meteomatics

Mastering the weather challenge

White Paper, March 2020

How Meteodrones Contribute to Weather Forecasting

Executive Summary

This white paper describes the observational data challenges that impact modern numerical weather forecasts and how these could be overcome with unmanned aerial vehicles (UAV). Small rotary wings UAV 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.

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Computation of a Numerical Weather Forecast

Mathematically modern weather forecasts are formulated as an initial value problem. Or in other words, knowing the current weather conditions allows to abstract 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:

(i) There are no analytical solutions known to the Navier-Stokes equations. A solution up to a certain degree of resolution can only be found by using numerical approximation.
(ii) The description of the initial (current) state of the atmosphere lacks sufficiently accurate information.

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, facing problem (i) is still challenging but manageable.

Regarding (ii) 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 were balloon soundings that collect and deliver readings of different weather parameters. Unfortunately, these balloons are usually lost after deployment as they are carried away with the wind. Moreover, their landing spot is often not easily accessible; thus, they cannot be retrieved after descending. Moreover, 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.

As a consequence, weather phenomena like fog, low stratus and storms cannot properly be predicted as they are triggered in the PBL.

A number of different attempts have been made to overcome this issue collecting more reliable data. Remote sensing techniques – either satellite-borne, airborne or ground based – have been designed over the last 20 to 30 years. 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 condition

Small unmanned aerial vehicles (UAV) do not suffer from 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 flown in one session or even during a longer time period. Hence, a temporal evolution of the measured parameters can be observed.

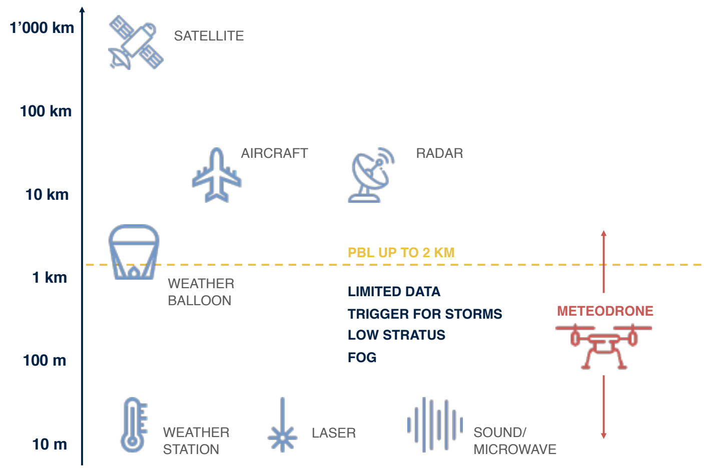


Figure 1: Meteodrone closes the data gap.

Meteodrone Systems

Meteomatics developed three different systems with different characteristics and advantages for usages. In the following, these three systems are described in more detail.

All systems are equipped with a ground station and a transport case. The ground station receives real-time telemetry data (incl. meteorological data). The case is IP65 rugged for transport and includes the ground station charger, tools, spare batteries, etc.

	 Meteodrone SSE	 Meteodrone Classic	 Meteodrone XL
Brushless motors	6	4	4
Battery powered	✓	✓	✓
Max. payload	-	-	ca.1 kg
Take-off weight	ca. 0.7 kg	ca. 1.5 kg	ca. 5 kg
Dimensions	40 x 40 cm	60 x 60 cm	70 x 70 cm
Max. climb rate	20 m/s	10 m/s	6 m/s
Max. wind speed	75 km/h	60 km/h	40 km/h
Max. flight altitude*	1'500 m	3'000 m	3'000 m
Max. flight duration	ca. 12 min	ca. 20 min	ca. 40 min
Waterproof (IP64)	✗	✓	✓
Navigation lights	✗	✓	✓
Position lights	✓	✓	✓
Rescue system	✗	✓	✓
Ground system	✓	✓	✓
EVLOS*	✗	✓	✓
VLOS*	✗	✓	✓
BVLOS*	✗	✓	✓
Measures parameters:			
Sample rate	250 ms	250 ms	250 ms
Temperature	✓	✓	✓
Wind speed	✓	✓	✓
Wind direction	✓	✓	✓
Dew point	✓	✓	✓
Air pressure	✓	✓	✓
Optional parameters:			
Particular matter/ black carbon	✗	✗	✓
Ozone	✗	✗	✓
Radioactivity	✗	✗	✓
Available formats:			
WMO TEMP (FM35)	✓	✓	✓
WMO TEMP MOBILE (FM38)	✓	✓	✓
PILOT (FM32)	✓	✓	✓
WMO PILOT MOBILE (FM34)	✓	✓	✓
WMO BUFR	✓	✓	✓
CSV	✓	✓	✓
Use case	Forecast of tornadoes	Gathering data for WRF assimilation	Measurement of pollutants

A Close-Up of the Meteodrone Classic

Each UAV is equipped with a ground station that enables a redundant 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. Hence, the pilot is able to keep track of the UAV at all times:

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

The primary radio link uses 2.4 GHz and the secondary uses either 433 MHz, 900 MHz (USA) or a frequency according to local regulations. The gathered data is stored on an SD card on the UAV. It further transmits the most important variables to the ground station where they are stored on another SD card. The Meteodrone Classic and the Meteodrone XL are equipped with an emergency rescue system (ERS) which is a necessity for flying under BVLOS conditions. The ERS can be manually triggered from the ground station.

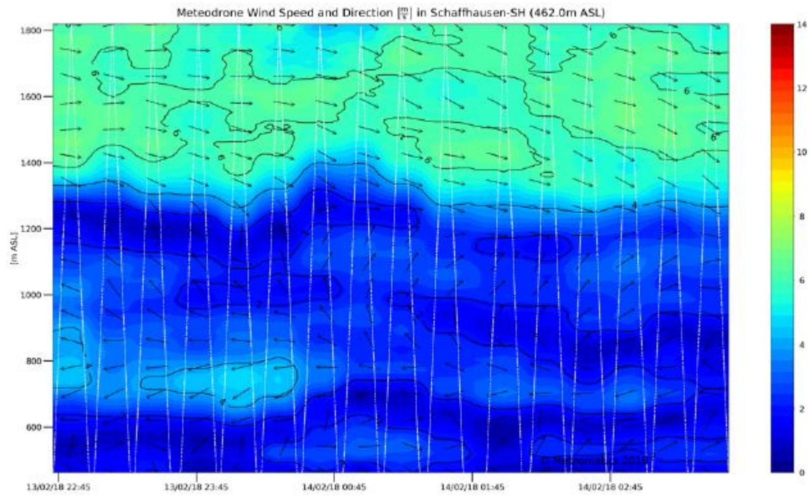
All Meteodrones are pre-programmed to perform vertical ascents/descents with constant climb rates around 3-10 m/s up to an altitude of 3000 m AGL. However, custom flight profiles are possible.

It is strongly recommended to ensure with your aviation safety authority that the aircrafts are considered to be airworthy. Moreover, the air traffic control and the operator must inform other air traffic participants of planned operations, e.g. by issuing NOTAMs, blind calls, restricted airspaces.

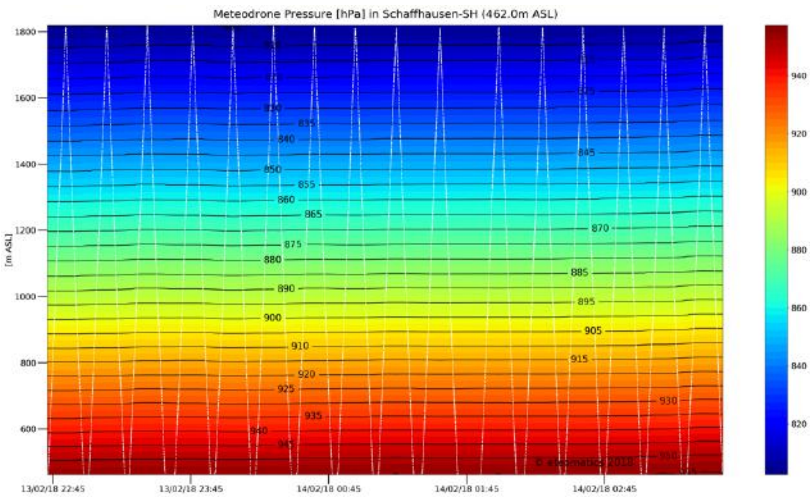
Meteorological Data

The raw meteorological data is sampled with 4 Hz and transmitted to the ground station. In addition, the data is stored on an on-board SD-card. After landing the data can be accessed via Wi-Fi. The raw data is post-processed online. This includes also the transformation into a RAOB format to display soundings. Sequences of flights can be visualized online with charts such as following:

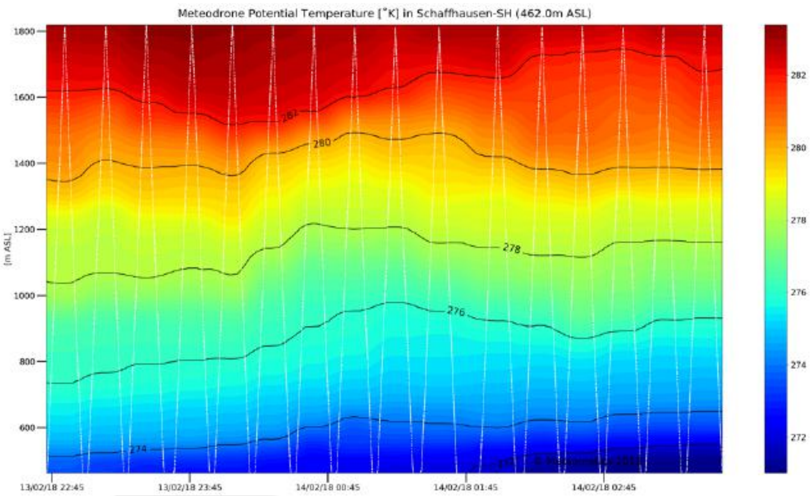
Wind Speed & Direction



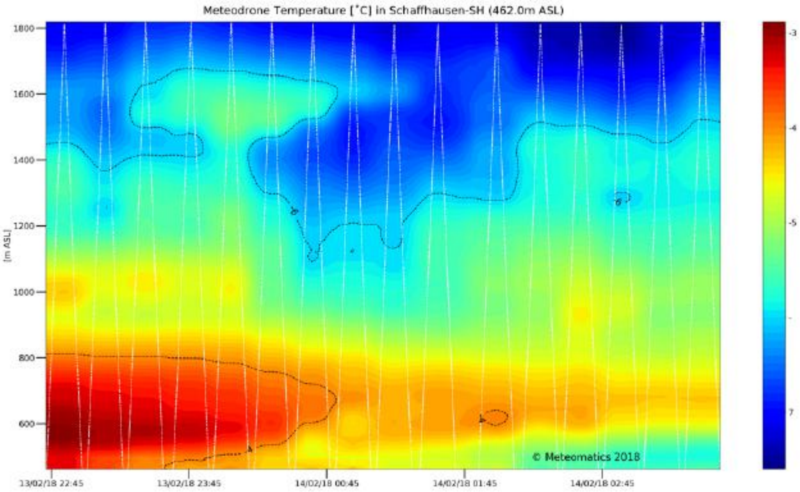
Pressure



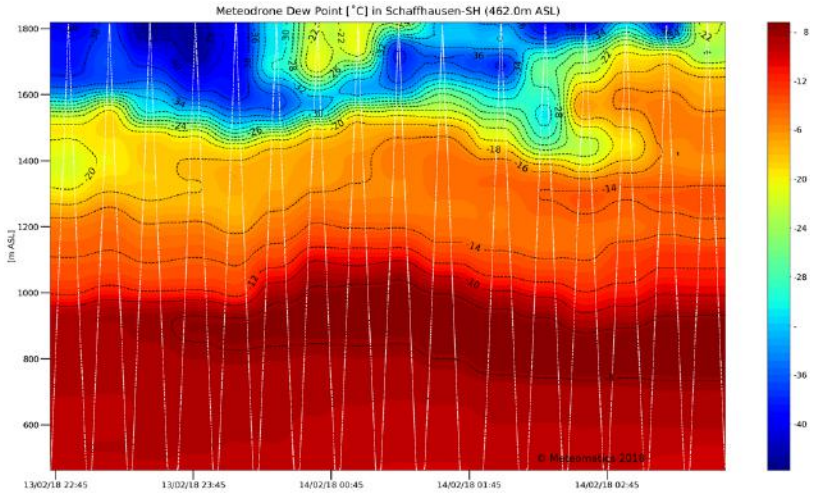
Potential Temperature



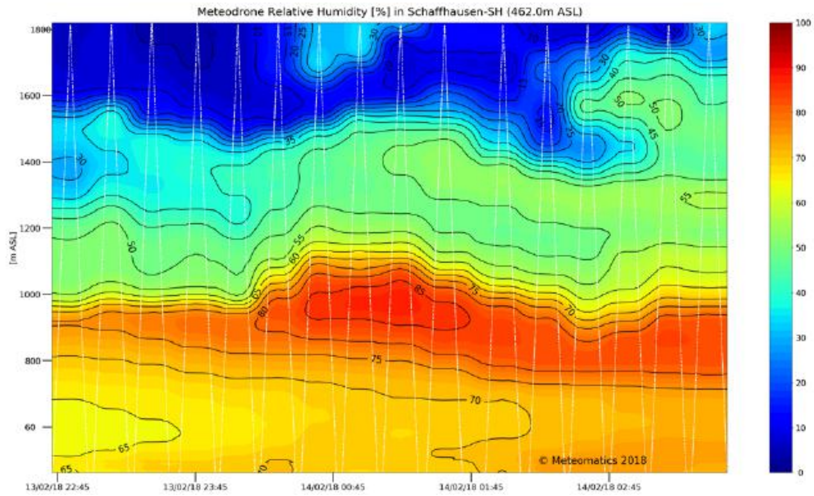
Temperature



Dew Point Temperature



Relative Humidity



Single flights can also be visualized in a skew-T log-P diagram (s. figure 2)

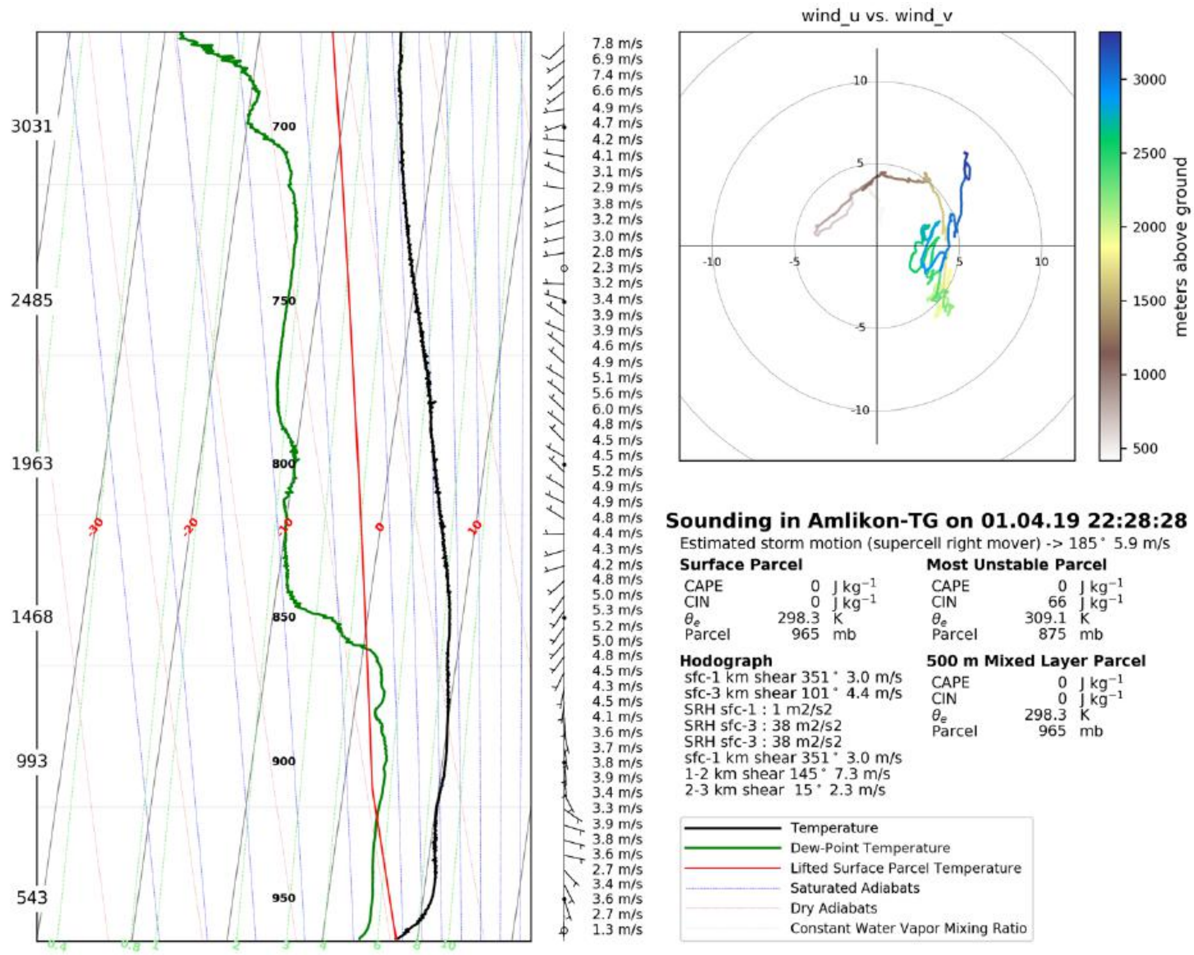


Figure 2: Skew-T log-P diagram including a hodograph

Using UAV data in Numerical Weather Forecasting

Assimilation into WRF

Once the data from the Meteodrone have been acquired, they 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.

In order 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. The Meteodrone data enable the measurement of the actual lapse rate which can then be applied to other regions as well.

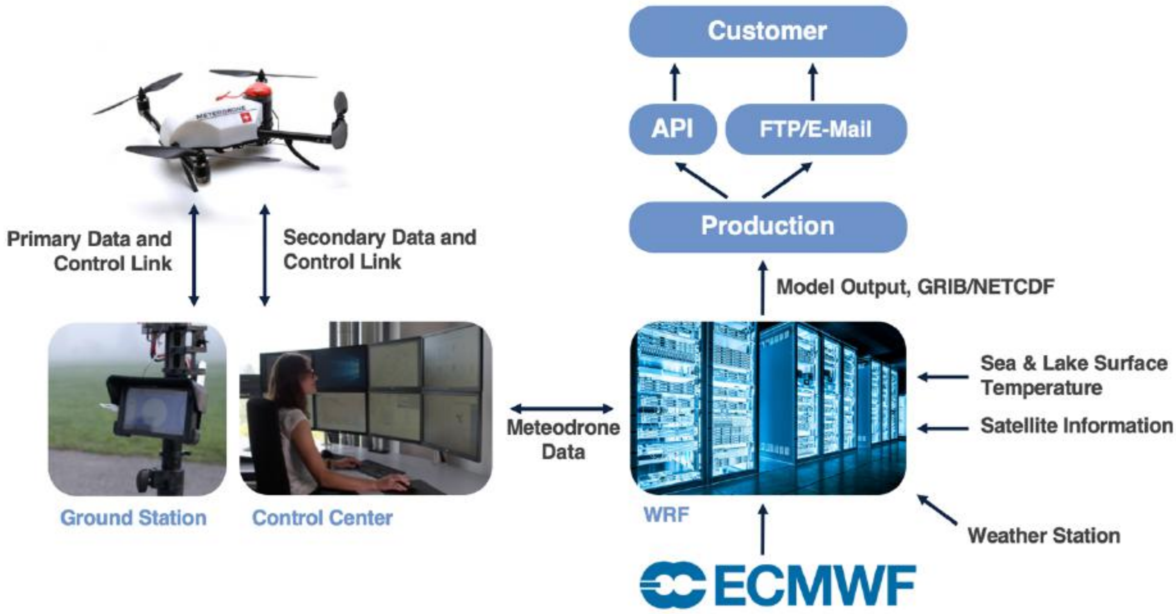


Figure 3: SWISS1k workflow

Case Studies

Fog Formation

The following shows an example comparing the occurrence of early morning fog and low stratus between model runs with and without Meteodrone data being assimilated into the WRF model.

Column a in Fig. 4 shows the satellite cloud cover for 7 AM (upper image) and 8 AM (lower image). The columns b and c in Fig. 4 represent the SWISS1k model forecasts for these two dates. Of special interest here 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 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.

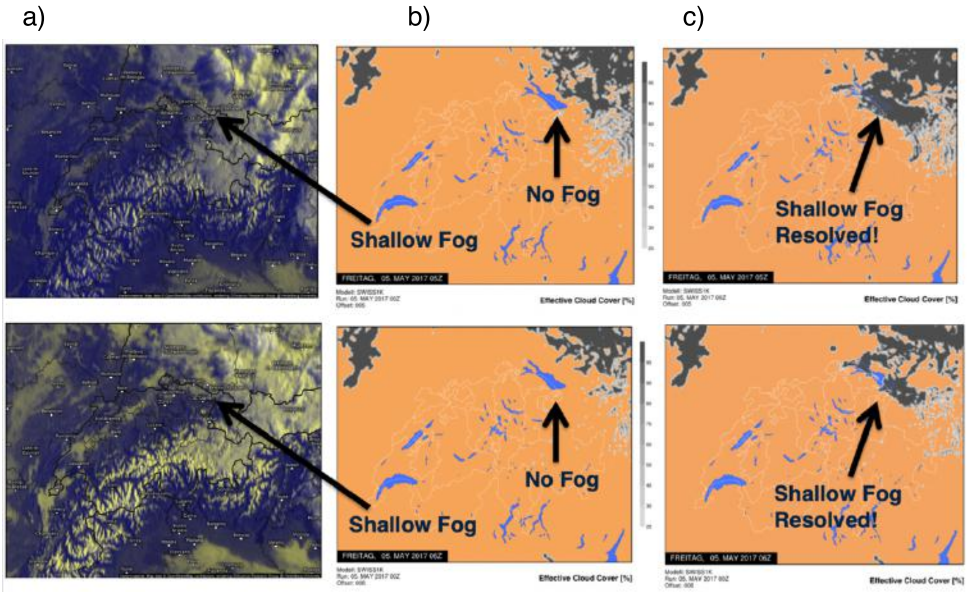


Figure 4: a) Satellite cloud cover during the event, b) SWISS1k forecasts without Meteodrone data, c) SWISS1k forecasts with Meteodrone data

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 May 2017.

The image on the upper left-hand side 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 comparison to the right, 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. The lower left picture shows the radar image data measured at that time.

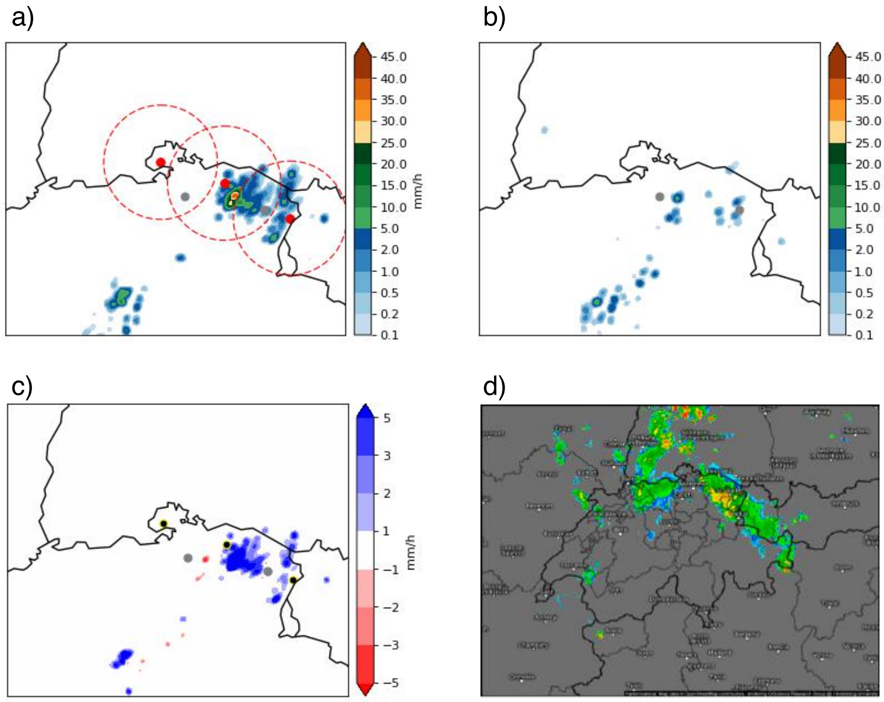


Figure 5: a) Precipitation in the model forecast with Meteodrone, b) Precipitation in the model forecast without Meteodrone, c) Difference between models with and without Meteodrones, d) Radar image of precipitation during the event

Icing Conditions

Icing does not only pose a problem to passenger 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 have to 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).

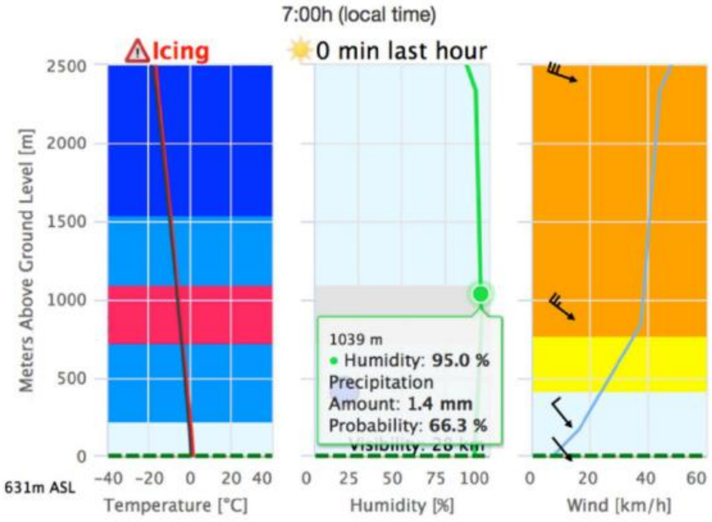


Figure 6: Drone weather by Meteomatics: Vertical profile of temperature, relative humidity and wind

In this project test-flights in real icing-conditions were conducted. Moreover, icing in different environments was tested: 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.

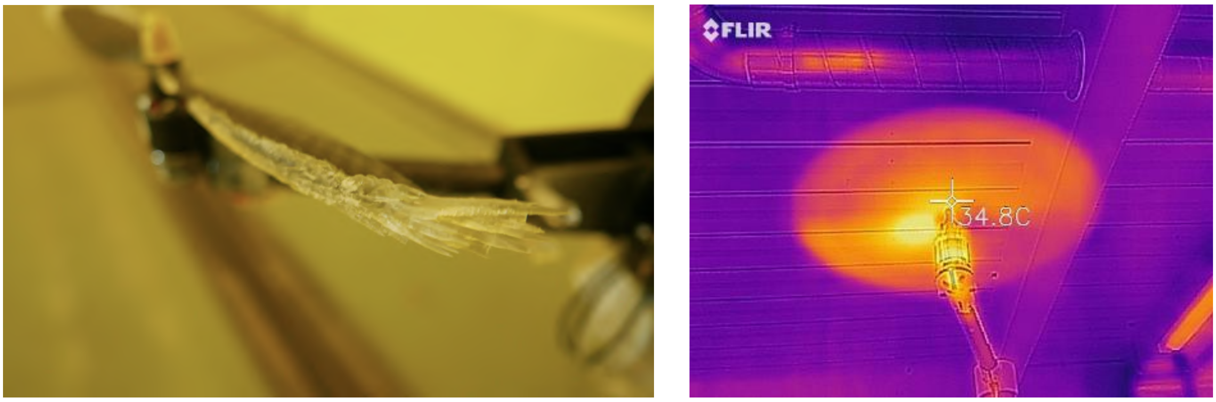


Figure 7: Extreme accumulation of clear ice amount (left) and heating of propellers (right).

Meteobase – a remote platform

An important step towards nationwide drone operations has been the development of the Meteobase. As a ground station, it allows the on-site support of Meteodrones. The ground station serves as a communication element between the 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 ground station site,
- logging of relevant data.

The Meteobase comprises the complete start- 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 (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 time of the operation.

Figure 8: Meteobase deployed at Illgraben.

What is next?

- Targeting altitudes of 5’000 m to 8’000 m AMSL
- Tackling higher operational wind speed
- Internationalization of display units (selectable)
- Provision of additional output formats such as WMO TEMP, WMO TEMP MOBIL, WMO PILOT and others

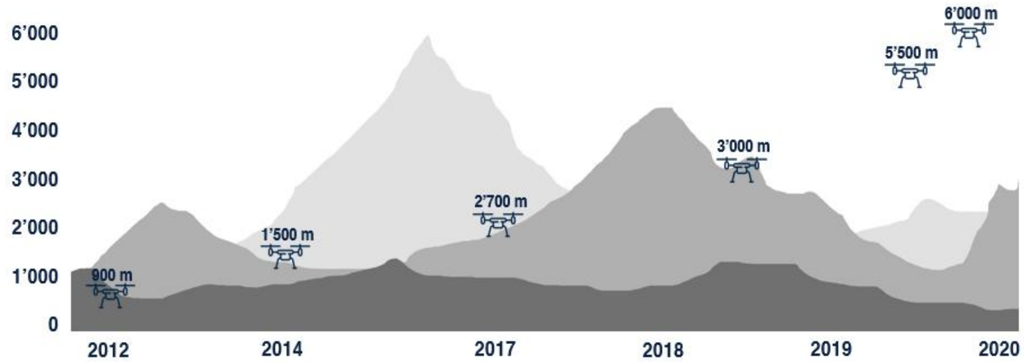


Figure 9: Timeline of flight altitudes of Meteodrones

Company Background

Meteomatics is a leading weather service provider with offices in St. Gallen, Berlin and Exeter 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 simple 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 Switzerland. The great forecast skill of SWISS1k is only possible due to the data received from the unique Meteodrone measurements within the lower atmospheric layers.

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

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