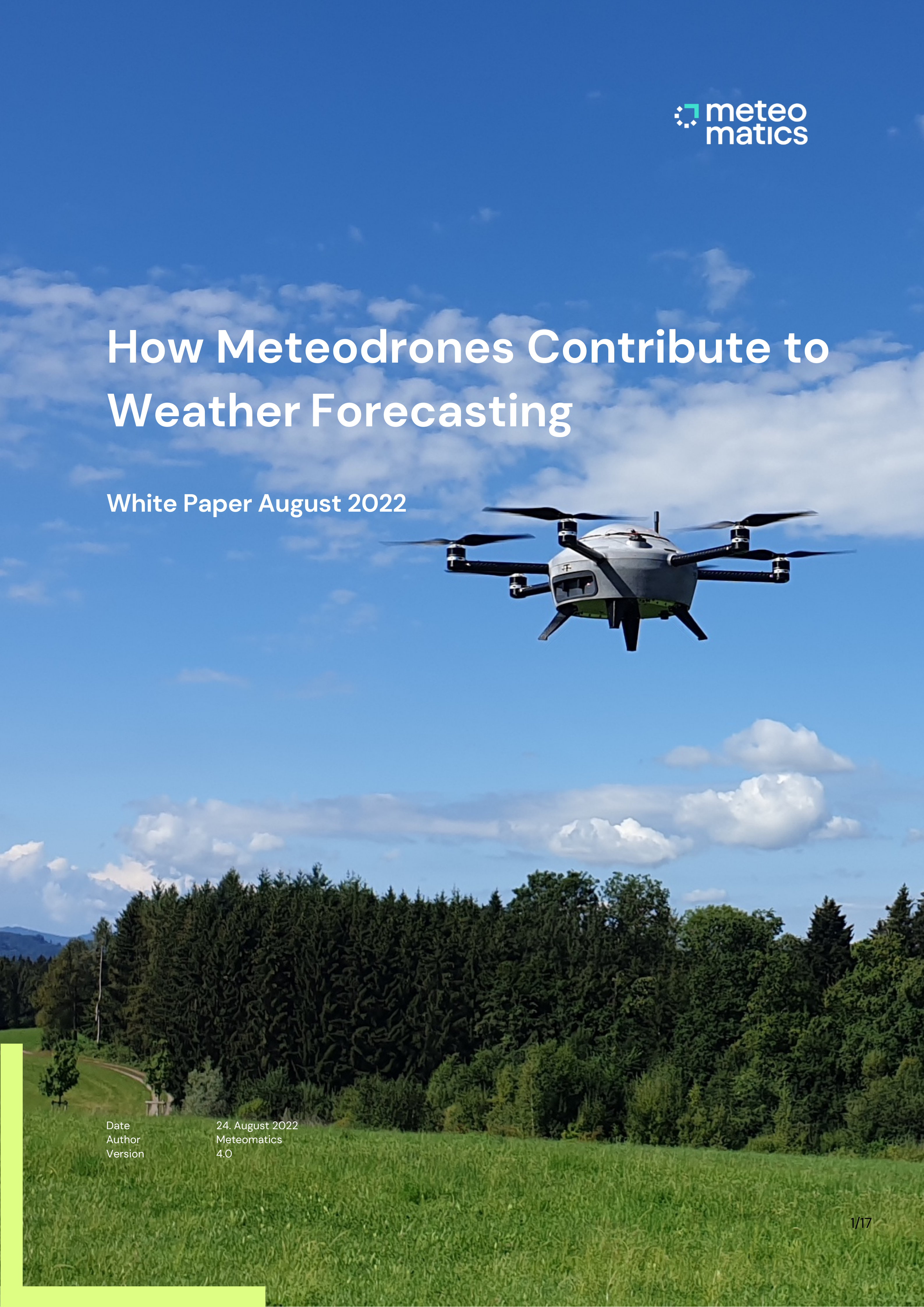

How Meteodrones Contribute to Weather Forecasting

White Paper August 2022

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Author Meteomatics
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Executive Summary

This white paper describes the observational data challenges that impact modern numerical weather forecasts and how these can be overcome with unmanned aerial vehicles (UAV). Small rotary-winged UAVs have the potential to provide a unique observing system capable of measuring detailed vertical profiles of temperature, humidity, air pressure and wind. These meteorological data - captured within the planetary boundary layer (PBL) - help to determine the potential for severe weather formation and enhance the forecasting ability for atmospheric conditions such as hail, icing and fog formation among others.

Table of Contents

1 Computation of a Numerical Weather Forecast 3

2 Meteodrone Systems 5

3 Meteorological Data 7

4 Using UAV Data in Numerical Weather Forecasting 10

5 Case Studies 11

- 5.1 Fog Formation 11
- 5.2 Storm Formation 12
- 5.3 Icing Conditions 13

6 Meteobase – A Remote Platform 14

7 What Is Next? 15

8 Company Background 16

9 Order a Meteodrone - Get in Touch 17

1 Computation of a Numerical Weather Forecast

Mathematically, modern weather forecasts are formulated as an initial value problem – in other words, knowing the current weather conditions allows the abstraction of a future weather state. Typically, a future state is derived by applying physical laws, like coupled thermo-dynamical and Navier-Stokes equations. Unfortunately, this practice suffers from two downsides:

1. There are no analytical solutions known to the Navier-Stokes equations. A solution can only be found by using numerical approximation.
2. The description of the initial (current) state of the atmosphere will always have some degree of uncertainty associated with it.

In the last 10 years the computational capacity for running global weather models in a resolution of 10 km or locally even less (1 km) has become more easily available and more affordable. Consequently, problem (1), whilst still a challenge, is increasingly a manageable one.

Regarding (2), major advances have been made thanks to satellite data that have been assimilated into global models. However, a closer look at the different data sources reveals a gap in the planetary boundary layer (PBL), i.e., the first 1 to 2 km above ground level (AGL). Even though weather phenomena forming in this layer directly affect us, actual measurements of meteorological parameters are scarce. A popular solution for the last 100 years has been radiosonde (balloon) soundings. Unfortunately, these balloons are usually lost after deployment as they are carried away with the wind, they cannot be retrieved after descending as their landing spot is often not easily accessible, and highly sensitive and accurate measurement devices attached to the balloons increase the costs of their operational use. Therefore, balloon soundings are carried out only twice a day and only at selected locations. Consequently, weather phenomena like fog, low stratus and storms cannot properly be predicted as and when they are triggered in the PBL.

Several different attempts have been made to overcome the issue of collecting more reliable data. Remote sensing techniques – either satellite-borne, airborne, or ground based – have developed over the past century. These remote sensing techniques usually make use of laser (e.g., LIDAR), active or passive microwave (e.g., radiometer) or different types of radar devices. All of these measurement methods share the following downsides:

- relatively expensive
- limited mobility
- designed for one specific use case/physical parameter
- no data in adverse conditions

Small unmanned aerial vehicles (UAV) do not suffer these issues. Therefore, they can improve the information gathered in the PBL by directly and accurately measuring prognostic variables. As UAVs are not lost during soundings, several atmospheric profiles can be retrieved in one session. Hence, a temporal evolution of the measured parameters can be observed.

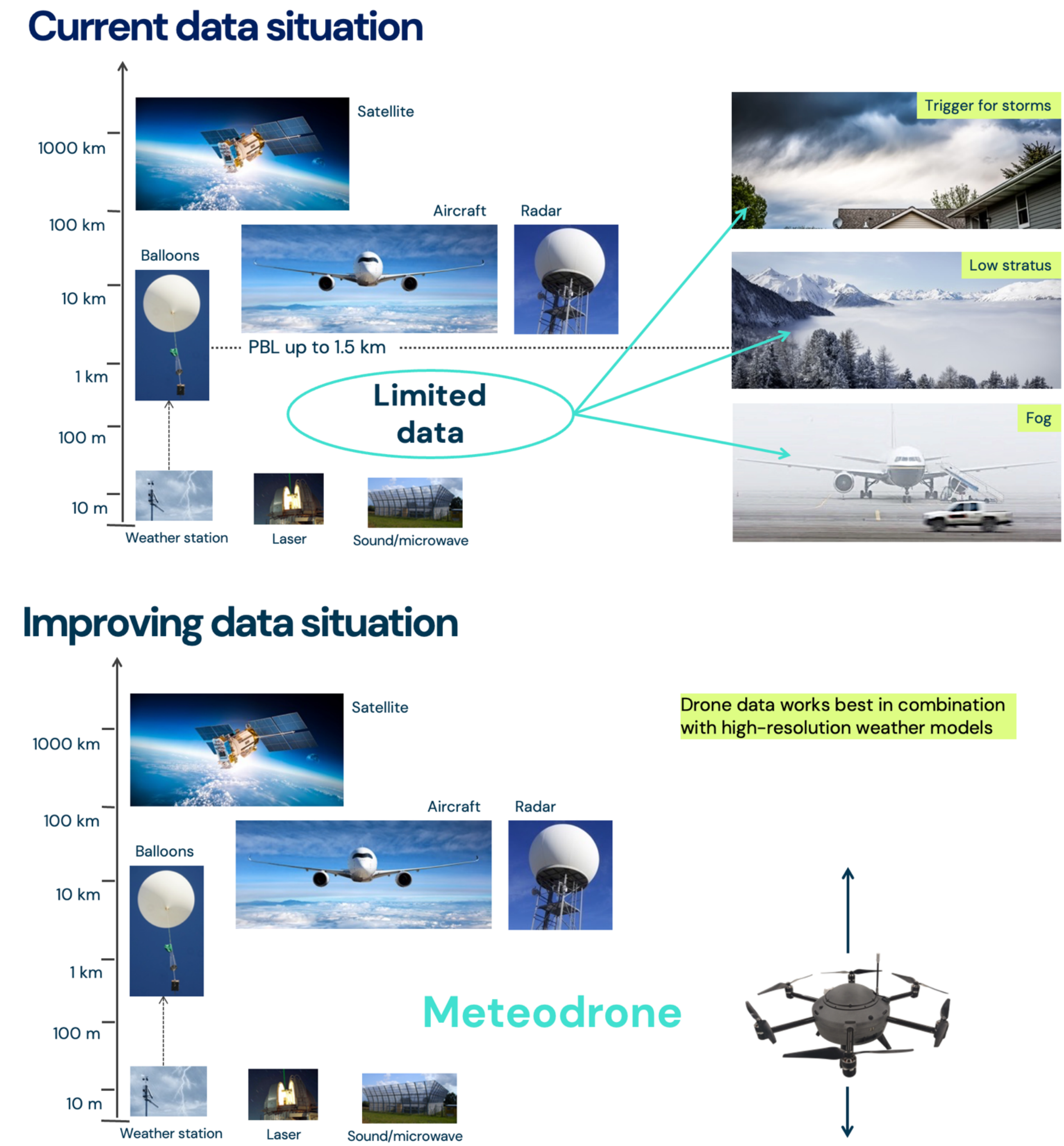


Figure 1: Meteodrone closes the data gap

2 Meteodrone Systems

Meteomatics has developed two different systems with different characteristics and advantages for operational applications. In the following these two systems are described in more detail.

All systems are delivered with a ground station and a transport case. The ground station receives real-time telemetry data (incl. meteorological data). The case is IP67 for rugged transport and includes the ground station charger, tools, spare batteries, etc.

	 Meteodrone MM-641	 Meteodrone MM-670
Brushless motors	6	6
Battery powered	✓	✓
Max. payload	-	1 kg
Take-off weight	ca. 1 kg	ca. 4.9 kg
Dimensions	40 x 40 cm	70 x 70 cm
Max. climb rate	20 m/s	10 m/s
Max. wind speed	100 km/h	90 km/h
Max. flight altitude	2'000 m AGL	6'000 m AMSL/500 hPa
Avg. flight duration	ca. 12 min	ca. 20 min
Waterproof	✗	✓
Navigation lights	✓	✓
Strobe lights	✓	✓
Rescue system	✗	✓
Ground control station	✓	✓
VLOS	✓	✓
EVLOS	✗	✓
BVLOS	✗	✓
Measured Parameters		
Sample rate	100 ms	100 ms
Temperature	✓	✓
Wind speed	✓	✓
Wind direction	✓	✓
Dew point	✓	✓
Air pressure	✓	✓
Option to Accommodate External Sensors and Payloads		
Particular matter/black carbon	✗	✓
Ozone	✗	✓
Radioactivity	✗	✓

Available formats

WMO TEMP (FM35)	✓	✓
WMO TEMP MOBILE (FM38)	✓	✓
PILOT (FM32)	✓	✓
WMO PILOT MOBILE (FM34)	✓	✓
WMO BUFR	✓	✓
CSV	✓	✓

Each UAV is equipped with a ground station that provides a telemetry link to the drone. All flight-relevant parameters are shown in real-time on a display attached to the ground station ensuring a direct monitoring of the flight. These include:

- Position (moving map)
- Altitude and heading
- Power consumption
- Current weather
- Wind conditions

Hence, the pilot can keep track of the UAV at all times. The radio link uses either an 868 Mhz (EU), 900 Mhz (US) or 5.8 Ghz (currently in development) frequency band. The gathered data is stored on an SD card on the UAV. Live data of all variables are transmitted to the Ground Control Station during the flight at a reduced sample rate. The data stored on the SD Card on the UAV can be downloaded after the flight to the Ground Control Station over a Wi-Fi connection. Data is visualized directly on the Ground Control Station.

All Meteodrones are pre-programmed to perform vertical ascents/descents with constant climb rates between 3 and 10 m/s up to an altitude of 6'000 m AMSL. Custom flight profiles are possible, however.

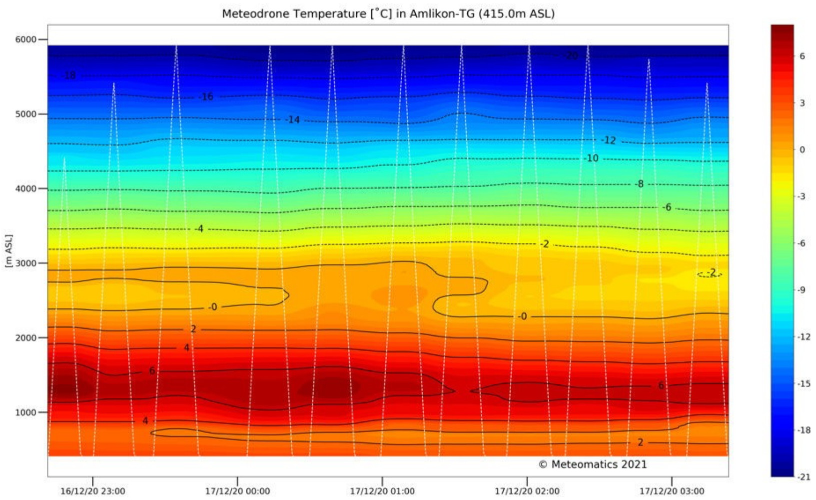
The Meteodrone MM-670 is additionally equipped with an Emergency Recovery System (ERS), which is required for flying under Beyond Visual Line of Sight (BVLOS) conditions and can be controlled from the ground. Parachute systems protect property and people, as well as the drone itself, from damage in case of an unforeseen event. Such an event could be, for example, engine failure or foreign interference.

Every country publishes their own drone rules and laws, typically with the oversight by the civil aviation authorities. It is mandatory to apply for an approval at your local authorities to operate the Meteodrone. Especially flying BVLOS typically requires special authorization. Reach out to Meteomatics specialists who are able to support your submission.

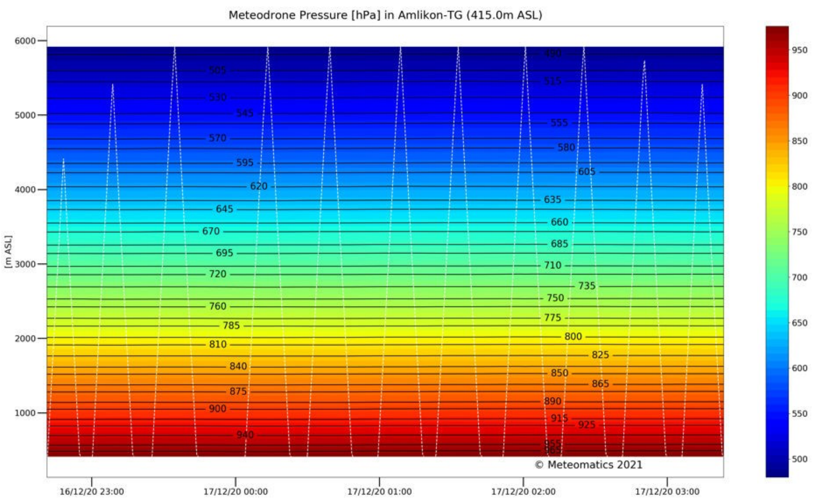
3 Meteorological Data

The raw meteorological data is sampled at 10 Hz and transmitted to the Ground Control Station. In addition, the data is stored on an on-board SD-card. After a finished flight, the data is transferred via Wi-Fi to the Ground Control Station, where it is post-processed. This also includes the transformation into a RAOB format to display soundings. Sequences of flights can be visualized online with charts such as the following:

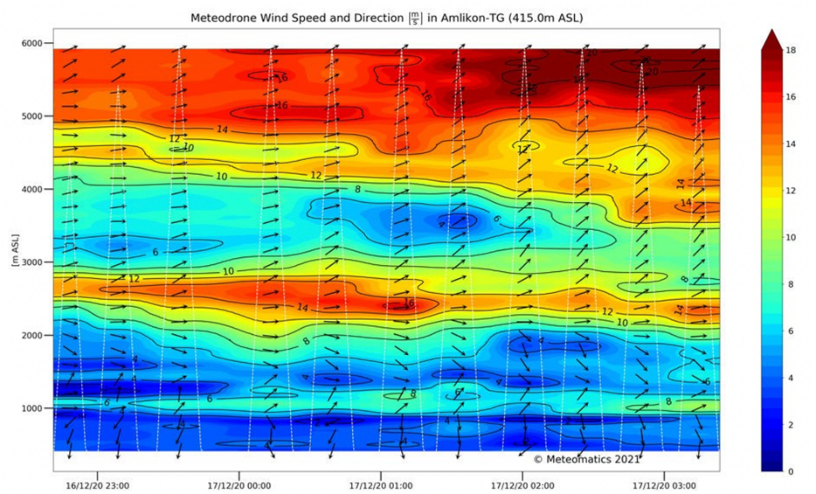
Temperature



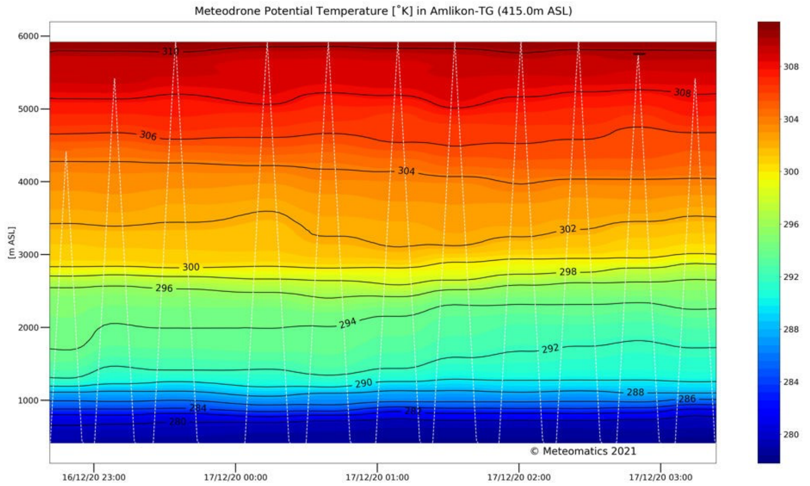
Pressure



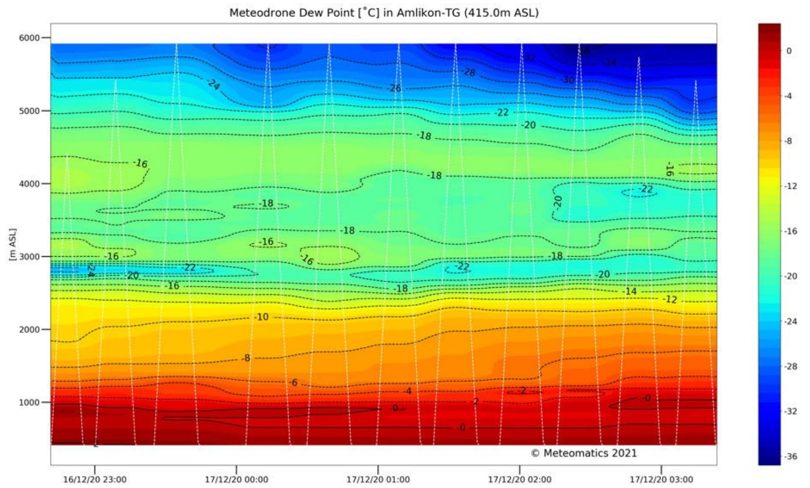
Wind Speed and Direction



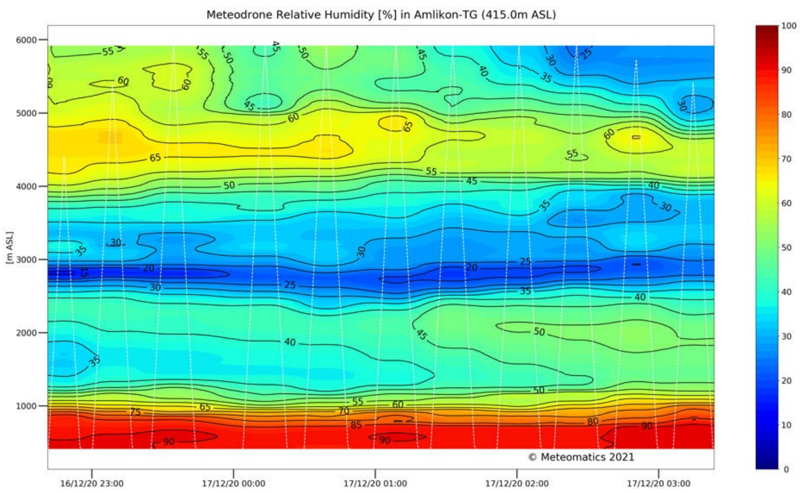
Potential Temperature



Dew Point Temperature



Relative Humidity



Single flights can also be visualized in a skew-T log-P diagram (s. Figure 2) and are also displayed within the graphical user interface of the Ground Control Station.

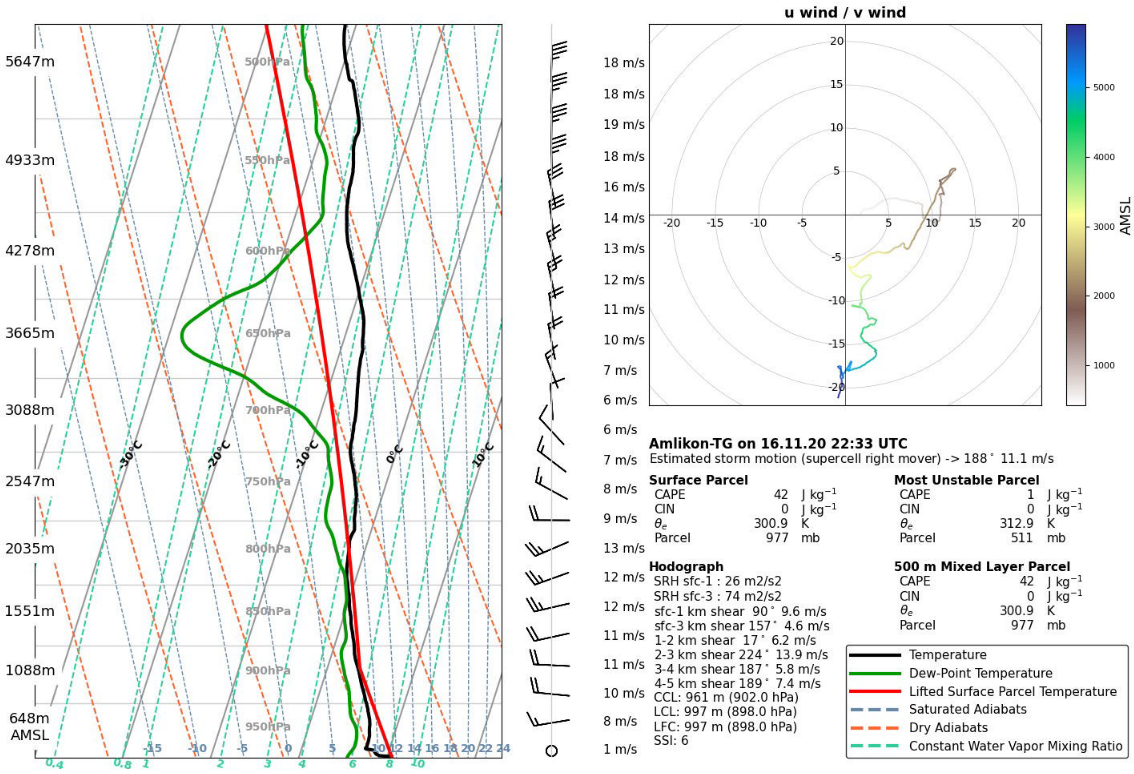


Figure 2: Skew-T log-P diagram including a hodograph

4 Using UAV Data in Numerical Weather Forecasting

Assimilation into WRF

Once the data from the Meteodrone has been acquired, it can be straightforwardly ingested into mesoscale models such as MM5 and WRF without implementing any additional forward observational operators. Therefore, we use a data format recognized by WRF which allows for the "recycling" of all existing data assimilation routines for balloon soundings.

Depending on the topography and the height of the mission, the radius of influence of the Meteodrone gathered data can be 15 to 45 km. Existing 4d-nudging or 4d-VAR routines can also be used to assimilate the drone data into the initial state of the weather model.

To estimate meteorological parameters at higher altitudes the atmospheric lapse rate is traditionally calculated using weather station data. However, these calculations are prone to errors. Meteodrone data enables the measurement of the actual lapse rate which can then be applied to other regions as well.

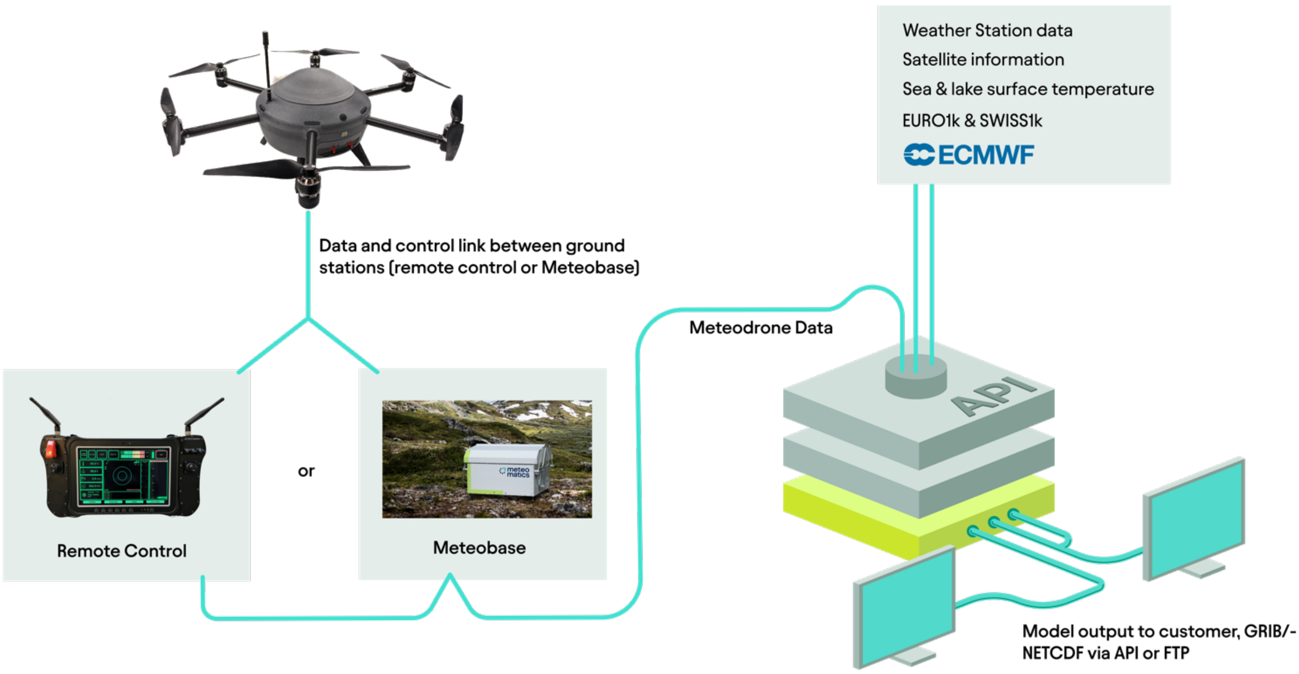


Figure 3: SWISS1k and EURO1k workflow

5 Case Studies

5.1 Fog Formation

The following example compares the occurrence of early morning fog and low stratus between model runs with and without Meteodrone data. In the example the data is assimilated into the WRF model Swiss1k.

Column a) shows the satellite cloud cover for 7 AM (upper image) and 8 AM (lower image). The columns b) and c) represent the SWISS1k model forecasts for these two dates. Of special interest is the area of Lake Constance (North-Eastern Switzerland) which is covered by fog and low stratus. In this particular case, the data of three Meteodrone systems - flown at three different locations at the southern west-east axis of the lake (Schaffhausen, Amlikon and Marbach) - were assimilated. In column b) the WRF run is shown without any drone data. Column c) shows how the moisture recorded by the drone flights has been picked up by the model: fog and low stratus were detected and resolved in the early morning.

An additional observation is the model's inability to pick up the shallow fog on the western Swiss plateau and in northern Italy. In these areas, no supporting Meteodrone data was gathered to help to correct moisture profile.

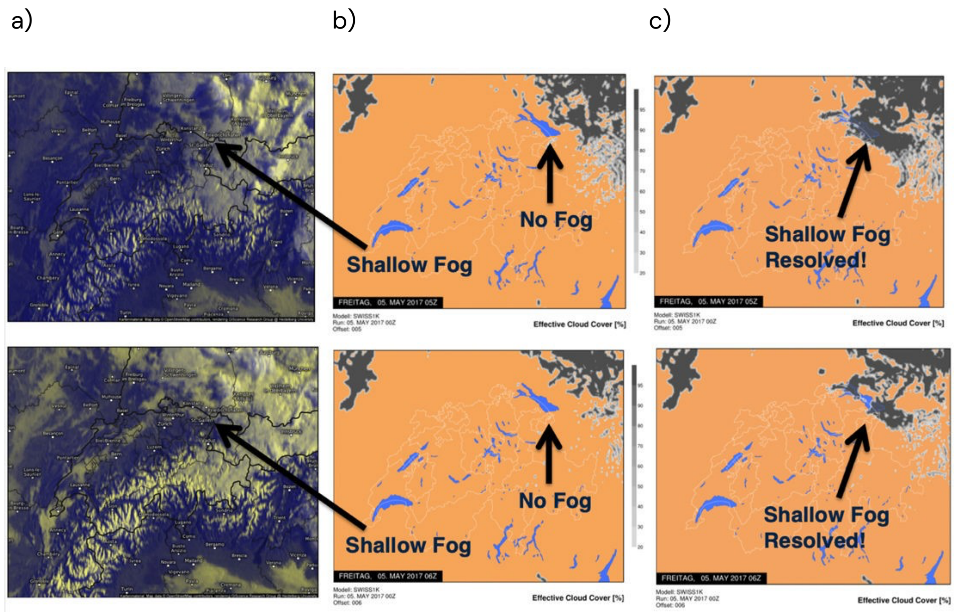


Figure 4: a) Satellite cloud cover during the event, b) SWISS1k forecasts without Meteodrone data, c) SWISS1k forecasts with Meteodrone data

5.2 Storm Formation

Depending on the stability of the atmosphere, topographically induced storms can be observed within Alpine regions. Such an event happened on the 29th of May 2017.

Figure 5a shows the precipitation rendered from the model with Meteodrone data. The red dots indicate flight profiles with their effective radius of impact (red dashed line) taken in Schaffhausen, Amlikon and Marbach – all cities close to Lake Constance. In 5b, in comparison, the operational models, without any additional drone data, such as ECMWF, NCEP and Met Office, were not able to capture the severe storms that formed in the late evening. 5d shows the radar image data measured at that time.

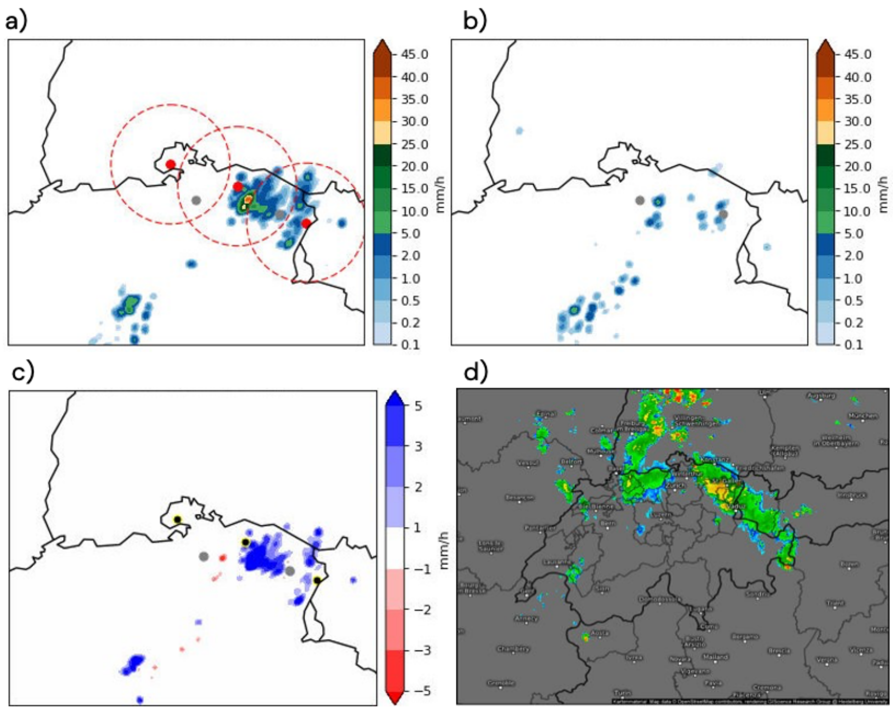


Figure 5: a) Precipitation in the model forecast with Meteodrone, b) Precipitation in the model forecast without Meteodrone, c) Difference between models with and without Meteodrones, d) Radar image of precipitation during the event

5.3 Icing Conditions

Icing does not only pose a problem to commercial aviation and helicopters but to UAVs as well. The ice accumulations cause a loss of controllability. Since more UAVs are used in everyday life the risk to the public is increasing.

Two conditions must prevail in order to cause ice accumulations on propellers:

- Air temperature < 0 °C
- Relative humidity > 95 %

Drone enhanced forecasts of temperature, relative humidity and wind speed allow for identifying icing conditions (red area in figure 6).

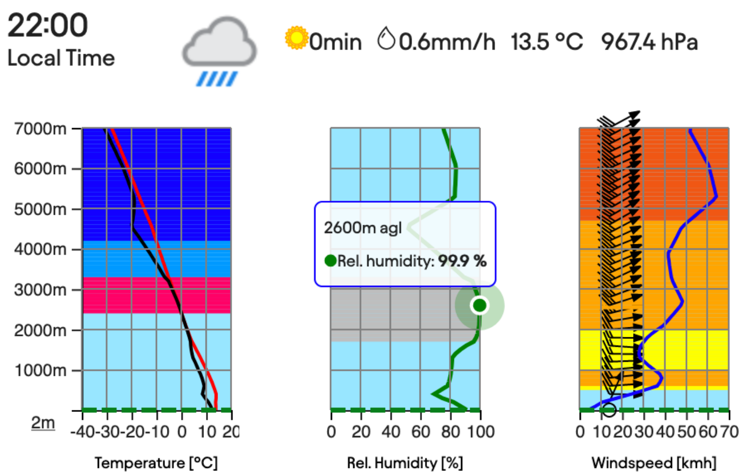
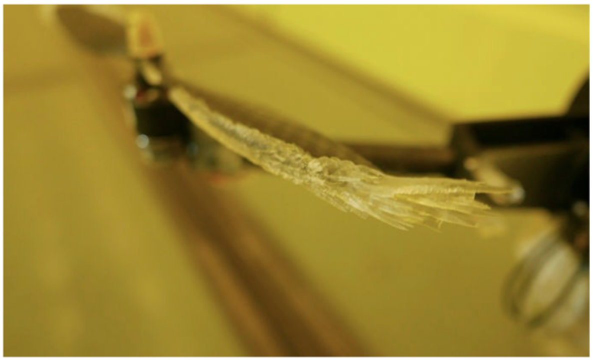


Figure 6: Global drone weather provided for free by Meteomatics for the whole world (www.droneweather.ch). A vertical profile of the temperature, relative humidity, and wind is shown.

The effect and ultimately the prevention of icing has been extensively studied by Meteomatics. In these research projects test-flights in real icing conditions were conducted. Moreover, icing in different environments was studied: outdoors during winter, in an indoor ski slope and in the Vienna Climatic Wind Tunnel (VCWT). Based on these tests the effect of icing on the Meteodrones was examined and different anti-icing methods were analyzed. A reliable heating method for the propellers is shown in the following image. This de-icing technology is an integral part of Meteomatics' high-tech all-weather drone solution.



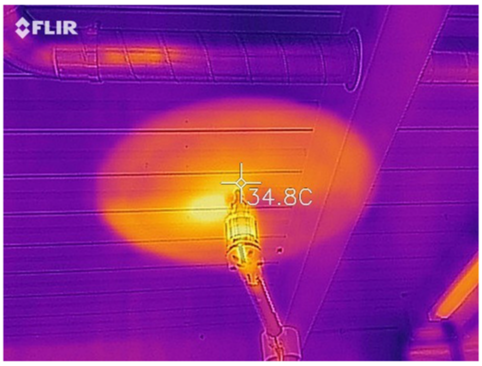


Figure 5: Extreme accumulation of clear ice amount (left) and heating of propellers (right)

6 Meteobase – A Remote Platform

An important step towards nationwide drone operations has been the development of the Meteobase. As a base station, it allows the remote control of Meteodrones. The Meteobase serves as a communication element between the Operations Control Center and the UAV. It consists of a central computer that controls and directs:

- communication of telemetry data from the Meteobase to the UAV via the serial downlink and a 4G redundant internet connection for the Meteobase to the Operation Control Center
- initiation of the opening and closing of the Meteobase lids before and after take-off and landing
- initiation of recharging of the UAV after mission completion
- controlling of climatization of the Meteobase, monitoring of optional camera footage and weather parameter at Meteobase site
- logging of relevant data

The Meteobase comprises the complete launch and landing platform, including a recharging unit, the radio link and ground station, and cameras for surveilling the direct surrounding of the box. The cameras allow for verifying that the UAV has landed correctly and for visually checking the UAV's general condition.

In addition, it incorporates an internal climatization unit (heating, air conditioning) to ensure optimal climatic conditions for the UAV, its electrical components and the batteries. The base is water- and snow proof, with rain gutters ensuring the smooth discharge of rainwater. It is a fixed installation: once it is deployed, it will stay at the operational site for the duration of the operation.

Figure 6: Meteobase

7 What Is Next?

- Targeting altitudes of 8’000 m AMSL and beyond
- Tackling higher operational wind speed
- Built and enhance capabilities for naval environments

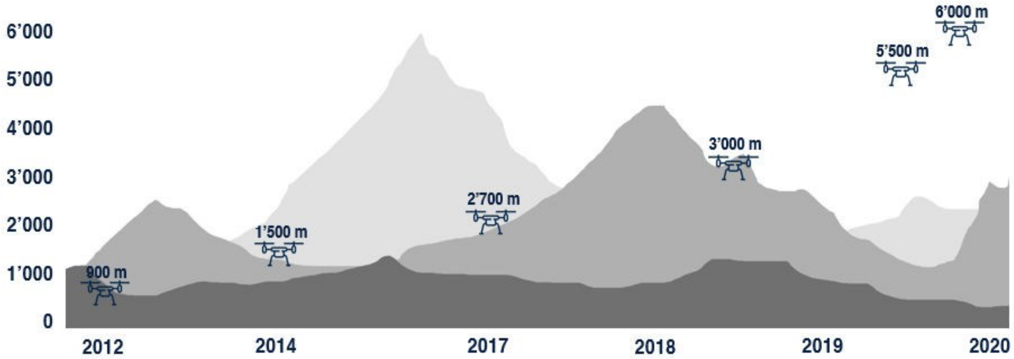


Figure 7: Timeline of flight altitudes of Meteodrones

At Meteomatics, we are always striving to improve and perfect our technologies. Our Meteodrone has already made many impressive development steps.

A constant challenge is flying in even higher air layers. Our Meteodrone can already climb to an altitude of 6000 meters and we are convinced that this is far from being the limit. For drones to be able to fly in higher air layers, several challenges must be overcome. The first challenge is the increasingly strong wind speeds, which increase with altitude. In order for the drone to remain stable, it needs more energy and power to counteract these winds. In addition, the air pressure gets lower with altitude, so the propeller systems have to turn faster and the drone correspondingly needs more energy. This means that the drone must be equipped with more powerful batteries, which in turn affects the weight of the drone. These factors must all be carefully balanced when designing new drone systems.

Another major challenge, besides the stronger winds and lower air pressure, is the low temperatures, which also decreases with increasing altitude. Low temperatures, in combination with high humidity, can lead to icing of the propeller systems. We have already developed a deicing system that has proven reliable under operating conditions. At even higher flights, the drone requires more flight time and thus more heating power for the propellers, which in turn affects the energy requirement additionally.

In addition, our drone systems will be adapted and further developed for new environments, especially maritime environments, but also for applications in desert areas.

8 Company Background

Meteomatics is a leading weather service provider with offices in St. Gallen and Berlin and employees with strong backgrounds in physics, mathematics, and computer science. Working closely with National Met Services and industry, Meteomatics is specialized in commercial high-resolution weather forecasting, power output forecasting for wind, solar and hydro, gathering of weather data from the lower atmosphere using Meteodrones and easy delivery of quality weather data via the Weather API. At its heart, Meteomatics pursues two core values: innovative technology and improved data quality.

Companies have a requirement to better integrate consistent, quality weather data across the whole business; to empower the various business units to enhance current operational performance and to deliver business insights that drive innovation resulting in new and improved services.

To provide the best data for any coordinate worldwide, Meteomatics aggregates the latest weather forecast models, satellite data, rainfall radar information and station observations from a variety of sources around the planet. To further enhance this data Meteomatics also produces its own high-resolution atmospheric model at a 1 km resolution across the whole of Europe. The great forecast skill of Swiss1k is only possible due to the data received from the unique Meteodrone measurements within the lower atmospheric layers. The national Swiss 1k model was recently expanded to entire Europe, providing high resolution weather model output for the whole of Europe. Thus, Meteodrone data can enhance weather forecasts with EURO1k throughout Europe. To learn more about our unique EURO1k weather model visit our EURO1k webpage.

By accessing the Weather API our customers' businesses will be far better positioned to address customer, regulatory and wider societal demands now and in the future. The API will also drive innovation by making data simply available for internal and external teams to deliver big data driven operational insight.

9 Order a Meteodrone – Get in Touch

Order Meteodrone

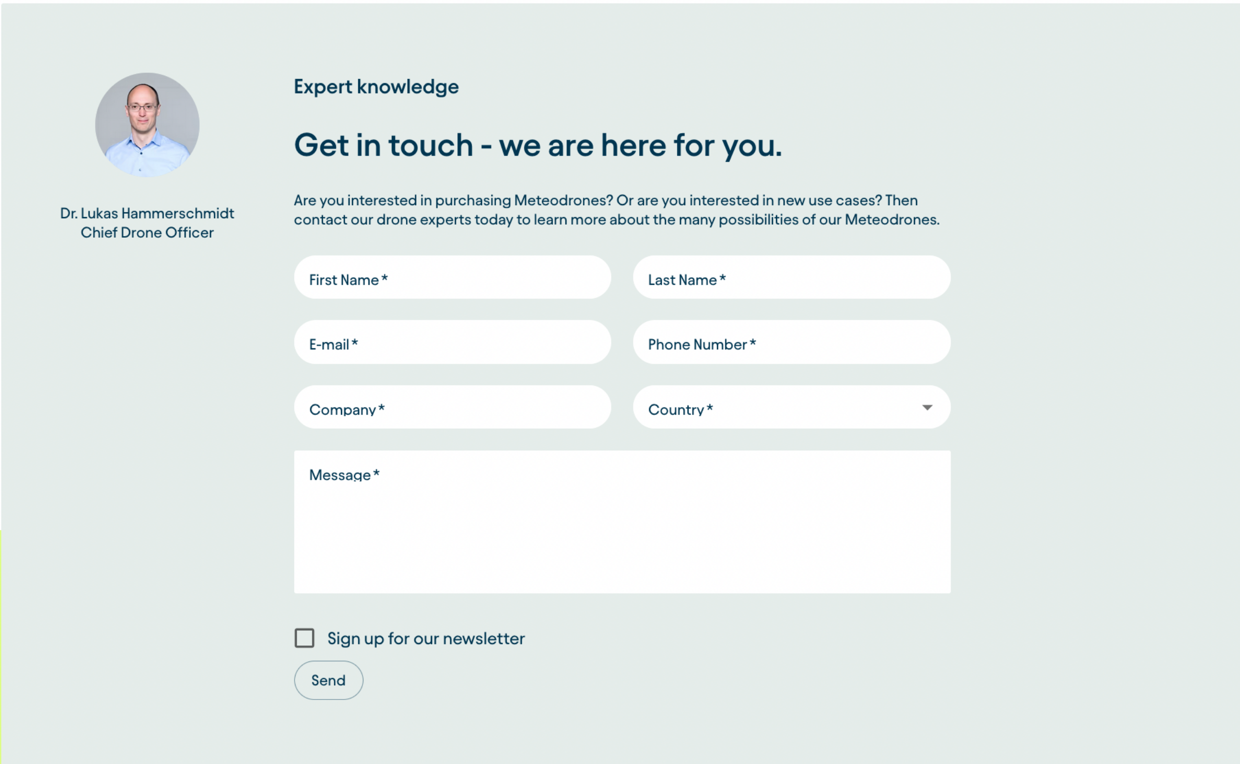
If you have decided to use a weather drone, our Meteodrones offer a system optimized for your purposes that can withstand all weather conditions.

Send us an enquiry and receive an offer tailored to your needs: no matter the application.

Depending on your requirements, you can make use of our expertise in addition to the product and its accessories. Together with you, we will make a test flight, train you on the use of the drone with a flight training course or even fly the drone on your behalf in a joint project. We have already been able to use our Meteodrones in many application areas.

Contact us – we are here for you!

The easiest way to contact us is to use the contact form on our homepage. You can find the contact form at the very bottom of our drone page:
https://www.meteomatics.com/en/meteodrones-weather-drones/



Alternatively, you can contact us directly via email, please write a message to sales@meteomatics.com.