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Highly Automated BVLOS Drone Operations: A Large-Scale Flight Campaign supporting Agricultural Monitoring in Saxony, Germany

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ABSTRACT

This paper details a highly automated Beyond Visual Line of Sight drone flight campaign conducted in Saxony, Germany, aimed at executing one of the largest and fastest land use mapping projects in a German federal state to date. Commissioned by the Saxon State Ministry of Energy, Climate, Environment, and Agriculture, the campaign involved photographing several thousand agricultural areas across Saxony. To accomplish this, up to four tilt-wing aircraft were operated in parallel. The project uniquely combined drone-captured images with satellite data which are analyzed using artificial intelligence. With just two days of preparation for flight planning, 24,000 images were generated within one month of operation. The images covered approximately 10,300 km^2 and facilitated the automatic monitoring of agricultural areas under the EU's Common Agricultural Policy. Due to the short notice of the numerous flight missions, it was not possible to approve a specific route for each survey mission. Therefore, for the first time in Germany, aviation authorities issued an area-wide permit covering almost the entire state of Saxony. This paper provides detailed information on the necessary preparation and organization, along with comprehensive statistics of the flight operation. This includes operational constraints, total distance flown, total flight time, and other relevant data, underscoring the operation's efficiency and scope.

Keywords: Agricultural Surveying; AMS; BVLOS; CAP; CEAS EuroGNC; Monitoring; UAS

1 Introduction

Recent changes in the European Common Agricultural Policy (CAP), as detailed in section 1.1, which require nationwide control of subsidies through the development and implementation of an area monitoring system (AMS), motivated this project. GAF AG, a leading company in the European geo-spatial service market, was contracted by the Saxon Ministry of Energy, Climate Protection, Environment, and Agriculture (SMEKUL; Department 3 Agriculture; Unit 34 Direct and compensatory payments) to perform the regular and systematic observation of agricultural parcels within the Free State of Saxony using Copernicus Sentinel satellite time series data at 10 m spatial resolution and other at least equivalent data. In this context, very high-resolution drone images were used on a large scale for the first time in Germany as a substitute for physical on-site inspections. flyXdrive GmbH together with RWTH Aachen University, were selected as drone operator and thus contributed to the *controls for direct payments and area-related agricultural support measures* by providing drone imagery in highest-resolution. To achieve all this, flights with unmanned aircraft systems (UAS) were conducted across the entire Free State of Saxony. All images had to be recorded within one month during the brief growth phase before the investigated parcels were harvested. In terms of technology and aviation law, this cooperation opened a completely new chapter in the CAP monitoring in Germany. This paper introduces to a paper series on several interesting topics which are detailed in the following contributions to the Euro GNC 2024:

- Operational Permit: Application for flexible flight operations in the EU-2019/947 specific category by Baader et al. [1],
- A Flight Operation Strategy for Highly Automated Parallel BVLOS Operations by Dobrev et al. [2],
- Automated Mission Generation and Dispatching for BVLOS Drone Operations by Islam et al. [3],
- Trajectory Planning for Efficient BVLOS Drone Flights over Agricultural Points of Interest by Hartmann et al. [4] and
- Robust and Fault-Tolerant Flight Control Architecture for BVLOS Drone Operations by Osterloh et al. [5].

1.1 Cloud-based monitoring of agricultural parcels as part of the area monitoring system

In 1962, the European Union (EU) introduced the Common Agricultural Policy (CAP) to regulate and support various aspects of the relationship between agriculture and society. It implements a system of agricultural subsidies and other programs with several main goals: to support farmers and improve agricultural productivity, to ensure that European Union farmers can make a reasonable living, to help tackle climate change, to maintain rural areas across the EU, and to keep the rural economy alive. Within the CAP, the EU supports about 7 million farmers with €60 billion in subsidies. In Germany, this amounts to more than €6.3 billion annually [6].

On January 1st, 2023, a new implementing regulation regarding the integrated administration and control system in the common agricultural policy came into effect. This regulation introduces significant changes for agricultural subsidies and the necessary control mechanisms. While in the past, only random inspections were required, member states must now implement an area monitoring system (AMS) to control subsidies. The AMS relies on remote sensing data and aims to establish more modern, fairer, and greener control mechanisms. Regulation (EU) 2021/2116 of the European Parliament and of the Council, Article 65 (4)(b), defines an area monitoring system as follows:

> [Area monitoring system means a procedure of regular and systematic observation, tracking and assessment of agricultural activities and practices on agricultural areas by Copernicus Sentinels satellite data or other data with at least equivalent value.]

The regular and systematic observation of hundreds of thousands parcels with satellite time series data within the growing season require the usage of scalable and efficient cloud infrastructures and modern analysis techniques. In general, multi-temporal and multi-sensoral data (optical and radar) is used for the technical evaluation of the eligibility criteria of agricultural parcels. Four different types of so-called monitors are important for the control of subsidies within CAP: a) *Crop survey*, identifying the crop cultivation out of up to 190 possible crop species, b) *Minimum activity*, detection of minimum activity on fallow lands, c) *Agricultural activity*, detection of agricultural activity on grasslands and d) *Base* *checks*, verification of non-eligible areas, land use changes, and homogeneity. Whereas the *Crop survey* is typically being conducted using artificial intelligence (AI), the other monitors are being addressed by time series analysis or a combination of AI and classical time series analysis.

The AMS explicitly allows the use of so-called 'other methods' to resolve uncertain cases. Other methods are to be understood as follow-up checks that can be applied if there is no clear result after the Sentinel-based technical evaluation. Data recorded through UAS can be considered equivalent to, or even better than Copernicus Sentinel satellite data with 10 m spatial resolution. In order to make use of UAS images beyond satellite-only capabilities, the technical evaluation was performed by GAF AG using its AgroCrop® software solution.

AgroCrop® is a state-of-the-art solution for reliable monitoring and evaluation of agricultural parcels. Being part of AgroSuite product family, AgroCrop® combines a longstanding thematic expertise with the synergy of knowledge, technology, and innovation. It facilitates effective agricultural monitoring and supports environmental management, planning and sustainability measures. It uses multi-temporal and multi-source data to perform machine learning algorithms and dedicated time series analyses on parcel level. The input data consists of Copernicus Sentinel data, Planet Fusion data, digital orthophotos, drone imagery, weather data and agro-climatic conditions.

1.2 Challenges of UAS utilization in Saxony

In 2023, almost 170,000 locations have to evaluated in Saxony for the area monitoring system in total. The number of parcels to be analyzed through UAS heavily depends on the type of control and the quantity and quality of the available Copernicus Sentinel data. For the *crop survey* the number in Saxony is between 2,000 and 5,000 parcels and for *minimum activity* around approximately 20,000 to 30,000 parcels. Figure 1 shows all potential monitoring locations in Saxony ($\approx$ 170,000) and the areas to be analyzed by drones in this campaign related to the *crop survey*.

The use of UAS for technical evaluation within CAP is basically possible anywhere in Europe. In this paper we describe challenges and solutions specific to the German state of Saxony. Saxony is located in eastern Germany and has an area of 18,450 km^2. In 2020, almost 49% of Saxony's area was used for agricultural purposes [7]. The areas to be recorded by UAS are defined by a geocentric coordinate and their contour. Their sizes vary between 30 m^2 and more than $1,200,000$ m^2. The geometries included square areas, U-shaped areas, and thin rectangular areas with a maximum width of less than 1 m.

The UAS data acquisition campaign was shaped by three key requirements: a) the data acquisition must take place within July, b) the target locations are disclosed by end of June, and c) about 3,000 target locations must be documented.

The agricultural parcels to be evaluated are distributed across the entire Free State of Saxony and are partly located in natural reserves, European Fauna-Flora-Habitat Directive (FFH) areas, European bird sanctuaries, and the National Park *Sächsische Schweiz*.

Furthermore, the topology within Saxony varies from the flat northern areas to the mountainous *Erzgebirge* in the south. This presents challenges not only for flight path planning with respect to maintaining a safe flight altitude above ground but also for airspace integration, considering paragliders and other private sport pilots flying in hilly areas in particular.

1.3 Using UAS to augment satellite images

The idea of conducting large area monitoring with drones is promising, although a couple of challenges regarding feasibility, costs, and timeline have to be addressed beforehand. Here, challenges with respect to terrain, as described in section 1.2, have been explicitly taken into account.

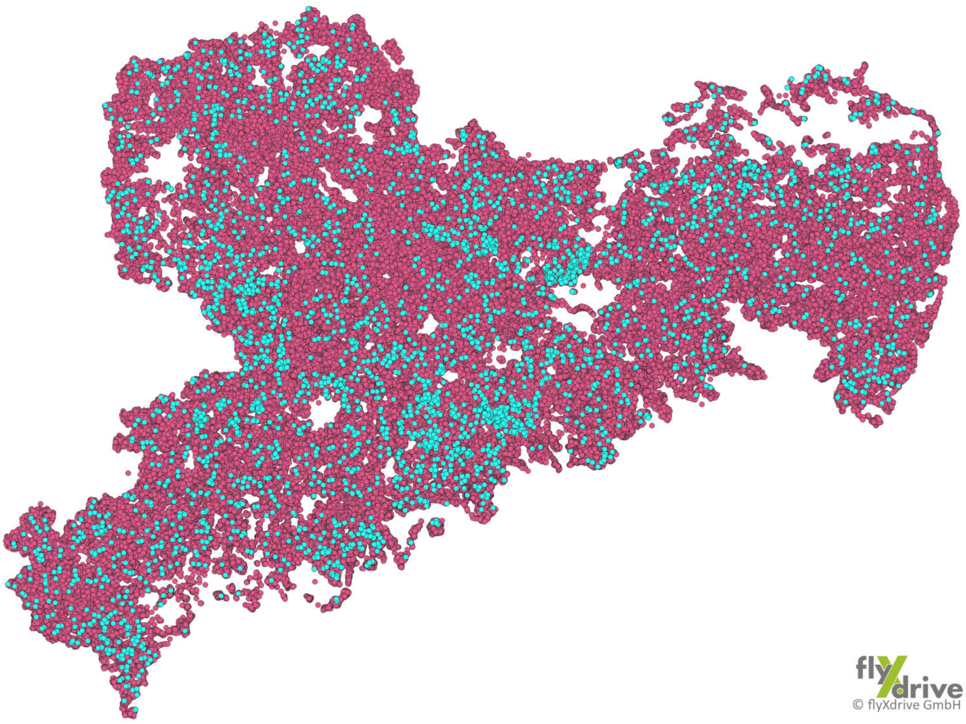

Fig. 1 All potential monitoring locations in Saxony (marked with pink dots) and areas to be analyzed by drones within this campaign (marked with turquoise dots)

To ensure sufficient image quality, UAS images were taken vertically from a height between 50 m and 100 m above ground. Images captured at these heights generally have a higher resolution than satellite imagery. Although the covered area is smaller, it is sufficient for both manual and automated post-processing and labeling. To cover large distances and survey a maximum number of parcels, an aircraft in tiltwing configuration (see Section 2.1) was used for this survey. Thanks to its vertical take-off and landing capability, it can be operated from very small fields without any infrastructure. Additionally, its highly efficient wing-borne flight allows it to cover large distances. The fully automated flight, combined with its high robustness to changes in environmental conditions and failures, allows for the safe operation of multiple aircraft simultaneously by one operator in a Ground Control Station (GCS)

The areas to be analyzed by UAS are those where analysis based on satellite data did not provide sufficient quality. There are several reasons why fields cannot be effectively analyzed by satellites, which include weather conditions, high voltage lines, field sizes and shapes and topography. Clouds and haze obstruct the view for satellites and powerl lines above the fields interfere with image quality. Very small and narrow fields as well as areas located on hillsides cannot or are challenging to capture accurately.

Since the specific fields to be evaluated by UAS operation are not known beforehand and the period for capturing agricultural images is limited to one month, a clustering algorithm is necessary to plan the routes efficiently. Considering the size of Saxony A_{Sax}, and the estimated number of parcels evenly distributed over the state to be recorded by UAS, n_{UAS}, the average distance d between two areas to be recorded, in the worst case, is 2,500 m.

$$d = A_{\text{Sax}} / n_{\text{UAS}} \tag{1}$$

Applying an aircraft range r of 70 km to 100 km, this results in theoretically covering 28 target locations per flight, and thus a total of 108 flights. In theory, only 10 starting locations, evenly distributed across Saxony, would be sufficient. However, it is important to note that this approximation significantly underestimates the effort involved. In most cases, direct flights between areas are not possible. For example, nature reserves and depending on the operations's acceptable risk level villages must be avoided when transferring between areas.

The national aviation authority of Germany (Luftfahrtbundesamt LBA) granted flyXdrive a permit to operate multiple UAVs over sparsely populated areas beyond the visual line of sight of an operator anywhere in Saxony without the need to validate each individual route. This authorization is a prerequisite for achieving ecological and economical benefits for large scale UAS operations. The detailed process of how the operational authorization was achieved is described in Section 2.2 and in [1].

In the following sections, we will delve into the details of BVLOS (Beyond Visual Line of Sight) operations, including specifics about the UAS used, the process for obtaining operational authorization, multi-UAS operations, and the necessary automation. This will be followed by an overview of achievements and challenges in Section 3.

2 BVLOS operation

For the BVLOS operation multiple UAS of the type TW-Neo were used. The UAS ist described in more detail in Section 2.1 and is also the basis for the operational authorization, described in Section 2.2.

2.1 UAS

flyXdrive GmbH operates multiple UAS, primarily using the tilt-wing TW-Neo for BVLOS (Beyond Visual Line of Sight) operations. The TW-Neo is a convertible fiber composite tilt-wing aircraft with vertical take-off and landing (VTOL) capabilities. Its autopilot and mission control software and hardware systems enable redundant communication and seamless airspace integration. The TW-Neo can tilt its wing to transition between hover and fast forward flight, depending on the commanded airspeed. In addition to a tiltable wing, the aircraft is also equipped with a tiltable tailplane, allowing it to take off and land vertically with high precision and robustness. TW-Neo is shown in Figure 2 and Table 1 gives its main characteristics.

Fig. 2 View of the aircraft. © flyXdrive GmbH

The tilting of the wing results in significant variations in the inflow conditions during the transition, leading to different flight performances in flight states between hovering to fast forward flight. Table 2 displays the key data for both hovering and wing-borne flight.

Table 1 Characteristics

Span:	1.85 m
Length:	1.5 m
Wing area:	0.27 m^2
MAC:	0.15 m
Aspect ratio:	12
Ø Wing propeller:	14” (0.356 m)
Ø Tail Propeller:	12” (0.305 m)

Table 2 Flight performance characteristics

	Hover	Fixed wing flight
MTOM:	8 kg	8 kg
Max. flight time	15 min	60 min
Range[1]	n.a.	100 km
Max. climb-/sink rate[2]	$\pm 2\,\mathrm{m\,s^{-1}}$	±2 m/s
Max. bank angle[2]	±40°	±40°
Cruise speed.[3]	n.a.	$25\,\mathrm{m\,s^{-1}}$
Max. speed.[3]	$-2\,\mathrm{m\,s^{-1}}$	$30\,\mathrm{m\,s^{-1}}$
Never exceed speed[3]	n.a.	$35\,\mathrm{m\,s^{-1}}$
Stall speed[4]	n.a.	n.a.

As a payload, a Blackfly® BFS-PGE-50S5C-C camera with a Tamaron M112FM12a obejctive was used to take the pictures. This setup allows for the necessary resolution and image size taking into consideration the planned flight altitude between 50 and 80 m. The images had to be recorded in nadir direction with an allowed deviation of up to 7°. The camera was installed directly into the fuselage and no gimbal was used due to technical simplicity and weight consideration.

Two mobile network modems provide a data link for flight supervision, command and control and payload functions. A satellite modem is available for regions with low mobile network coverage. Onboard systems for FLARM (send and receive) and ADS-B (receive only) contribute to airspace integration and are complemented by a connection to the Droniq UTM system. The flight controller is a proprietary system described in more detail in [5][8][9].

2.2 Operational authorization

The agricultural areas to be photographed were determined on short notice, making long-term flight route planning and clearance by aviation authorities unfeasible. Consequently, for the first time on this scale, the German Aviation Authority (Luftfahrtbundesamt, LBA) issued a permit for BVLOS operations

[1]At minimum hover time, a cruise speed of $25\,\mathrm{m\,s^{-1}}$ results in a range of 100 km. The actual range depends on the flight speeds and wind conditions specified in the mission profile.

[2]The allowed climb/descent rates and bank angles are crossfaded by the flight controller depending on the airspeed.

[3]The speeds are given as calibrated airspeed (CAS). Depending on the actual wind speed, other speeds relative to ground (groundspeed) result. Maximum hover airspeed is only limited in the tailward direction due to the mechanical tilt limit of the wing.

[4]Since the tilt angle of the wing is automatically adjusted by the flight controller according to the airspeed, there is no stall speed to consider. The attitude of the aircraft is stabilized throughout the entire flight envelope by the flight controller, using appropriate control variables.

covering an entire agricultural and forestry area of a federal state, outside of control zones. The detailed process of obtaining this operational authorization is provided in [1]; this paper presents only a short overview. flyXdrive already holds an operational authorization for BVLOS operations with this aircraft, which simplified the process of obtaining further authorization.

For the given UAS, operating beyond visual line of sight requires an operational authorization in the specific class. To obtain this, several conditions based on a Specific Operation Risk Assessment (SORA) must be fulfilled. The SORA process consists of ten consecutive steps detailed in [10]. These steps ensure that all risks associated with BVLOS operations are thoroughly assessed and mitigated, providing a framework for safe and efficient UAS operations.

In order to achieve an acceptable operational risk level, the following constraints for the operation were in place: a) only operation over sparsely populated areas combined with an additional mitigation was planned to reduce the ground risk and b) control zones, helicopter landing sites, airports, and airfields were excluded from the operational flight volume.

With these basic specifications, the team of flyXdrive and RWTH Aachen University examined publicly available geodata and implemented an automatic toolchain to calculate acceptable the height H and lateral dimension S of the flight geography (FG), contingency volumes (CV), and ground risk buffer (GRB) for different flight parameters such as the maximum ground speed $v_{\max}$, as shown in Table 3. Due to the lower maximum allowed ground speed, the efficiency and thus range of the UAS are significantly reduced, but the required safety margins to areas of higher risk are also smaller.

Table 3 Operational Volumes in Saxony

Zone	$v_{\max}$	H_{FG}	H_{CV}	S_{CV}	S_{GRB}	Formulas for
Main Zone	$33\,\mathrm{m\,s^{-1}}$	110 m	146 m	170 m	147 m	fixed-wing operation
Low Zone	$21\,\mathrm{m\,s^{-1}}$	60 m	79 m	79 m	80 m	fixed-wing operation
Low-MR	$10\,\mathrm{m\,s^{-1}}$	60 m	71.5 m	38.5 m	39.5 m	multirotor operation

While the automated processing as described in [1] is based on a very straightforward concept, in reality it is complicated by a number of challenges. These include poor data quality (inconsistent, outdated, unverified, poorly documented data), and eventually also the large bulk of data. But also the reviewing processes, both on side of the operator and the authorities, revealed to be work intense. A representative example of the characteristics of the authorized operational volume is shown in Figure 3.

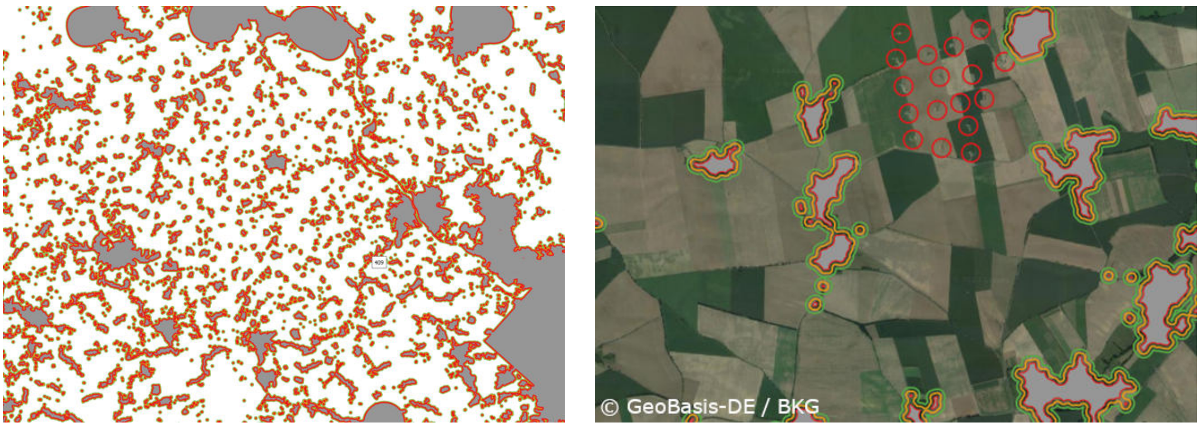

Fig. 3 On the left side, the city of Dresden and its control zone, as well as some smaller airfields, are shown as greyed-out areas where flight is not allowed. The flight geography is represented by the white area. On the right side, a much more detailed view of a small part of the operational volume is provided including a wind park depicted as obstacles.

After obtaining the operational authorization, the flight geography was further augmented to include geozones by German national law, wind energy parks, natural reserves, and more. For the natural reserves in the area, 16 individual local nature conservancy authorities have been contacted to obtain permits for overflight. Also information about bird hatching grounds, which had to be excluded from the flight routes to comply with the German Nature Conservation Act, as well as information on "Landschaftsschutzgebiete" (landscape protection areas), which are German local zones designated to preserve specific landscapes have been gathered in preparation of the mission. There are individual regulations that must be adhered to for each landscape protection area; some prohibit the take-off and landing of UAS, while others even prohibit UAS flights over these areas.

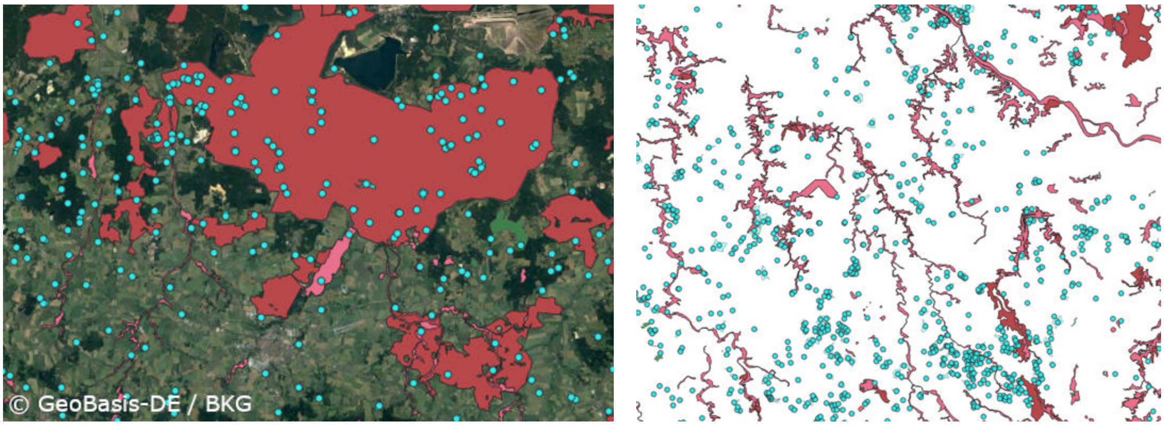

Fig. 4 Natural reserves within the flight geography. On the left the national park *Sächsische Schweiz* covering a large area is shown and on the right a multitude of nature reserves along rivers cut through Saxony. Areas to be recorded are marked with turquoise dots.

During path planning for flight execution, natural reserves were avoided wherever possible, and flight heights above 100 meters above ground were maintained. Overall, the complexity of dealing with flights over natural reserves and the numerous geozones significantly increased the preparation effort.

This careful planning was necessary to ensure compliance with various regulations and to minimize environmental impact. The detailed consideration of geozones, natural reserves, and other restricted areas is crucial for the successful and lawful execution of the flight missions.

2.3 Automation

Automation is a crucial keystone in large-scale unmanned flight operations. This is true for both, the UAS, and the flight preparation. On the one hand preflight planning divided into clustering, Section 2.3.1, and pathplanning, Section 2.3.2, and on the other side the automated flight execution described in Section 2.4.

2.3.1 Clustering

The clustering process is described in detail in [3]. Inputs into the clustering algorithm included the points to be observed, the operational volume, and the range of the aircraft. The different zones according to Table 3 were taken into account. The optimization goals were to minimize the number of starting points (referred to as depots in this context) and to minimize the number of flights.

The results showed that due to the dispersed operational volume, significantly more depots were necessary than estimated by Equation 1. Considering the actual operational volume, the number of starting points increased to 115 (in contrast to 10 estimated by Equation 1), with 64 depots covering more than one or two fields. Still, with only 35 depots, 90% of all fields can be recorded. In the clustering process, the UAS range was reduced to account for increased energy consumption due to challenging topography that can not be followed in fixed-wing flight mode. The take-off locations were set at one of the fields to be recorded.

Figure 5 shows the results of the clustering algorithm for the complete area of Saxony, and Figure 6 provides a detailed view for one starting point. The largest number of targets that can be recorded from

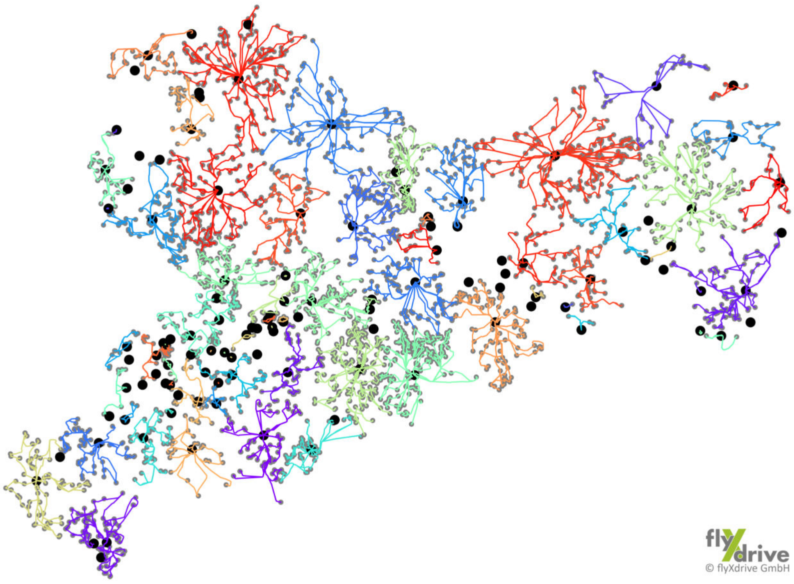

Fig. 5 Clustering results. Starting locations are marked with black dots and target locations with small grey dots. All lines represent flight paths with flight paths in the same color starting from the same take-off location.

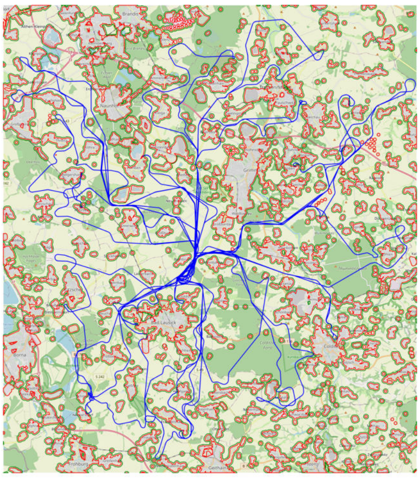

Fig. 6 Clustering and path planning results of one depot (blue lines). In contrast to solely clustering results the paths are smoothed and approved internally. The boundary of the operational volume is depicted in red, orange and green.

a single starting point is 252, and considering 90% of the areas, the average is 76 areas per starting depot. The maximum number of flights from one starting point was 35.

Within the clustering, only a two-dimensional planning was achieved. Additionally, points of interest (such as paragliding starting and landing zones, model airfields), and further restrictions from geozones were not considered. Furthermore, the orientation of the areas was not taken into account during the clustering process. For very narrow fields, the flight path had to be adapted accordingly in a separate step. Since the starting point was initially set to an area to be recorded, it often had to be moved to a more suitable location, frequently to an area outside of natural reserves.

This clustering process was essential to ensure efficient and feasible flight planning, considering the complex and variable operational conditions across Saxony.

2.3.2 Path planning

In the next step, a semi-automated path planning and validation process was used to prepare the actual flight routes. For this, a proprietary mission control system software was used. This software allows the inclusion of several maps as layers and the simulation of planned paths under different wind conditions. The complete system and process behind the path calculation are described in more detail in [4]. A brief overview of the functionalities and steps conducted before the actual flights is provided below.

Within the path planning, all areas not included in the clustering are taken into account. In detail, this includes areas which should be avoided (model airfields, paragliding areas, vicinity to airfields and radio mandatory zones, nature reserves) and areas that have to be crossed perpendicularly (power lines, highways and railways). In addition, the flight path is fine tuned to finalize the take-off location, take into account the orientation and size of the agricultural areas as well as the topology and flight height. In a final step safety landing points are included in the flight path and the path is validated.

In cases where areas that should be avoided cannot be completely circumvented, the relevant stakeholders were contacted to work out a safe procedure, or as a last resort, these planned flights were not approved internally. Outdated and incomplete contact information (e.g., for paragliding take-off locations, model airfields and even helicopter sites) posed a big issue in this step.

In the case of natural reserves, the different requirements from local authorities had to be followed. Most required that, whenever possible, the flight height had to be increased to 100 meters above ground. For regions where this was not possible, either an additional permit from the local nature conservation authority existed, or the prepared routes were sent to the authorities. For the greater portion of all natural reserves, a solution with the nature conservation authorities could be found. However, this communication and the non-standardized process significantly reduce efficiency when planning large-scale flight campaigns.

Due to the operational authorization, there was an obligation to cross highways and railways perpendicularly to reduce ground risk. The flight path was also adjusted to account for the orientation of narrow fields and to allow safety landing spots at least every three kilometers. The first and last part of each trajectory was also adjusted to allow parallel flight with up to four aircraft. After finalization, each route was checked manually with respect to energy consumption, height and velocity profile, and safety spots. In Figure 7, the altitude boundaries of a planned flight are shown.

This meticulous path planning process ensured compliance with safety and environmental regulations while optimizing flight efficiency and effectiveness. Flights requiring additional procedures were labeled as such. The actual operation as well as special pre-flight procedures are described in the following section.

2.4 Operating multiple UAS System beyond visual line of sight on ad-hoc basis

The actual operation covers several different topics ranging from general preparation over pre-flight preparations to the flight operation.

As general preparation for this campaign, all relevant stakeholders were informed three weeks prior to the start of the flight campaign. This step included notifying other airspace users through their respective organizations. Although not required by the operational authorization, this step was taken to enhance

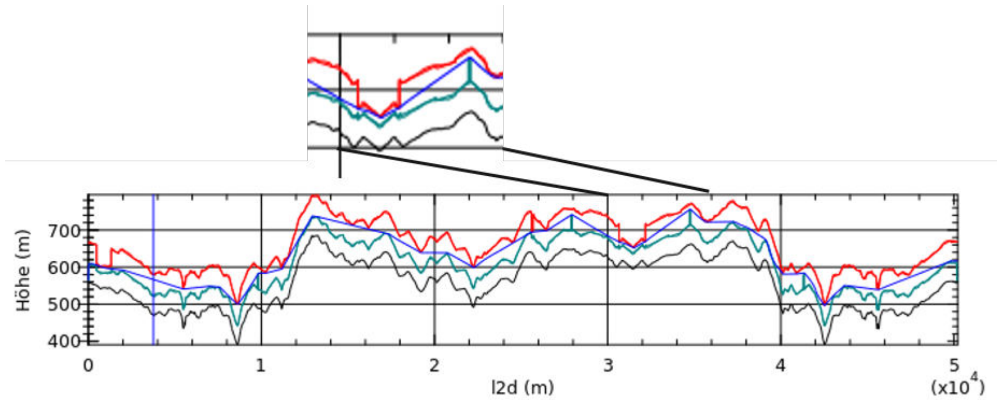

Fig. 7 Elevation (black line) and lower and upper altitude limits (red and green) over a planned flight of 50 km with the planned flight altitude (blue line). The maximum flight height is ≈110 m above ground.

safety for everyone involved. As a result, many questions and concerns were raised, which were addressed as thoroughly as possible. Valid concerns were taken into consideration, increasing the organizational effort. Consequently, a procedure was established to inform all aviation stakeholders in Saxony of the areas where flights were planned each day.

In addition to daily updates to the police helicopter squadron, rescue helicopter units and local authorities around the starting points were notified to make the UAS operator aware of local events or peculiarities. In addition, airfields in the vicinity were contacted and the emergency response plan was adapted for each location. For a flight route planned close to a helicopter landing site at a hospital, a call with the hospital was arranged beforehand to ensure separation.

Take-off locations for each day were selected based on the location of the local team, the weather forecast, and the number of validated flights. The remote control station from where all flights were monitored was set up in Aachen. The detailed setup is described in more detail in [2]. Figure 8 shows the setup of one starting location. The order of flights at each starting location was determined using a scheduler tool to ensure sufficient separation between all UAS in air at the same time. The scheduler is detailed in Figure 9.

Fig. 8 Parallel start with four UAS. © flyXdrive GmbH

During the flights, a remote pilot monitored the system health of the aircraft, surrounding air traffic, and actual weather and onboard wind estimation. One remote pilot was capable of monitoring up to four aircraft simultaneously, although in most cases, two remote pilots monitored two UAS each. The UAS operated fully automatic. Possible commands from the remote pilot included pausing and continuing a

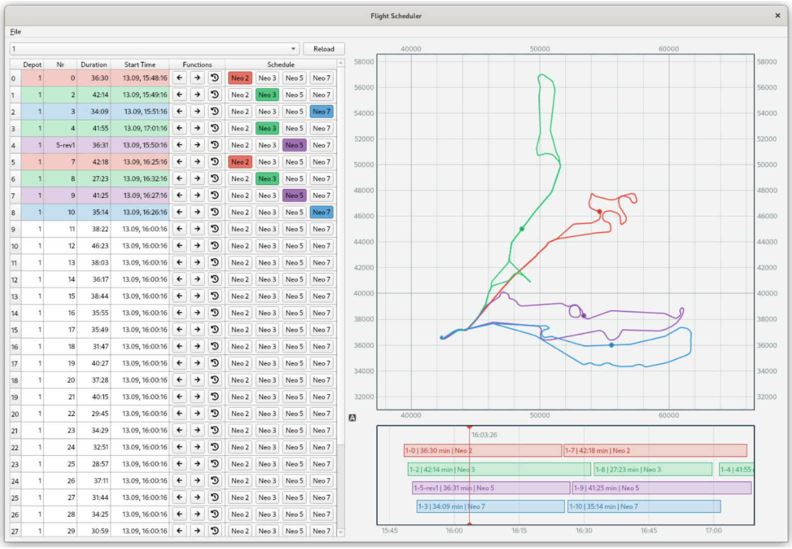

Fig. 9 Scheduler tool giving an overview of all flights from one location, their duration to allow for multiple simultaneous flights from one take-off location without conflicts between the UAS.

flight on its pre-planned path, returning home, landing at the next landing site, and immediate landing. Additionally, safety functions for GPS loss and system failure were in place.

3 Achievements

Overall, 321 flights were conducted between June 28th and August 4th, 2023, covering over 10,900 km with four UAS flying in parallel. During this period, 1,977 agricultural parcels were recorded, resulting in a total of over 24,000 images. The maximum number of flights conducted in a single day was 35. Exemplary resulting images are shown in Figure 10.

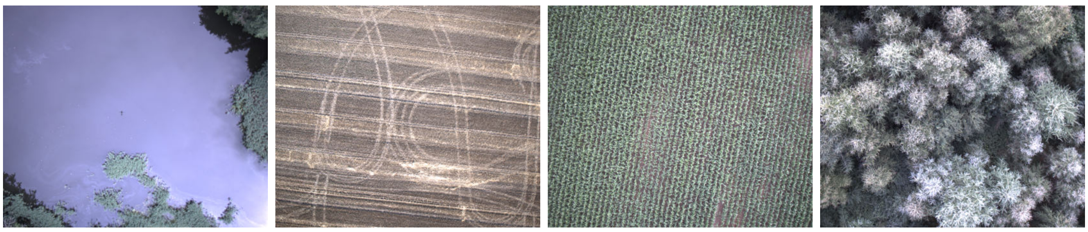

Fig. 10 RGB images recorded during the flight campaign, showing (from left to right) a pond, a harvested field, a crop field and a forest. © flyXdrive GmbH

A summary of the achieved flight distances and durations is given in Figure 11 and Table 4. The maximum flight distance of over 100 km and duration of over 60 minutes were not reached due to the height profile and velocity constraints of our flight geography. During the 321 flights, 4 flights had to be aborted beyond visual line of sight due to detected peculiarities in attitude angles. After the abort command from the operator, the UAS automatically flew to the next predefined landing spot and landed there.

Additional commands from the operator included two return-to-home commands and two stops on path to avoid helicopters in the vicinity and ensure enough separation between UAS and helicopter. Mobile data connectivity over all flights was available about 95.25% of the time. In cases of no mobile data connectivity, communication over satellite was available.

After consultation with the police helicopter squadron of Dresden, one of their helicopters visited the starting area to determine whether the UAS were electronically visible and also visible to the pilots

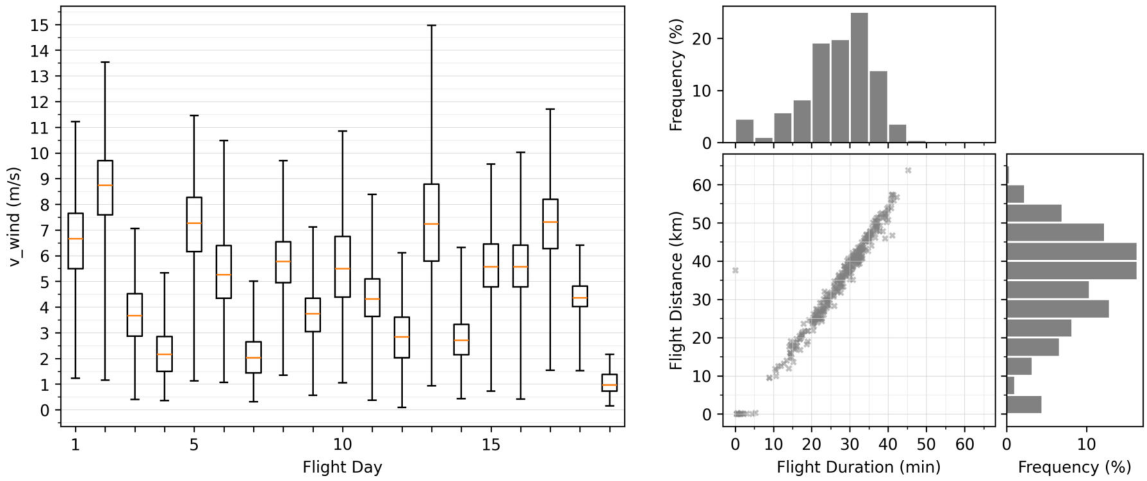

Fig. 11 Average wind velocities, flight duration and distances over the campaign

Table 4 Statistics over the flight campaign in Saxony

	# Flights	mean	std	25%	50%	75%	max
Flight Distance in km	321	33.96	13.15	25.58	36.18	42.98	63.80
Flight Duration in min.	321	26.69	9.26	21.43	28.31	33.10	45.22

on board. The perspective from the ground is shown in Figure 12. The height difference between the helicopter and the UAS shown in the image was 200 meters. The UAS were electronically visible to the police helicopter. Additionally, the police helicopter was visible to the UAS and the remote operator in Aachen. It became evident that, without any prior warning or indication of where to look, the UAS would not have been visible to the helicopter crew. This exercise demonstrated the importance of electronic

Fig. 12 Rendezvous with visiting police helicopter. © flyXdrive GmbH

visibility for both the UAS and the helicopter to ensure mutual awareness and avoid potential collisions, highlighting the need for robust communication and coordination during flight operations.

The extensive flight campaign demonstrated the capability and efficiency of the UAS operations to capture high-quality images of a significant number of agricultural areas. During the flight campaign, data acquisitions have been transferred to GAF AG in 14 batches in total. After a first data screening, the provided RGB images were geometrically processed through georeferencing and clipping (see Figure 13) using GAFmap®, a Geo-Information System (GIS) Desktop application. Subsequently, the image data was annotated by means of visual interpretation and directly split into training and test (validation) data sets for the Deep Learning (DL) modelling approach.

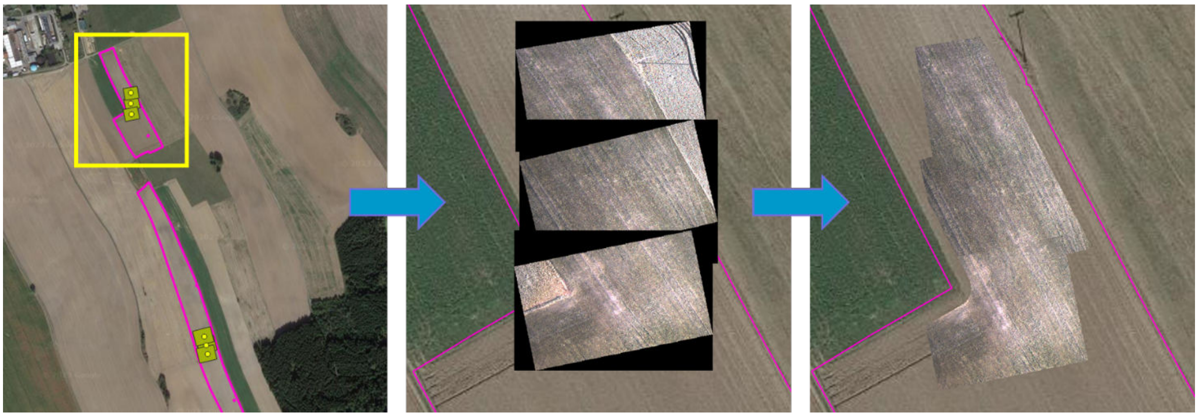

Fig. 13 Data preparation of acquired images on parcel level. © GeoBasis-DE / BKG © SMEKUL

The model architecture chosen was Resnet34, a state-of-the-art image classification model, structured as a 34-layer Convolutional Neural Network (CNN). the model was trained on the nine pre-dominant crop classes and the training progress was monitored continuously (see Figure 14).

The training process was followed by the actual prediction, visualization of the results and model evaluation. This step made it possible to optimize the model according to the results of the validation set. The initial classification results fell short of expectations. The causes were identified as heterogeneous structures on the images, especially lanes and churned-up soil, as well as fields that had already been harvested. A detailed image analysis showed that, unfortunately, a significant proportion of the plots had already been harvested at the time of UAS image acquisition. A new model with fewer classes was created and trained to exclude interfering image structures. The resulting model accuracies achieved acceptable to very good results, especially for the permanent grassland and maize groups.

The relevant model accuracies per class, including initial results, optimized results and final ones are shown in Figure 15.

Results with a low confidence value were then subject to Computer-Assisted Photo Interpretation (CAPI), which was carried out by agricultural experts. After quality control, the results were finally submitted to SMEKUL.

The combined approach of deep learning plant classification and CAPI on UAS images and additional Very High Resolution (VHR) satellite data resulted in a clear technical assessment of almost 97% of the 1,977 plots. A few parcels that could not be clearly identified for various reasons (lanes, churned up soil, harvest residues) remained at SMEKUL for detailed evaluation.

4 Conclusion

The large-scale BVLOS flight campaign in Saxony, Germany, showcased the successful implementation of highly automated drone operations for agricultural observations. Conducted between June 28th and August 4th, 2023, the campaign involved 321 flights, covering over 10,900 km and capturing more than 24,000 images of 1,977 agricultural parcels. The use of up to four tilt-wing UAS flying in parallel demonstrated the efficiency and effectiveness of automated UAS operations over extensive areas.

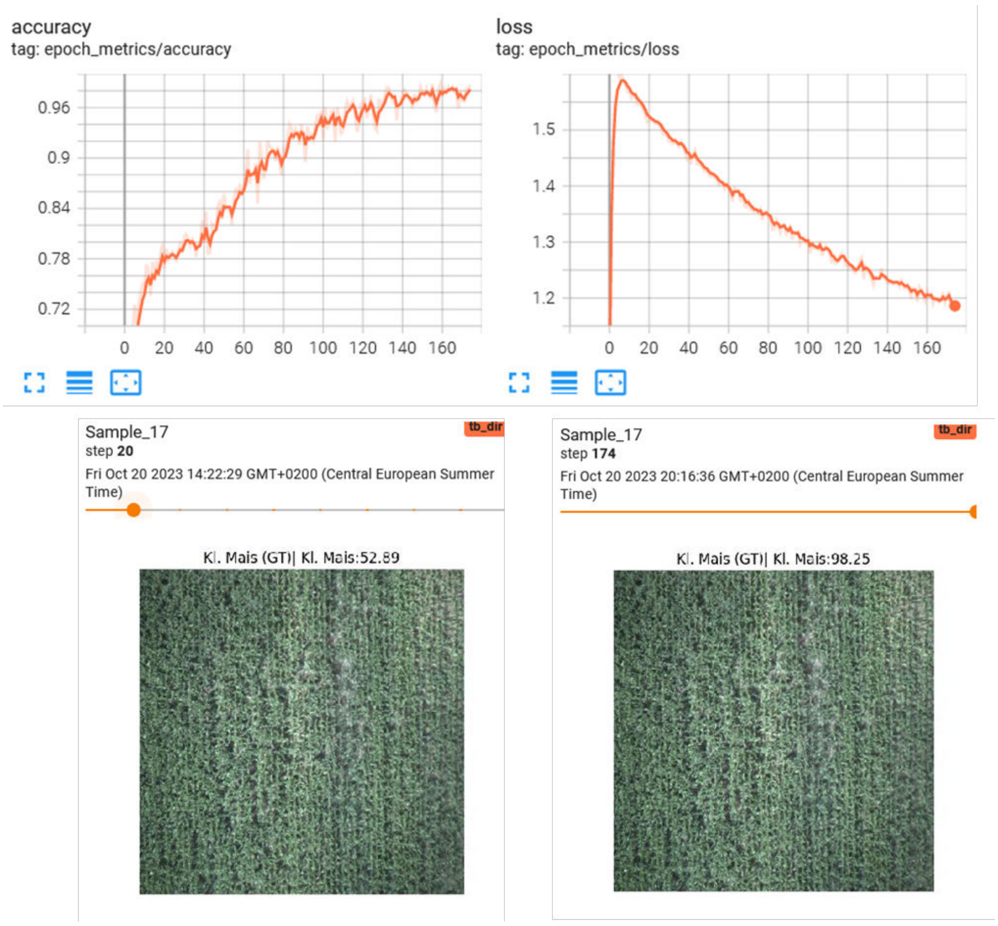

Fig. 14 Model training and monitoring of the training progress for a specific crop species (maize).

Key achievements included the successful integration of UAS-captured images with satellite data and AI analysis, contributing to the monitoring of agricultural parcels under the EU's Common Agricultural Policy. The campaign highlighted the importance of meticulous planning and coordination, particularly in managing complex geozones, natural reserves, and various local regulations.

The operational authorization granted by the German Aviation Authority for BVLOS flights over an entire federal state without validating each individual route was a pioneering step and established a framework for similar large-scale operations in the future. The collaborative effort between flyXdrive GmbH, GAF AG, and RWTH Aachen University, supported by advanced mission control software and a robust communication strategy, ensured safe and efficient flight operations.

Challenges faced during the campaign, such as outdated geographical data sets and the need for continuous stakeholder communication, underscored the necessity of real-time data verification and stakeholder engagement. The exercise with the police helicopter squadron of Dresden further emphasized the critical role of electronic visibility in maintaining airspace safety.

From a data analytics perspective, the project served as a proof-of-concept for crop classification based on thousands of drone images using a Deep Learning model. Even though the image dataset was too small to serve a wide variety of crop species, a first reference database built on UAS imagery and satellite data was created and good accuracies could be achieved for very distinct crops (i.e. maize, permanent grasslands). GAF AG has successfully established a pipeline for UAS crop classification, which is a) scalable for use with larger datasets, and b) transferable to other image classification use-cases, and thus gained important experience and knowledge related to Deep Learning methods utilizing UAS imagery. Ultimately, the use of UAS imagery can be recognized as having great potential for future applications in agriculture, particularly when multispectral images are considered.

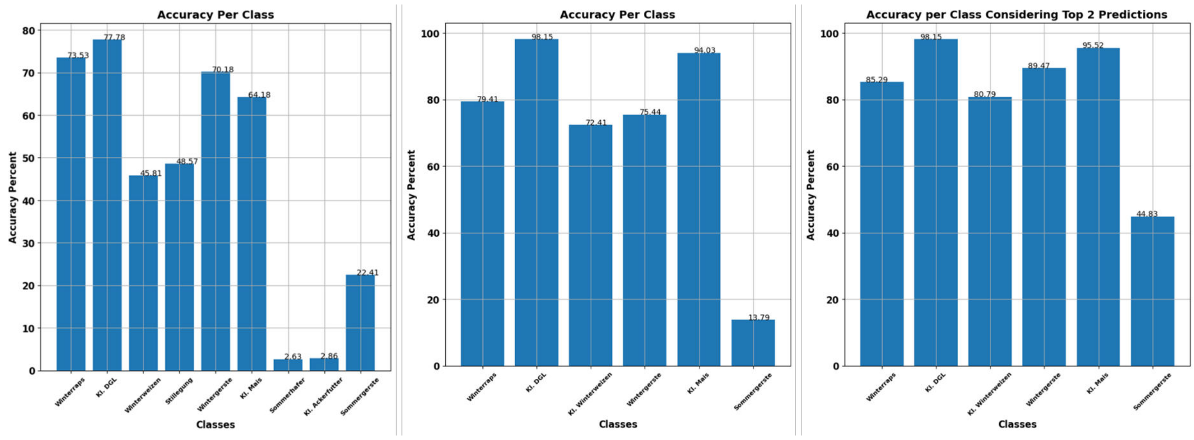

Fig. 15 Initial classification results (left), optimized classification results with 6 classes (mid) and final results (right).

Overall, this campaign set a benchmark for future BVLOS drone operations. It demonstrated that with proper automation, and stakeholder collaboration, it is possible to conduct extensive and efficient aerial surveys in a short time, providing valuable data for agricultural monitoring and other applications. The findings and methodologies from this campaign provide a solid foundation for further advancements in drone technology and its applications in various fields.

Acknowledgments

We fully acknowledge SMEKUL's decision to use drone images as an alternative to conventional on-site inspections, as this has made the large-scale flight campaign possible in the first place, and would like to thank you for using the image and data material provided.

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