Elastic-backscatter lidars sample the light scattered back to the emissor by the different atmospheric constituents at the same wavelength as it was emitted. The LANL's lidar uses a Nd:YAG laser, operating at a wavelength of 1.062 μm. A near-infrared laser, such as the one used in this campaign, produces a much larger return signal from particulate aerosols than from molecules. This is why we can say that what the lidar "sees" is the distribution of aerosols within the volume of atmosphere scanned. Lidar data have been range-corrected (to deal with the \( r^2 \) decay of the signal) and low-pass filtered, to improve image appearance. To extract a vertical profile of range-corrected elastic backscatter, we have taken data comprised between a fixed range (4,250 to 5,500 m), and calculated averages of these data at the altitudes where we had a measurement from the radiosondes.

On the other hand, and for the days of the campaign, radiosondes were launched at 4 Local Solar Time (LST) by the Instituto Nacional de Meteorología. The radiosondes measured atmospheric pressure, dry temperature, dew point temperature, relative humidity and wind speed and direction. We decided to represent potential temperature instead of dry
temperature in order to have an easy way to know which was the stability condition of the atmosphere. A look at the slope of the potential temperature profile is enough to know whether the atmosphere is stable, neutral or unstable. We also calculated the specific humidity profile, from the relative humidity data, in order to know which was the water content of the atmosphere (it is to say, kg of water per kg of air.

Figure 1: Vertical scan acquired at 5:35 LST on July 26, 1992 in Barcelona, from which a vertical profile of range-corrected backscatter has been extracted (stars) and represented together with the profiles of potential temperature, relative and specific humidity (circles) acquired with the radiosonde at 4:00 LST.
Figure 2: Same as Figure 1, but for July 27, 1992. The vertical scan was acquired at 4:18 LST.

Figure 3: Same as Figure 1 but for July 28, 1992. The vertical scan was acquired at 6:25.
4. Data Analysis

In Figures 1 to 3 we have represented, for each of the days studied, July 26, 27 and 28, 1992, a vertical scan acquired at the closest hour when the radiosondes were acquired. We have also represented pairs of profiles of range-corrected lidar return and potential temperature, relative humidity an specific humidity. The profile of range-corrected lidar return has been scaled each time in order to fit as much as possible within the range on the other variable we have represented with it.

4.1 Temperature Profiles and Lidar Data

By looking at the graphs of range-corrected backscatter and potential temperature profile, we cannot say that lidar data correlate well with temperature data, at least in the sense that a higher backscatter return corresponds always to higher temperature and vice versa. However, we can see how aerosol layer revealed by lidar correspond well with layers of different stability condition.

We can see how aerosols are accumulated in the first meters of the atmosphere. This is due to the nocturnal temperature inversion present (and revealed in the potential temperature profiles as a layer of strong and positive gradient) which avoids aerosols that are originated at the surface to achieve higher altitudes. At the end of these layer there is usually a layer of neutral stability (constant potential temperature profile), which coincides with a high content of aerosols. This is the Residual Layer (RL). It is thought that the RL contents pollutants emitted during daytime and lofted to highest altitudes by convection. This elevated layer is separated from the one near the surface by a zone of clean air and coincides with the top of the temperature inversion.

The RL is very clear on July 27, 1992, where we can see an increase in aerosol backscatter between 800 and 2,000 m. This layer with strong aerosol content coincides with a neutralization of the temperature profile between this altitudes. Aerosols are trapped within this layer because of the strong stabilization present at its top and its bottom, which prevents aerosols from being dispersed in the vertical dimension. This layer can be located between 500 and 1,000 m on July, 28, 1992, and is still narrower on July 26, 1992, since it is located between 600 and 900 m approximately.

On July 26, 1992, another elevated layer was observed between 1,500 and 2,000 m. However, this layer coincides with a layer of stable temperature profile. So, as opposed to what happened in the other layers commented before, in this case we have a zone with elevated aerosol content in a stable atmosphere. We believe that those are aerosols that have been positioned there by some other mechanism different than free adiabatic ascent (i.e., some orographic injection or return from the surrounding mountains), and, once there, since the stability condition does not allow its vertical dispersion, remain trapped. And the same applies for the elevated layer at 3500 m on July 27, 1992. Also for this day, we have that a zone with neutral stratification, between 2,300 and 3,500 m, has a very low content of aerosols. This arrangement could be explained if we take
into account that this layer is bounded above and below by highly stable parcels of air. The stable air would prevent aerosols from mixing with the clean air.

Finally, and in agreement for all the days, we can locate the top of the Planetary Boundary Layer (PBL) as a sudden decrease of range-corrected backscatter or as a sudden stabilization of the atmosphere. This point marks the beginning of the Free Atmosphere (FA). As opposed to the PBL, the FA is not directly influenced by the present of the terrain, and as such, is free of aerosols which were originated in the surface. The top of the PBL can be located at 4,000 m on July 26, 3,800 m on July 27, and 3,500 m on July 28. The PBL thickness is observed to be decreasing along those days. The decrease of the PBL thickness was probably caused by the synoptic high pressure zone present above the area and that provoked a large scale subsidence.

3.2. Specific Humidity Profiles and Lidar Data

Lidar data were also compared to specific humidity profiles. Specific humidity tells us the water content of a mass of air. So, if the mass of air is well mixed, it will show a constant profile of specific humidity within that layer of good mix. By this mean, water content is a good index to identify air masses of different origins.

But again, we won't be able to obtain good correlation coefficients between lidar backscatter and specific humidity content, though the layers identified by the Lidar will also correspond to layers with different content of water with respect to the layer immediately above or under.

For instance, on July 27th, high water content is observed near the surface, and coincides with an elevated presence of aerosols. The elevated layer located between 800 and 2000 m shows also a height content of water. The atmosphere between this layer and the surface layer, which consists of air more or less clean, has a low content of water, which confirms that its air completely different from the one immediately above or under. However, the elevated layer located at 3500 m coincides with a decrease of water content. This confirms the different characteristics of this layer that had been already identified with the temperature profile. And the same can be said about the elevated layer located between 2800 and 3500 m on July, 28th. Immediately below that layer we have air with higher water content, but immediately above we have air with much lower specific humidity.

3.3. Relative Humidity Profiles and Lidar Data

According to the graphs we have represented, relative humidity is the variable which correlate better with range-corrected lidar backscatter. It is to say, always that we find an increase in relative humidity we find also an increase in range-corrected backscatter. The reason is the following. Relative humidity is an index that tells us how near the atmosphere is of sat-
uration. This factor strongly modifies the aerosol's characteristics, specially its size. It has been reported how aerosols swell with increasing relative humidity (Werner [6], Dupont et at. [7]). This swelling is important at high values of relative humidity. In fact, each aerosol specie has a critical value of relative humidity. Below this value, particles can aggregate molecules of water only by adsorption, resulting in an increasing of the radius of less than 5%. Above the phase transition points, particles can grow by absorption of water molecules. The radius is then much more sensitive to the relative humidity. As said before, this critical value of relative humidity is a function of the dry radius and of the chemical nature of the soluble material. However, and according to the high values of relative humidity registered in Barcelona, due mainly to its seaside location, it is easy to assume that humidity effects will be important in our data.

Since the agreement in the graphs between range-corrected backscatter and relative humidity profile is rather good, we have calculated mathematical correlations between both profiles. Figure # shows the results of that correlation. We see how we obtain a maximum correlation of ###% at a zero lag between distributions, which confirms that both profiles are related.

It is hard to say if what we are seeing when we find a higher return in backscattered energy is a zone with a major concentration of aerosols or a zone with the same concentration of aerosols but of bigger size. However, the increase of backscatter located at the top of the elevated layers does not correspond probably to an accumulation of aerosols at the top of the layer, but to an accumulation of moisture that can not move aloft because of the stable atmosphere above, which results in a swelling of the aerosols.

4. Conclusions

It has been shown how lidar’s revealed layers of aerosols correspond well with atmospheric layers of different characteristics according to its stability condition or water content.

Lidar data have confirmed that aerosol's arrangement in the vertical dimension is mostly determined by the temperature structure of the atmosphere. We have identified two different kinds of aerosol arrangement: one is an accumulation of aerosols within a zone neutrally stabilized, where aerosols are confined by the sudden stabilization that appear at the top and at the bottom of this layer; the other, is an accumulation of aerosols in zones of highly stable atmosphere. Those aerosols can not be dispersed vertically either, since the sub-adiabatic profile of temperature that exists does not allow vertical movements.

As far as specific humidity is concerned, good agreement has been found between lidar's revealed aerosols layers and different water content. We can then say that we can separate different layers of the atmosphere according to its specific humidity. every-time we found a sudden change in the range-corrected backscatter lidar’s signal, we found also a sudden change in the water content of the atmosphere, which indicates that we are entering to a different air mass.
Finally, and regarding the comparison of Lidar data with relative humidity profiles, we have found that those data are the ones who are best correlated. An increase of relative humidity always corresponds to a higher signal return of the Lidar. This can be explained if we take into account the aerosols swelling with moisture, increasing then its effective cross-section and scattering back the light towards the receptor.

References


