**Introduction to Doppler Lidar**

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**What is lidar?**

The word “lidar” is actually an acronym that stands for LIght Detection And Ranging. It is a remote sensing instrument that transmits laser light towards a target. Some of this laser light is reflected/scattered back to the lidar where it is detected and analyzed. When the transmitted light interacts with a target, sometimes properties of the light are changed in some way, depending on the molecular composition of the target and its motion. It’s the change in the properties of the light that makes it possible for the lidar software and the lidar operator to determine properties of the target. The range, or radial distance, to the target is determined from knowledge of the speed of light and how long it takes the light to travel the round trip distance between the lidar and target.

**How is lidar different from radar?**

Lidar technology is based on the same principles as radar technology. A lidar is basically a radar that utilizes electromagnetic radiation at optical frequencies as opposed to radio frequencies. In other words, the radiation used by lidars is at wavelengths which are 10,000 to 100,000 times shorter than that used by conventional radars. Because lidars operate at optical wavelengths (on the order of 102 - 103 nanometers), they are sensitive to much smaller targets than radars, that is, all they require is that atmospheric molecules and microscopic aerosols are present, as opposed to the much larger objects required by radar like airplanes and storm systems.

Laser pulses emitted by lidars are very well collimated, often referred to as a “pencil beam”, so that in general, the laser beam is less than 1 meter in diameter at a distance of 1 km from the lidar. Because of the extremely short pulses of laser light emitted by lidars, the natural spatial resolution that these systems offer is many times better than that offered by other atmospheric sensors, e.g. radars and sonars.

**What is Doppler lidar?**

While all lidars generally function off the same basic principles, they are actually a diverse class of instruments. For example, there are lidars that are designed to simply detect the presence of atmospheric aerosols and provide an indication of their concentration; there are lidars designed to provide information regarding the molecular composition of gases and aerosols in the atmosphere; and there are lidars designed to map topographical features on earth.

Scientists in the Battlefield Environment Division of ARL have extensive experience conducting research with Doppler lidars. In general, these lidars are used to measure the velocity of a target. When the light transmitted from the lidar hits a target moving towards or away from the lidar, the wavelength of the light reflected/scattered off the target will be changed slightly. This is known as a Doppler shift - hence Doppler lidar. If the target is moving away from the lidar, the return light will have a longer wavelength (referred to as a red shift), if moving towards the lidar the return light will be at a shorter wavelength (referred to as a blue shift). The target can be either a hard target, such as a vehicle, or an atmospheric target, such as the many microscopic dust and aerosol particles that are carried by the wind. Therefore if one’s goal is to measure the wind, the atmospheric targets are of interest because they are small and light enough to move at the true wind velocity and therefore, they make it possible for a remote measurement of the wind velocity to be made.

In most commercially available Doppler lidar systems, a short pulse of light is generated and emitted into the atmosphere (Figure 1). These systems tend to operate in the near-IR (1.5 microns) region of the electromagnetic spectrum which tunes them to be sensitive to backscatter from micron-sized aerosols which are plentiful throughout the troposphere. As this pulse travels away from the lidar, aerosol particles and molecules reflect some light back to the lidar. These returned pulses are recorded temporally and analysis is performed to compute the speed and range of the reflecting particle.

Another common feature of commercially available Doppler lidars is “coherent detection”. These coherent Doppler lidars require the mixing of the captured backscattered light with a copy of the original emitted pulse. This allows for the determination of the frequency difference between the backscattered Doppler shifted light and the emitted light. This frequency difference is directly proportional to the speed of the wind along the line of sight of the lidar.

Doppler lidars also tend to be monostatic, meaning that from one location, they transmit and receive data (light pulses). The location of a measurement taken by a pulsed monostatic lidar is determined by knowledge of the laser pointing direction (i.e. the scanner), and of the time delay between the firing of the laser pulse and the detection of the signal (Figure 1). Furthermore, many Doppler lidars have full upper-hemispheric scanning capability, which enables three-dimensional mapping of turbulent flows in the atmospheric boundary layer.

**What are Doppler lidars useful for?**

Doppler LIDARs are a class of tools that can examine a large volume of space with fine spatial resolution in short periods of time. The possibility exists then of mapping and capturing atmospheric processes as they develop. For example, Doppler lidar data can contain signatures of many different atmospheric phenomena such as wind shear, chaotic turbulence, thermal-induced up drafts, topographic impacts on the wind field, etc. In addition, Doppler LIDARs are effective tools for monitoring and mapping the sources, the transport, and the dilution of aerosol plumes over local regions in urban areas.



Figure 1 Doppler lidar schematic.

**System design and data products**

A lidar consists of the following basic functional components: (1) a laser source of short, intense light pulses, (2) a light detector, which collects the backscattered light and converts it into an electrical signal, and (3) a computer/recording system, which digitizes the electrical signal as a function of time (or equivalently, as a function of the range from the light source).

Most commercial lidar systems today provide multiple levels of output data that are defined based on the level of processing that they are dependent on. For example, raw lidar data involve very little pre-processing, such as spatio-temporal averaging, and leaves it up to the data analyst to apply more complicated algorithms to the data to extract information. On the other hand, most lidar systems also log processed data which implies that spatio-temporal averaging, set initially by the lidar operator, has already been performed so that the data is organized into equally spaced chunks of averaged backscatter returns along the line of site of the lidar. These equally spaced chunks are called range gates.

The primary variables logged by Doppler lidar systems are the following: radial velocity, intensity of return signal, attenuated backscatter (which takes into account the transmission effects of the atmosphere), time of measurement, range to center of range gate, azimuth angle of scanner, and elevation angle of scanner. There are a variety of Doppler lidar scan strategies and post-processing algorithms that can be applied to the resultant data to extract useful information like vertical profiles of wind speed and direction.