MOBILE DRONE DOCKING STATIONS TO SUPPORT SITE-SPECIFIC AVALANCHE OBSERVATIONS AND FORECASTING

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ABSTRACT: During periods of elevated avalanche hazard, field observations may be restricted due to safety concerns, limited accessibility, or rapidly changing conditions. This can increase uncertainty in decisions related to road closures, reopening, and emergency response.

This paper presents the design, technical configuration, and operational use of a trailer-mounted drone docking station developed to increase the availability of site-specific avalanche observations along avalanche-exposed roads. The mobile system enables repeated, remotely operated flights without permanent infrastructure and can be rapidly relocated according to operational needs and changing avalanche conditions. The station combines a UAS with high-resolution RGB and thermal imaging, a web-camera, airspace monitoring, independent power supply, and remote communications.

During the 2025/2026 winter season, 85 UAV missions were conducted from two mobile drone stations, resulting in 38 observations published in Regobs natural hazard database. The imagery documented recent avalanche activity, controlled avalanche releases, release areas, deposition areas, and impacts on road infrastructure.

The results indicate that mobile drone stations can complement weather stations, remote cameras, field observations, and snowpack information by increasing the frequency and availability of direct, site-specific observations while reducing the need for personnel to enter avalanche terrain. Mobile drone stations therefore have potential as a complementary observation system for avalanche forecasting, road management, and emergency response.

KEYWORDS: site-specific forecasting, road avalanche warning, mobile drone station, autonomous

1. INTRODUCTION

Avalanche forecasting combines information from different classes of data, ranging from direct evidence of instability to indirect information about weather and snowpack processes (McClung, 2002). Class 1 data — recent avalanche activity, avalanche debris, cracking of the snow cover, and other visible signs of instability — provide direct evidence of how the snowpack is responding to current conditions. Class 2 and 3 data, such as snowpack structure, precipitation, wind, temperature, and weather forecasts, describe the processes that may cause that response, but require interpretation to assess the actual avalanche situation. Combining both reduces uncertainty in avalanche assessment.

In many mountain regions, however, access to avalanche terrain is limited, especially during periods of elevated hazard — precisely when class 1, direct-evidence observations are most needed.

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Uncrewed aerial systems (UAS) have emerged as a valuable tool for collecting class 1 observations while reducing personnel exposure, but most deployments remain manual and require operators to travel to the site. Mobile drone stations overcome this limitation, complementing conventional weather stations, models, and field observations with repeated direct observations from avalanche terrain — documenting snow distribution, wind transport, cornice development, fresh avalanche activity, and avalanche deposits without exposing personnel to hazardous terrain.

2. PREVIOUS UAS EXPERIENCE IN AVALANCHE APPLICATIONS

Numerous studies have demonstrated the value of UASs for snow and avalanche applications. Bühler et al. (2016) showed that UAS photogrammetry can provide highly accurate snow-depth measurements. Harder et al. (2016) demonstrated repeatable snow-depth mapping using structure-from-motion photogrammetry. Masný et al. (2021) evaluated fixed-wing UAS for snow-depth mapping in alpine environments. Dewali et al. (2023) combined UAS imagery and machine learning for automated avalanche deposit detection. The GEOSFAIR drone project documented several benefits by implementing UAS in avalanche hazard evaluation (Humstad et al., 2025).

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Recent work by Lim et al. (2026) demonstrated autonomous large-scale avalanche monitoring using UAS. Maschler et al. (2026) demonstrated the capabilities of using a drone station for monitoring of unstable slopes and glaciers. Together, these studies show that UAS can increase spatial coverage, improve temporal resolution, and reduce exposure of observers in hazardous terrain.

3. MOBILE DRONE STATION CONCEPT

To collect class 1 information more frequently to support avalanche forecasting within the Norwegian Public Roads Administration (NPRA), a drone station was proposed. Electrical power is often limited in avalanche-prone mountain passes, so the drone station needed its own power supply. In addition, our goal was to develop a mobile drone station that could easily be transported between natural hazard sites.

The mobile drone station was first designed in winter 2025 and later upgraded to a self-sufficient power supply in autumn 2025. It was built by NPRA's own drone crew and put on a road-legal trailer that can be transported by a standard vehicle (Figure 1). The total weight of the trailer is approx. 1000 kg. The mobile drone station includes:

- UAS platform with RGB and thermal imaging capability.
- Automated landing, charging, and mission management.
- 360-degree web camera for continuous visual monitoring.
- Airspace awareness capability.
- Autonomous power supply and a power monitoring system.
- Cellular internet connectivity.
- Remote monitoring and mission planning software.

The trailer configuration allows deployment near roads, avalanche paths, or temporary operational sites without requiring permanent infrastructure. The set-up time on site is 1-2 hours.

Figure 1: Mobile drone station set up: 1) Drone station (DJI Dock 2/3). 2) Airspace surveillance system. 3) 360˚webcam. 4) Mobile cellular network antenna. 5) Solar panels cover trailer walls and roof. 6) Diesel generator exhaust and air-cooling outlet. 7) Weight to prevent overturning.

4. TECHNICAL SYSTEM DESCRIPTION

Drone station: The tested drone station systems are DJI Dock 2/3, tested at several locations, both in summer and winter conditions. The multirotor UAS is capable of autonomous waypoint missions and high-resolution image and video acquisition. The drone is automatically charged in the dock after landing.

Web camera: Four fixed lenses 360˚ camera from Axis Communications providing continuous situational awareness, weather observations and visual inspection of the drone station.

Airspace monitoring: Other airspace users transmitting ADS-B, ADS-L and Remote ID signals are received at the site by an openAir multi-track from Avionix engineering and published to Safesky live map. This is how we detect and avoid other airspace users.

Power supply: Integrated 10 kWh $LiFePO_4$ battery system with solar panels on the walls and roof, supported by a diesel generator for reliable power supply. The energy system is connected and monitored through Victron Energy system. An external diesel fuel tank let this setup run without service for three months from mid-January to mid-April. See Figure 2 for the visual setup inside the trailer.

Communication: All communication is made through a 4G/5G modem with APN access, while a cloud-based mission management system enables remote supervision of power supply and drone station.

Drone flight surveying software: The flights are monitored through FlightHub2 from DJI.

Figure 2. Inside the trailer: Upper left: Solar panel connections and power monitoring system. Lower left: Batteries in an isolated box. Right side: Diesel generator and fuel tank.

The mobile drone station system can be schematically illustrated as in Figure 3.

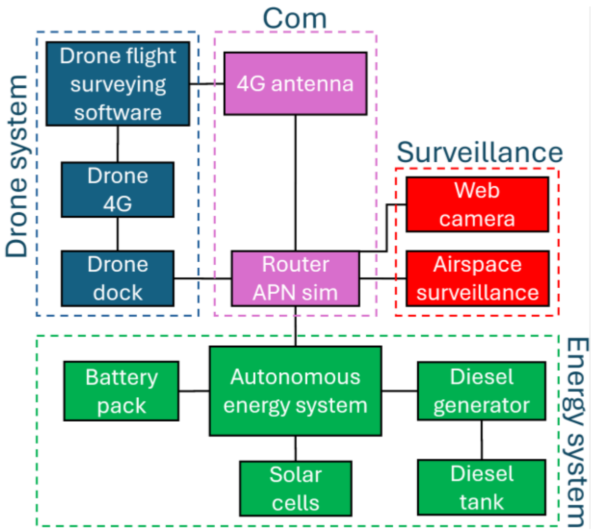

Figure 3: Schematically illustration of the mobile drone station system.

5. OPERATIONAL EXPERIENCE DURING WINTER 2025/2026

Drone flights supporting site-specific avalanche warning were usually performed in the morning if weather conditions were within operational limits. The workflow for these flights is summarized in Figure 4. The most crucial information was published in the public observation platform Regobs.no accessible by the regional public forecast (varsom.no), while more detailed information was shared to the site-specific forecaster.

According to the airspace legislation we were allowed to fly the drone in a radius of 5 km from the drone dock. Theoretically the drone can cover approximately 80 km^2, while the drone camera can cover an even larger area by zooming in to interesting areas.

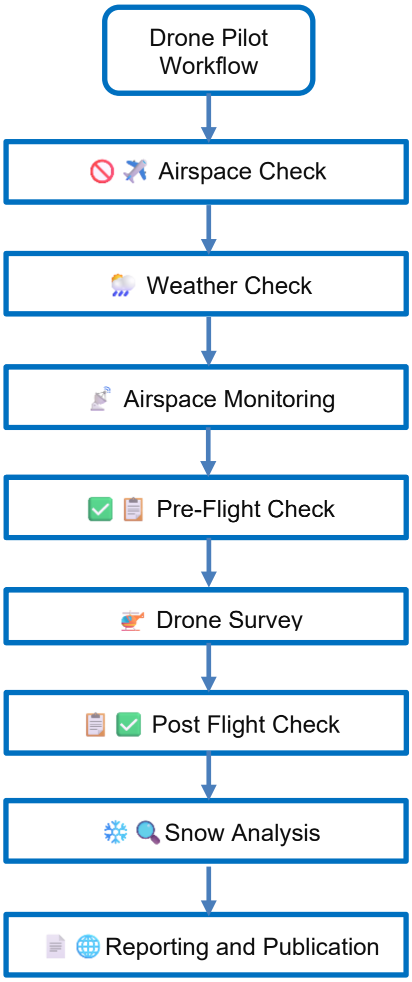

Figure 4: Drone pilot workflow supporting site specific avalanche warning.

Our drone pilots are also avalanche practitioners and avalanche forecasters. In this way the pilots can identify snow information needed for avalanche forecasting.

Two mobile drone station systems were deployed near avalanche-prone transportation corridors at the National Road 13 Vikafjellet and the National Road 15 Strynefjellet where site-specific avalanche warning projects are in place. Repeated collection of imagery during snowfall events and avalanche cycles was performed. UAS missions documented avalanche release areas, avalanche debris, cornice development, snow redistribution, and road impacts as illustrated in Figure 5. Repeated observations allowed comparison between storm cycles and improved situational awareness for road operators and avalanche forecasters.

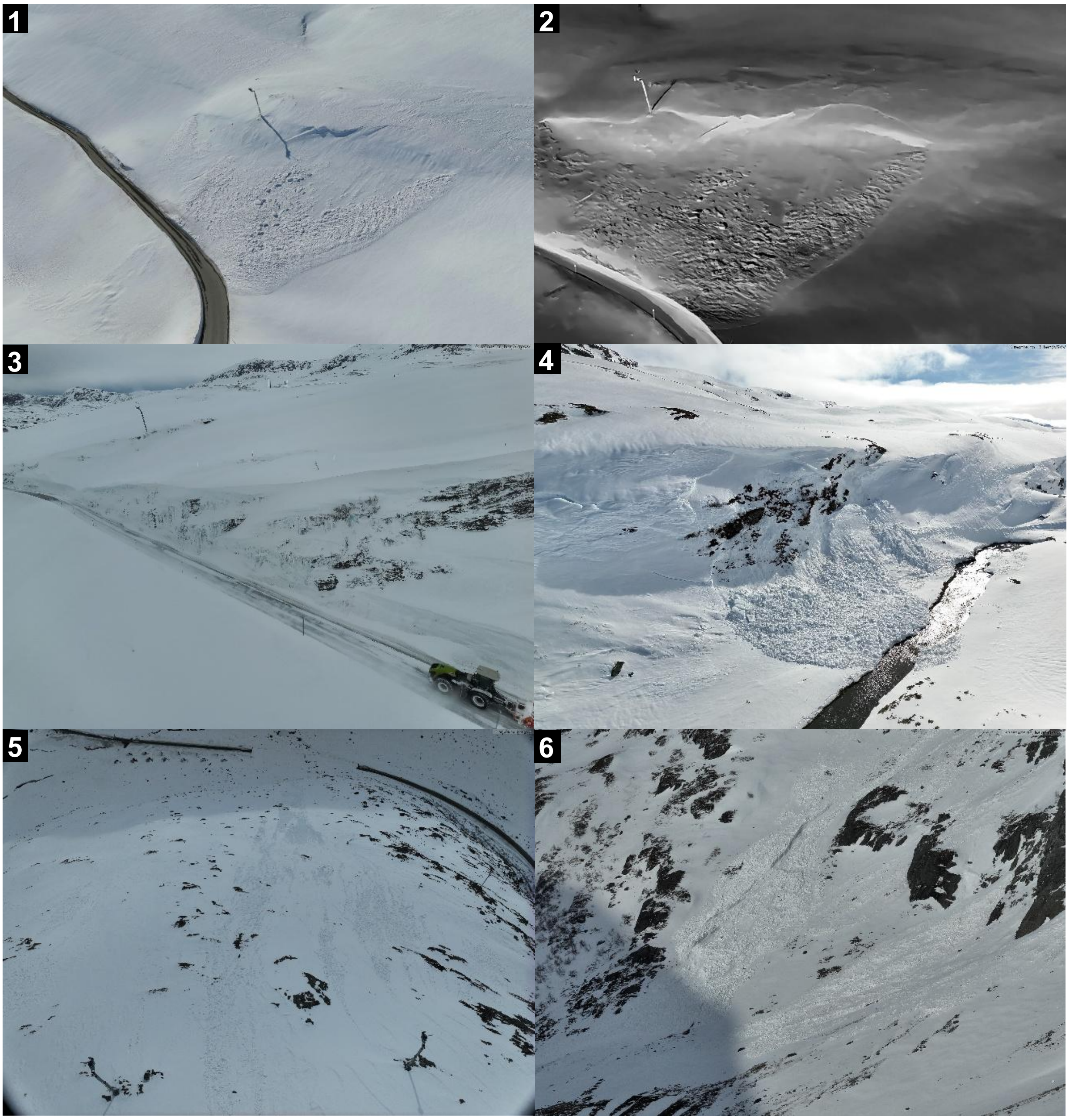

Figure 5: UAS imagery documenting avalanche activity. 1) Avalanche artificially released by RACS. 2) Thermal image of the avalanche in nr. 1. 3) Documenting snow accumulation in an avalanche-starting zone close to a road. 4) Avalanche activity close to the road, however not visible from the road. 5) Wet snow avalanches. 6) Slab avalanche deposits close to the road.

During winter 2025/2026, 85 UAS missions were conducted from the two mobile drone stations. The missions resulted in 38 observations published in Regobs. Flight data and number of observations are summed up in Table 1.

In a post-winter survey, seven of eight avalanche forecasters reported using drone station imagery. Drone imagery was the fourth most frequently used data source, after weather station data, PTZ camera imagery and Regobs observations, as illustrated in Figure 6.

The forecasters often ask for more observations of avalanche activity which can validate their forecast. Both these avalanche-prone mountain passes are very remote, and the number of field observations is limited. The mobile drone station has not replaced any observer. The station provided additional observations that were used to support both regional and site-specific avalanche assessments.

Table 1. Drone flight data at the sites.

Site	***Nr. of flights***	***Avg. flight time***	***De-ploy-ment***	***Dis-mount***	***Nr. of Regobs***
Rv.15	60	25 min	28. Jan.	12. May	23
Rv.13	25	20 min	10. March	30. April	15
SUM	**85**	**-**	**-**	**-**	**38**

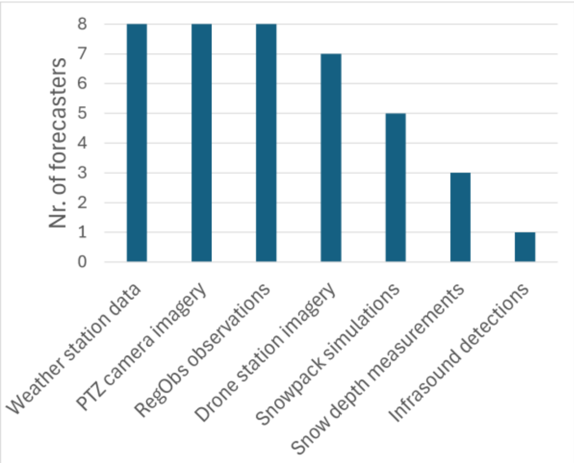

Figure 6. Data sources used by the avalanche forecasters. The numbers indicate the number of forecasters reporting use of each data source (n = 8).

6. DISCUSSION

The operational experience from winter 2026 demonstrates that mobile drone docking stations can provide frequent and repeatable site-specific observations of snow and avalanche conditions. Compared with conventional field observations, the system can reduce the need for personnel to enter avalanche-prone terrain, particularly during periods of elevated avalanche danger. This provides an important safety benefit while increasing the availability of observations from locations that may otherwise be difficult or unsafe to access. Timing is also a factor. The drone can be deployed in two minutes while an observer must drive up to the mountain pass first.

An important aspect of the system is the type of information it provides. Avalanche forecasting traditionally combines weather observations such as precipitation, wind, temperature and snowpack simulations, with direct observations of snow and avalanche conditions. Remote monitoring systems such as cameras and drone stations can increase the availability of class 1 observations while the observer remains at a safe distance. Drone imagery can provide class 1 data of avalanche activity, release areas, snow redistribution, cornice development and avalanche deposits. In this respect, mobile drone stations can partly bridge the traditional distinction between remote sensing and field observations.

The trailer-mounted configuration provides additional operational flexibility. Unlike permanent monitoring installations, the system can be relocated to different avalanche paths and transportation corridors according to operational needs and seasonal hazard patterns. Observation capacity can therefore be concentrated in areas where additional information is required. The independent power supply and communication system also allow the station to operate without relying on permanent infrastructure.

Repeated UAS missions provide an opportunity to document temporal changes in snow distribution, cornice development, avalanche activity and impacts on transportation infrastructure. The combination of high-resolution RGB imagery and thermal imaging can further increase the information available from individual missions. This information can support avalanche forecasting as well as operational decisions related to avalanche response, infrastructure inspection and road reopening.

Several limitations remain. Weather is an important operational constraint, as strong winds, icing, low visibility and precipitation can restrict flight opportunities during critical periods. Regulatory requirements and airspace restrictions may also limit operational flexibility. Remote operation depends on reliable communication coverage, while battery capacity and power management become important during extended periods of limited solar charging in winter. In practice, periodic maintenance and site visits are still required. A wired power connection may therefore be preferable where available.

As the system supports safety-critical infrastructure, cybersecurity and data protection are also important considerations. Secure communications, access control and protection of operational data should therefore be incorporated into the system design.

The economic benefit of the system should be evaluated in relation to the resources required for operation. The current study does not provide sufficient data to quantify this benefit. However, future evaluations could compare the operational cost of drone missions with the cost and personnel exposure associated with conventional field observations and assess the value of increased observation frequency and availability.

The trailer can also accommodate other instruments relevant to avalanche forecasting and natural hazard monitoring. During summer 2026, a doppler radar for landslide detection was mounted on the trailer. The concept has therefore evolved from a dedicated drone station into a mobile instrument platform that can host different sensors according to operational needs.

Overall, the operational experience indicates that mobile drone stations can complement, rather than replace, existing weather stations, cameras, field observations and snowpack information. Their contribution is the ability to provide repeated, site-specific direct observations while keeping personnel at a distance from avalanche terrain.

7. CONCLUSION AND FURTHER WORK

Mobile drone docking stations provide a viable complement to existing avalanche observation systems, increasing the availability of site-specific direct observations while reducing personnel exposure to hazardous terrain.

The trailer-mounted design allows the system to be deployed where and when observation capacity is most needed, without dependence on permanent infrastructure.

Operational experience during winter 2025/2026 showed that drone station imagery was readily adopted into forecasters' routine workflow.

Further work should focus on improving weather resilience and communication redundancy, and on quantifying the operational costs and benefits of drone-based observation relative to conventional methods.

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