VAISALA

Vaisala CL61 and FD70 provide unprecedented situational awareness for aviation operations

TECHNICAL PAPER

Vaisala has developed two new sensors that fundamentally change the state-of-the-art of weather sensing for aviation. The Vaisala Forward Scatter Sensor FD70 and the Vaisala Ceilometer CL61 with Depolarization allow unprecedented sensing of both surface-based weather phenomena as well as aloft.

In this paper we will discuss the technologies employed in these new sensing platforms and then illustrate how these sensors, when used together, can provide a new level of situational awareness for weather forecasters and aviation decision makers. We will also look at a real-world case study from a winter weather event in Helsinki, Finland in January of 2022 where both sensors were deployed.

1 Vaisala Forward Scatter Sensor FD70

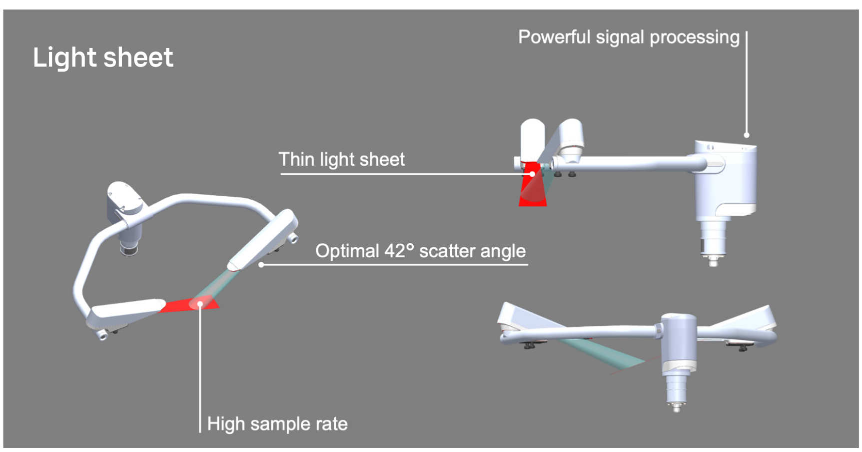

Figure 1: Vaisala Forward Scatter Sensor FD70 with thin light sheet technology.

The Vaisala Forward Scatter Sensor FD70 simply offers the best performance and best value-for- money visibility and present weather sensing available in the market. It can be delivered in various configurations and at its simplest, it can be configured as only a visibility sensor for Runway Visual Range applications. The top-end performance configuration enables the FD70 to identify precipitation particle-by- particle and reports present weather, precipitation type, intensity, accumulation, droplet size distribution, radar reflectivity, droplet fall speed distribution, and kinetic energy.

Thin light sheet technology

The unprecedented accuracy of the FD70 stems from the use of thin light sheet technology where the transmitter head on the FD70 emits a very thin light sheet rather than the light cone that is emitted by traditional forward scatter sensors. This unique technology allows the FD70 to evaluate scatterers particle-by-particle rather than simply using the standard volumetric averaging methodology of all other visibility/present weather sensors.

This particle-by-particle sensingcapability employs an extremely fast scan rate of 5 MHz, which allows the sensor to fully evaluate each particle's size, type, and fall rate. Using this technique enables the FD70 to characterize the droplet size distribution (DSD) of the atmospheric scatterers and includes the capability to sense particles as small as 0.1 mm, up to 35 mm in diameter in 41 size classes.

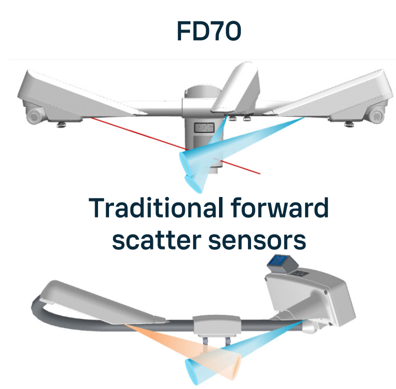

Figure 2: Vaisala Forward Scatter Sensor FD70 with 2nd receiver head vs. typical traditional forward scatter sensor sensing.

A new level of present weather fidelity

Supercooled liquid precipitation types (freezing rain and freezing drizzle) have always been the ultimate challenge for forward scatter sensors. Vaisala's patented thin light sheet technology, combined with the use of an external temperature and humidity sensor, has given the FD70 a remarkable advantage in this regard, but Vaisala was able to take the sensor's performance to the next level by adding a second receiver. This setup removes all the guesswork from identifying these mission-critical phenomena.

The second receiver enables an even greater fidelity in the evaluation of particle type, especially during freezing/frozen/mixed precipitation events, and, in addition, it also allows the FD70 to evaluate visibility in sand/dust storms with much greater accuracy than has ever been possible with a forward scatter sensor. The FD70 scans each particle's scatter signal signature from two separate angles, which enables even more robust solid-liquid differentiation.

This approach improves the ability to differentiate between solid and liquid particles and puts the FD70 present weather identification in a class by itself.

2 Vaisala Ceilometer CL61


Figure 3: Vaisala Ceilometer CL61

Vaisala has been a market leader in ceilometers since the 1980s when it introduced the dual-lens CT12K that had an install base of more than 2,000 units worldwide. In the 1990s Vaisala released the single-lens CT25K ceilometer, and the market share expanded further with more than 2,500 new units fielded globally. The single-lens technology solved several issues that dual-lens ceilometers suffer from, including the ability to sense the very lowest part of the atmosphere that is not possible with a dual-lens topology approach.

In the 2000s, Vaisala introduced the CL31, which had significant performance improvements over the CT25K and enabled the sensing of higher clouds as well as offering a much better signal-to-noise ratio. This enabled the ceilometer to be used for profiling of the boundary layer, and with the release of the even more powerful CL51 in 2010, the ability to evaluate the atmosphere up to a height of 15km.

Vaisala's engineers continue to push the envelope of innovation and in 2022 officially released the CL61 Lidar Ceilometer with Depolarization, which yet again fundamentally changes the state-of-the-art. In a similar manner to how dual-polarization weather radars allowed for new levels of performance for hydrometeor identification and improved rainfall rate estimation, evaluating the backscatter from the vertically pointed lidar ceilometer can provide new insights into the microphysics of the atmosphere.

Depolarization explanation

Lidar ceilometers emit linearly polarized laser pulses. When a portion of this light scatters back towards the instrument, the polarization direction may change. This depolarization depends strongly on scatterer shape, orientation, and laser wavelength. The laser pulses that are returned to the receiver have interacted at a 180° backscatter angle with spherical, homogeneous scatterers, such as liquid cloud droplets or small raindrops. Due to the symmetry of the scattering event, the detected return signal is not depolarized.

However, non-spherical solid particles can cause significant depolarization due to multiple internal reflections at solid-air interfaces. Larger raindrops with flattened bottom shapes also produce some depolarization. The level of depolarization for lidars can be described by the linear depolarization ratio (LDR). LDR is the ratio of the perpendicular or cross-polarized (XPOL) components and the parallel (PPOL) signal components and is equal to or greater than zero. The maximum LDR value is less than one because PPOL is the dominant backscattered signal component from atmospheric particles. Both particles and air molecules affect the degree of depolarization.

Their mixed contribution is known as the volume depolarization ratio (VDR). Accurate depolarization measurements require relatively high backscatter, for example, from dust, smoke, ash, or boundary layer aerosols. The Lidar Ceilometer CL61 measures VDR. Vertical depolarization ratio profiles allow straightforward identification of several weather phenomena, such as liquid vs. solid precipitation, cloud phase, and melting layer. Near-zero values from liquid scatterers are clearly distinguished from larger values from complex ice crystal shapes.

This measurement enables differentiation between solid, liquid, or mixed phase clouds and precipitation providing much needed information about, for example, icing conditions. Additionally, dust and volcanic ash can also be differentiated from liquid particles more reliably. Figure 4. shows a range of approximate LDR value ranges for various scatterers, indicated by the widths of the gray boxes.

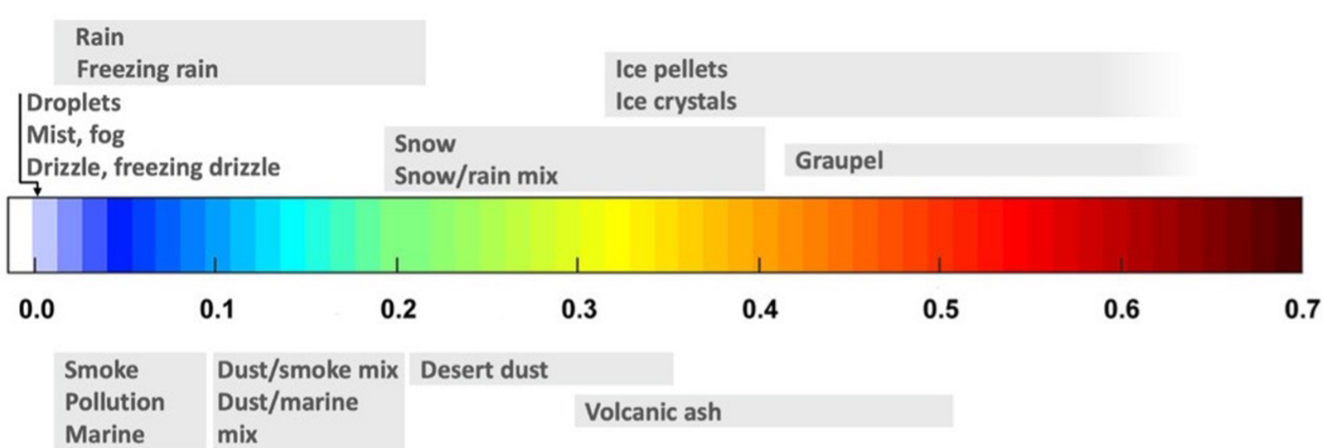

Figure 4: Approximate ranges for Linear Depolarization Ratio(LDR) measurements

3 Case Study – Freezing rain at Helsinki Airport on 2nd of January 2022

The case study presented here is from a freezing rain event that occurred on January 2nd, 2022, at the Helsinki International Airport. The Finnish Meteorological Institute (FMI) has the new Vaisala Ceilometer CL61 with Depolarization as well as the dual receiver variant of the Vaisala Forward Scatter Sensor FD70 in use at the airport. These new Vaisala sensors equip operational meteorologists with vastly superior situational awareness.

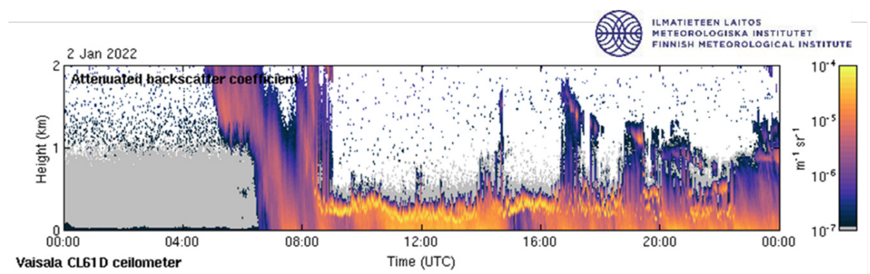

Figure 5: Vaisala CL61 attenuated backscatter coefficient time series plot from 2 Jan 2022.

Backscatter coefficient (a first look)

Figure 5 is the attenuated backscatter profile provided by the CL61. The x-axis is time in UTC for 24 hours and the y-axis is height up to 2 km. The color scale indicates the attenuated backscatter coefficient intensity, where the yellow colors represent high signal levels (such as from clouds) and the grey areas describe areas of lower signal strength.

Figure 5 clearly shows a typical weather front approaching with descending clouds just after 04:00 UTC. The cloud is precipitating with this precipitation reaching to ground at around 06:30 UTC. The low cloud is visible in the data from 08:00 onwards, described by the bright yellow line, and it is continuously precipitating for the remainder of the day. This is the type of information that users can see from the ceilometer attenuated backscatter profile, which is much more helpful than only receiving data on the cloud base heights and sky condition information (both parameters are also available from the CL61 for inclusion in METAR observations).

Depolarization ratio (even more insight revealed)

However, the CL61 can provide even more information by examining the depolarization vertical profile. When looking at the depolarization ratio, the meteorologist can identify the solid and liquid precipitation (both at the surface and aloft), which is often (as it is in this case study) the most important information. Figure 6 is from the same time period as Figure 5 but is now showing the vertical profile of depolarization ratio. The x-axis and y-axis are the same as before, but the colors indicate the depolarization ratio from 0 to 0.3. Here values close to zero (the blue colors) indicate liquid precipitation, whereas values above 0.15 (yellow to red) indicate the presence of solid or mixed precipitation.

We can see that the precipitation reaching the ground at 06:30 UTC is solid precipitation, and since the local ambient temperature was below 0 °C for the entire day, it can be interpreted as snowing.

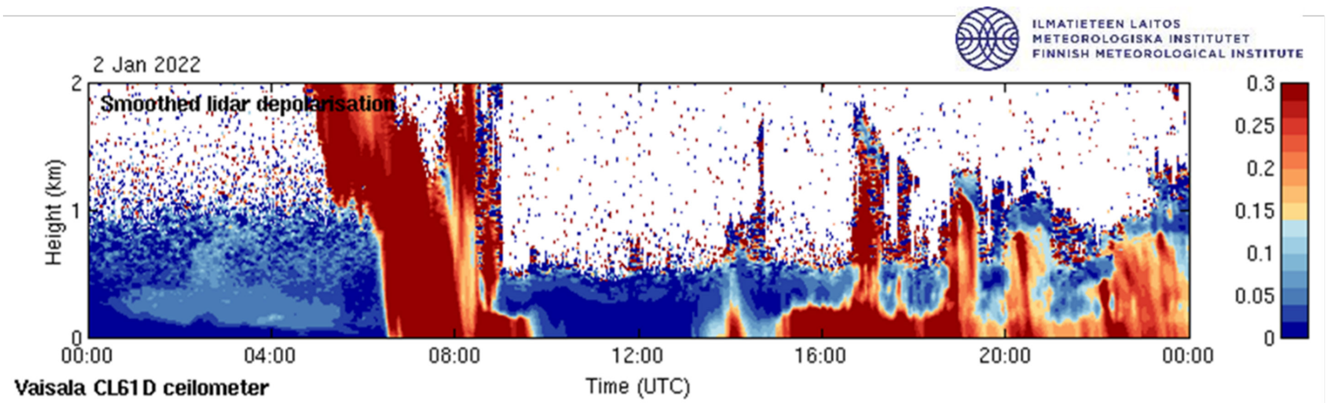

Figure 6: Vaisala CL61 smoothed lidar depolarization time series plot from 2 Jan 2022.

At around 09:30 UTC the solid precipitation ends, but as we saw from the attenuated backscatter plot, the precipitation was continuous for the remainder of the day, so the observer can interpret that there is now liquid precipitation present. Since the ambient temperature is still below freezing, it is therefore interpreted as indicating the presence of freezing rain (FZRA) or freezing drizzle (FZDZ). During the afternoon, the precipitation changes phase from liquid to solid, and user may interpret that it is again snowing.

What does the FD70 data show?

The FD70 WMO 4680 present weather codes are shown in Figure 7. At 02:00 UTC the FD70 reports a few minutes of ice crystals (the air temperature was -11.4 °C and the relative humidity was 94%) and beginning at 06:35 UTC the FD70 reports snow. The transition from snow to freezing precipitation agrees well with what we have just interpreted from the CL61 profiles.

The first freezing drizzle report by the FD70 is at 10:15 UTC and just prior to the freezing drizzle the FD70 is sensing frequent snow grains (WMO 4680 code 77).
The freezing drizzle event turns into mixed liquid and snow (WMO 4860 code 67-68) at around 13:00 UTC. This is also well visible in the CL61 depolarization graph, where the depolarization value is clearly higher than zero, but not at the level that would correspond to being pure snow.

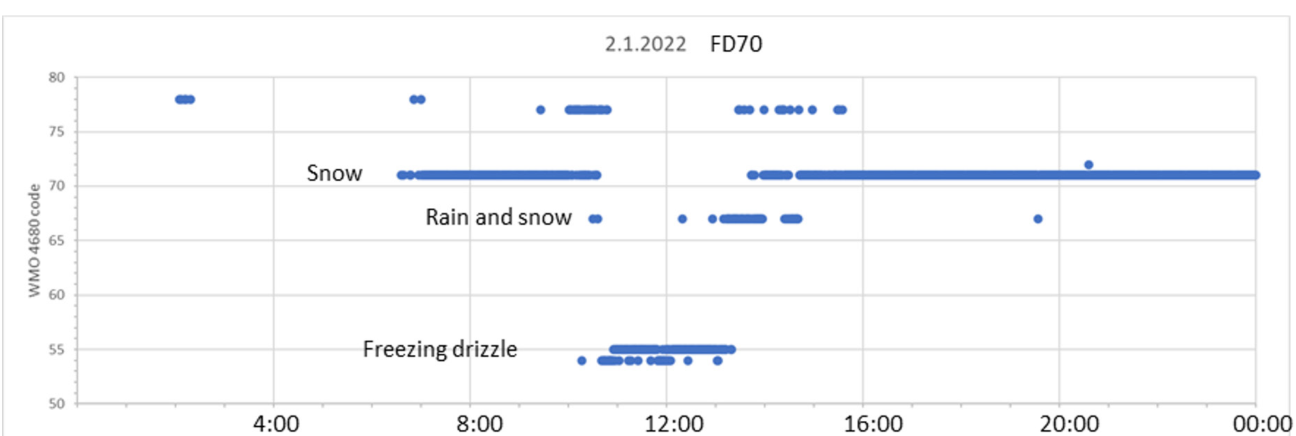

Figure 7: WMO 4860 code plot from Vaisala FD70 time series plot from 2 Jan 2022.

How does this fit with what the human observer reported?

In this case the measurement site also had a human observer on duty. The human generated METAR observations have been included in the next picture with vertical blue lines to indicate the change in the reported precipitation type.

The precipitation types from the human observations are very well correlated with CL61 and FD70 onsets and transitions to different precipitation types. Especially notice the freezing rain and freezing drizzle events which caused a significant ice build-up at the airport and therefore caused delays and maintenance activities for the operations at the airport.

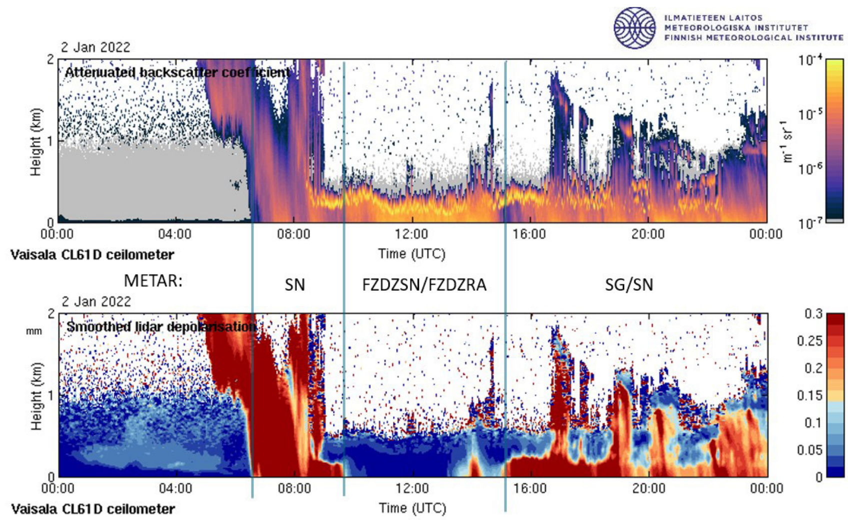

Figure 8: Comparison of CL61 attenuated backscatter coefficient and smoothed lidar depolarization with observer-generated METAR precipitation types from 2 Jan 2022.

Agreement with freezing rain detector

The FMI has an existing dedicated freezing rain instrument to measure the ice build-up at the airport. Figure 9 shows the data from that sensor for this same day merged with the depolarization ratio and human observation of present weather. The ice build-up is on the y-axis in units of millimeters and shows about 3.5 mm of ice accumulated at the sensor during the period of freezing rain/drizzle.

The ice build-up measured by the freezing rain instrument correlates very well with the CL61 and FD70 observations of liquid precipitation. During the day there was also one special report from approaching airplane. The special message was:

ARS FIN2XL MOD ICE OBS AT 1650Z N6019 E02457 BLW 4000FT=

The pilot reported moderate ice build-up on the plane at 16:50 UTC below 4000 feet (below 1220 meters). The plane has likely gone through the ice cloud that is visible in the CL61 profile data during that same time which reaches up to a height of about 6000 ft. Thus, pointing out how valuable the data from the CL61 can be once weather forecasters and observers become familiar with these new measurements and how to interpret them. Similar insights can be obtained through weather radar analysis, but since most winter precipitation events happen very close to the surface, the proximity of the radar is paramount to being able to observe the lowest parts of the atmosphere.

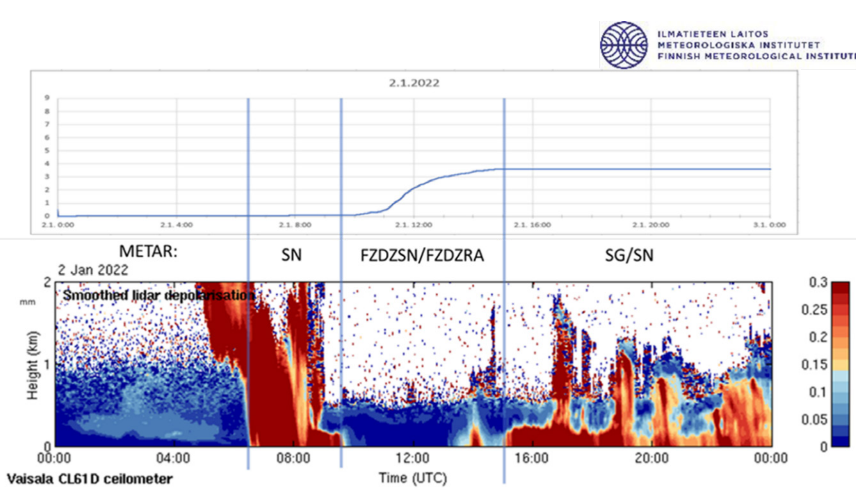

Figure 9: Plot showing the ice build-up measured at the Helsinki airport on 2 January 2022 along with the plot of CL61 depolarization ratio with the METAR present weather observations.

4 Summary

This case study demonstrates the capabilities of the new Vaisala Ceilometer CL61 with Depolarization to improve the situational awareness for operational use at airports. The CL61 provides detailed information about what is happening aloft, and the Forward Scatter Sensor FD70 provides confirmation of exactly what is reaching the ground and moreover what is the intensity of the event.

The CL61+FD70 combination provides unprecedented awareness of high-impact freezing conditions affecting aviation operations. These data are meant for on duty meteorologists to enable them to make critical decisions and more accurate forecasts of the conditions to improve the safety of airfield operations both on the ground and aloft.

Why Vaisala?

For over 45 years, Vaisala has been a pioneer in aviation weather technology, ensuring that every measure is taken for unparalleled safety, efficiency, and sustainability.

Our gold standard suite of solutions is trusted in more than 170 countries and over 2000 airports globally. In fact, every commercial flight around the world will use weather observations produced by Vaisala equipment or forecasts driven by our sensor measurements at some point in their journey.

With a commitment to constantly evolving our portfolio, Vaisala remains at the forefront of the industry, continuously exploring new horizons.

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