THE 1ST INTERNATIONAL ELECTRONIC CONFERENCE ON FORESTS — FORESTS FOR A BETTER FUTURE: SUSTAINABILITY, INNOVATION, INTERDISCIPLINARITY

Project PROTECT^{FOREST}: Early detection of bark beetle infestation by drone-based monoterpene detection

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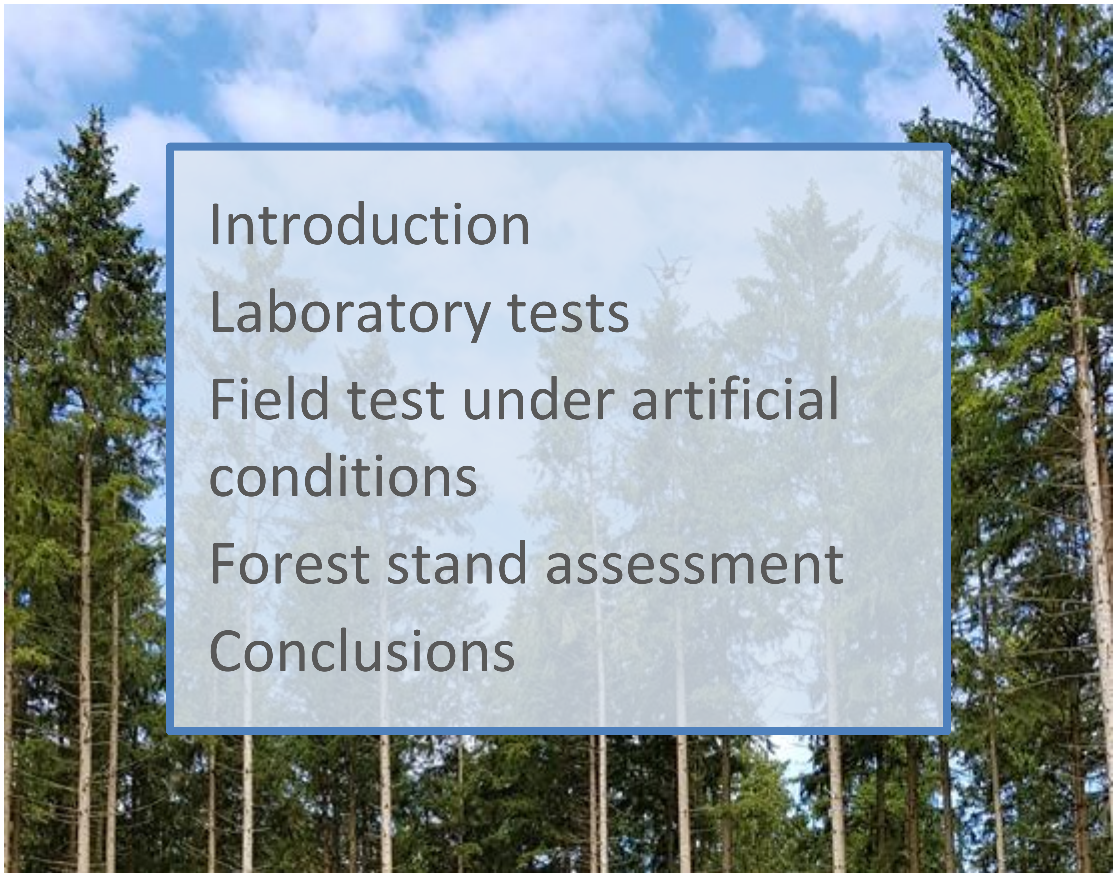
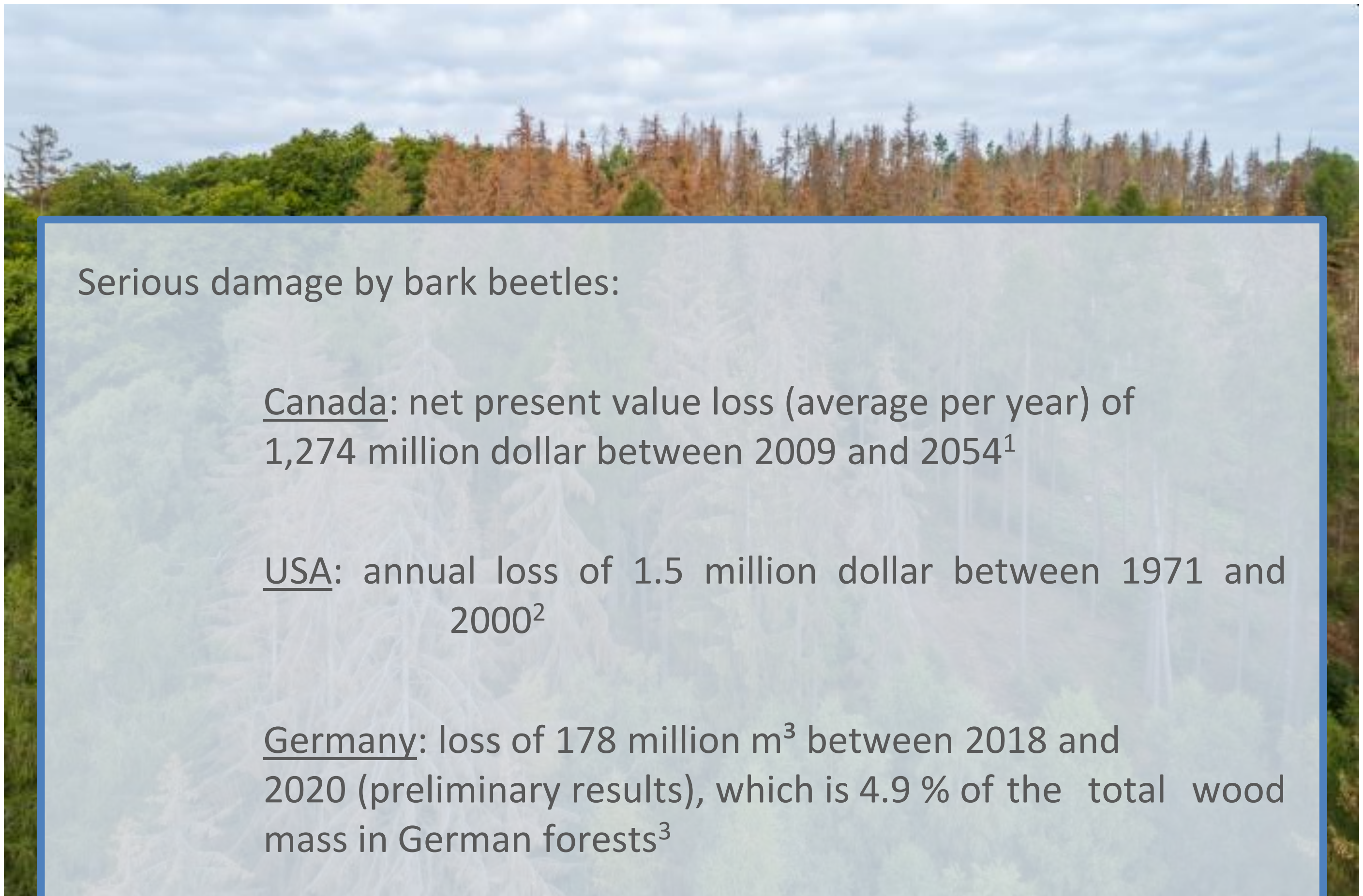
Structure of the presentation



- Introduction
- Laboratory tests
- Field test under artificial conditions
- Forest stand assessment
- Conclusions

Introduction



Serious damage by bark beetles:

Canada: net present value loss (average per year) of 1,274 million dollar between 2009 and 2054[1]

USA: annual loss of 1.5 million dollar between 1971 and 2000[2]

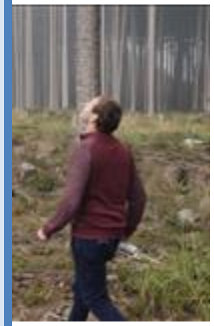
Germany: loss of 178 million m³ between 2018 and 2020 (preliminary results), which is 4.9 % of the total wood mass in German forests[3]

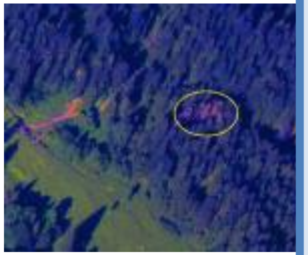
[1]Corbett et al. 2016, Forestry 89 (1), p. 100–105; [2]Dale et al. 2001, BioScience (51), p. 723–734; [3]BMEL 2020, https://www.bmel.de/SharedDocs/Pressemitteilungen/DE/2020/040-waldschaeden.html;jsessionid=E322EBC9C439CDFD426657E41A3E9DC5.internet2851

Introduction

Conventional detection methods are

- Eye-sight detection during stand inspection
  - Trees are hard to detect, depending on branch-density in the middle and lower stem section
  - Walking through the forest can be very hard and slow, depending on the forest floor vegetation and the steepness
- Drone based optical methods
  - based on red crown detection (e.g. RGB or NIR)
  - allow only a late detection (four month to one year[1]) with low detection rate (70-80 %[2])
  - ->bark beetle population did already increase

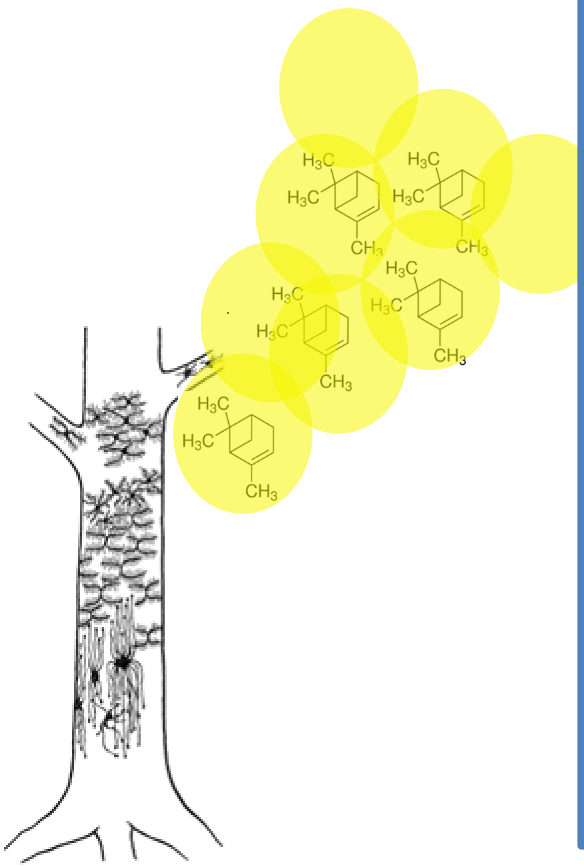




Conclusion: Even the combination of both methods is time and cost intense and does not provide a sufficient detection rate to prevent a population gradation

[1]Immitzer et al. 2019, AFZ-Der Wald 17, p. 20–23; [2]Dale et al. 2001, BioScience (51), p. 723–734; [3]BMEL 2020, https://www.bmel.de/SharedDocs/Pressemitteilungen/DE/2020/040-waldschaeden.html;jsessionid=E322EBC9C439CDFD426657E41A3E9DC5.internet2851

Introduction



Early detection of bark beetle infestation could be possible by using chemical cues:

The bark beetle bores into coniferous trees

The tree defends itself with resin

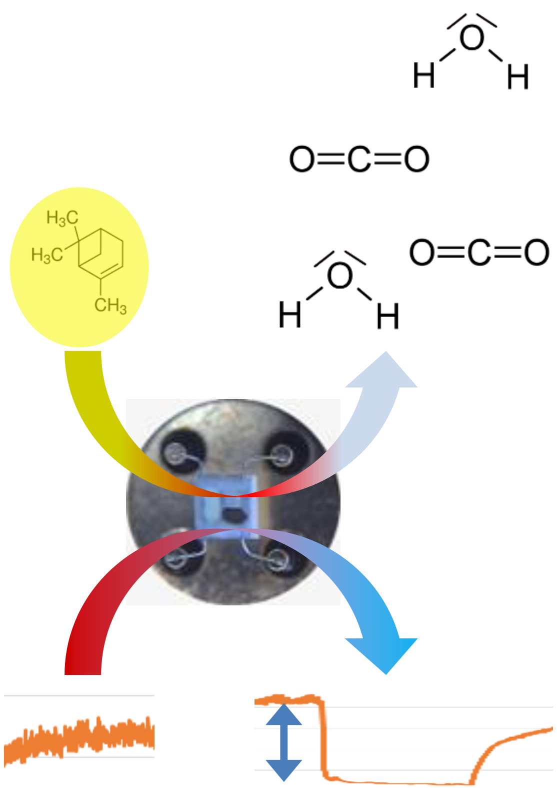
The resin is a composition of monoterpenes and resin acids

Monoterpenes emit[1,2,3,4] and resin acids polymerize to close the bore hole

The monoterpenes are a cue for early infestation in the „green“ stage

[1]Thatcher 1981, The Southern Pine Beetle: United State Department of Agriculture; [2]Giunta et al. 2016, Environmental entomology 45 (4), p. 920–929; [3]Page et al. 2012, Canadian Journal of Forest Research 42 (8), p. 1631–1647; [4]Page et al. 2014, Forest Science 60 (4), p. 691–702

Introduction



Semi conductor metal oxide sensors can detect volatile gases

The heated surface of the sensor oxidizes or reduces VOCs (volatile organic compounds), e.g. monoterpenes

Thereby, the oxygen in the metal oxide also changes the oxidation state

This leads to a change in the band structure of the semi conductor

This leads to a change in conductivity

Therefore, a voltage over the sensor surface changes in the presence of VOCs[1,2,3]

[1]Kohl et al. 2001, Sensors and Actuators B: Chemical, 1-3, p. 43-50; [2]Paczkowski et al. 2013, Sensors and Actuators B: Chemical, 183, p. 273–282); [3]Paczkowski et al. 2012, International Journal of Wildfire Management, 28, p. 167–175

Laboratory Tests

Material and Methods

Sensor calibration method

A defined concentration of α-pinene (main monoterpen of european conifers) was mixed by using two air flows

The concentration was led over the sensor surface (sensor array with three sensors) for three minutes

The sensor chamber was purged with synthetic air for three minutes

Sensor test

The sensor was placed in front of a wind tunnel

α-Pinene was placed in a petri dish in front of the wind tunnel exit

Room temperature (15 °C, 20 °C, 25 °C), α-pinene amount (0.1 ml, 0.5 ml), distance between sensor and wind tunnel (1.5 m, 3 m) and wind flow (1 m × s-1, 2 m × s-1) were combined to 32 set up combinations

The sensor values of each set up were related to each other in order to compare the results independend from the deviating base lines

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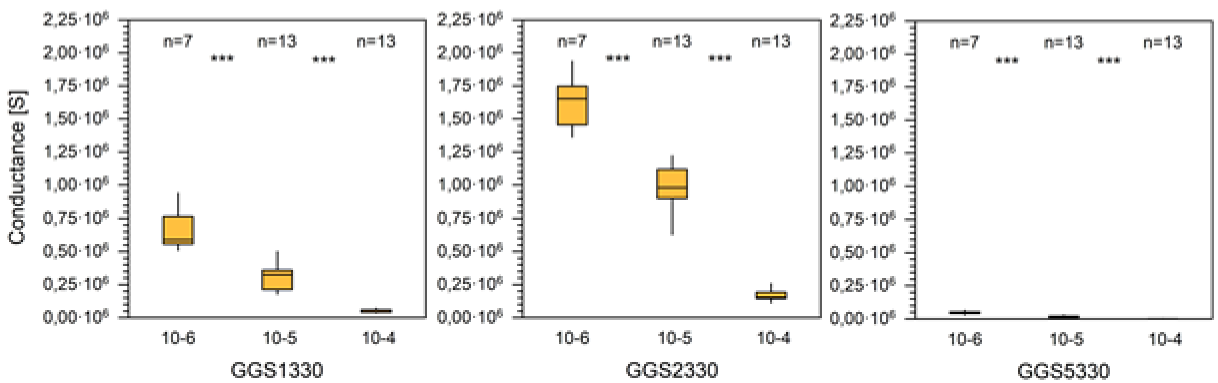
Laboratory Tests

Results

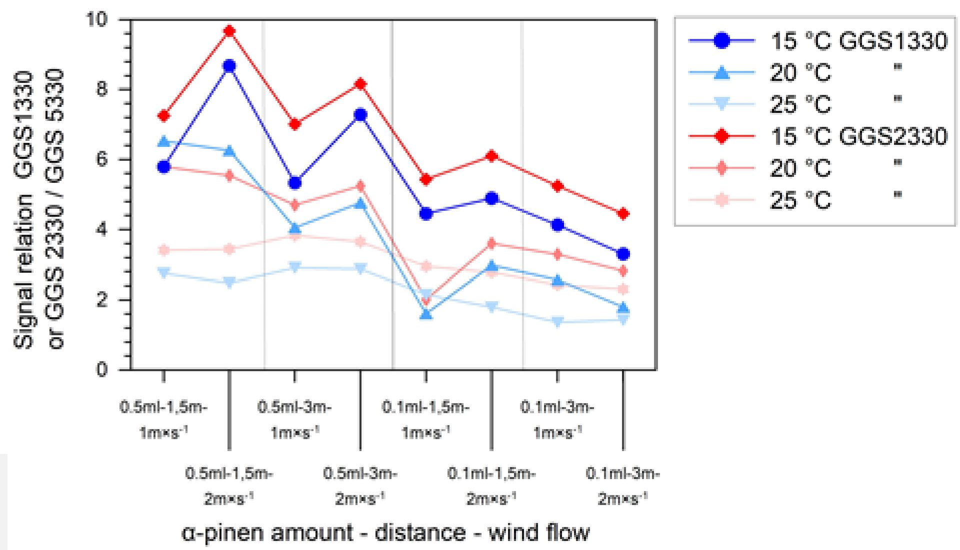
Sensor calibration method



- Linear relation between concentrations (conductance value decreases with increasing concentration)
- Relatively low variation
- Significant differences between concentrations

Sensor test

- Significant impact of temperature and α-pinene amount
- No explanatory impact of distance and wind flow



Field test under artificial conditions

Material and Methods

A pole (4 m) was set up on a field at the forest botanical garden at the Georg-August University Göttingen on March 17, 2020

The weather was sunny with 15 °C and the wind was below 1 m × s-1

A tissue paper was drenched with app. 10 ml α-pinene and fixed on the top of the pole

The sensor was mounted on a drone and connected to the drones GPS to merge sensor data and position of the sensor signal

A pump sucked the air through a capillary that was mounted to the drone in order to be able to sample the air outside the rotor down winds

The drone was maneuvered in straight lines across the field

The resulting data was processed to a heat map

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Field test under artificial conditions

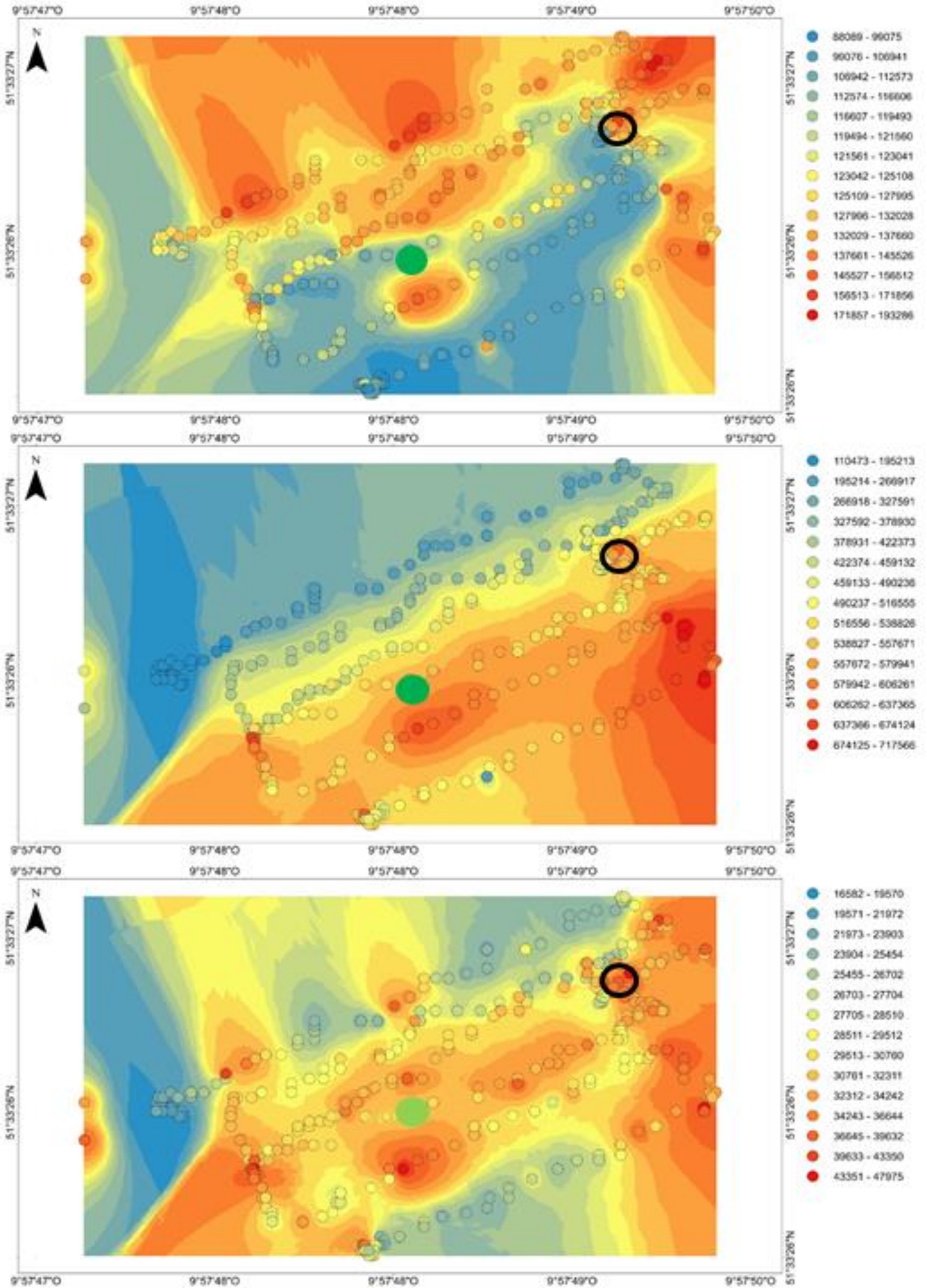
Results

All three sensors in the sensor array responded to the α-pinene source (red area close to the green dot in the middle of the map)

Only using all three sensors allowed to locate the α-pinene source

prunus domestica

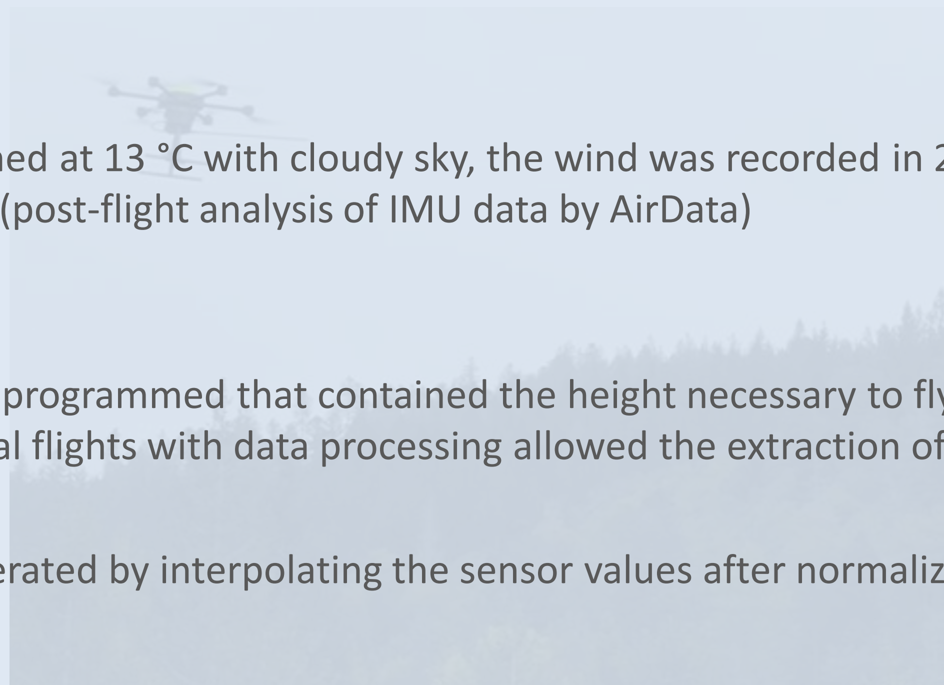
A tree led to a sensor response, as well (small red dot inside the black circle)



Forest stand assessment

Material and Methods

A spruce stand with 40 × 40 m at the Windgfällweiher close to Lenzkirch, Baden Württemberg, Germany, was selected for the field test



The test was performed at 13 °C with cloudy sky, the wind was recorded in 27 m height by a DJI Mavic 2 zoom drone (post-flight analysis of IMU data by AirData)

100 Waypoints were programmed that contained the height necessary to fly 10 m above the stand. Previous multispectral flights with data processing allowed the extraction of the canopy heights

A heat map was generated by interpolating the sensor values after normalization and standardization

All of the trees were checked for beetle infestation and the data was merged in the heat map

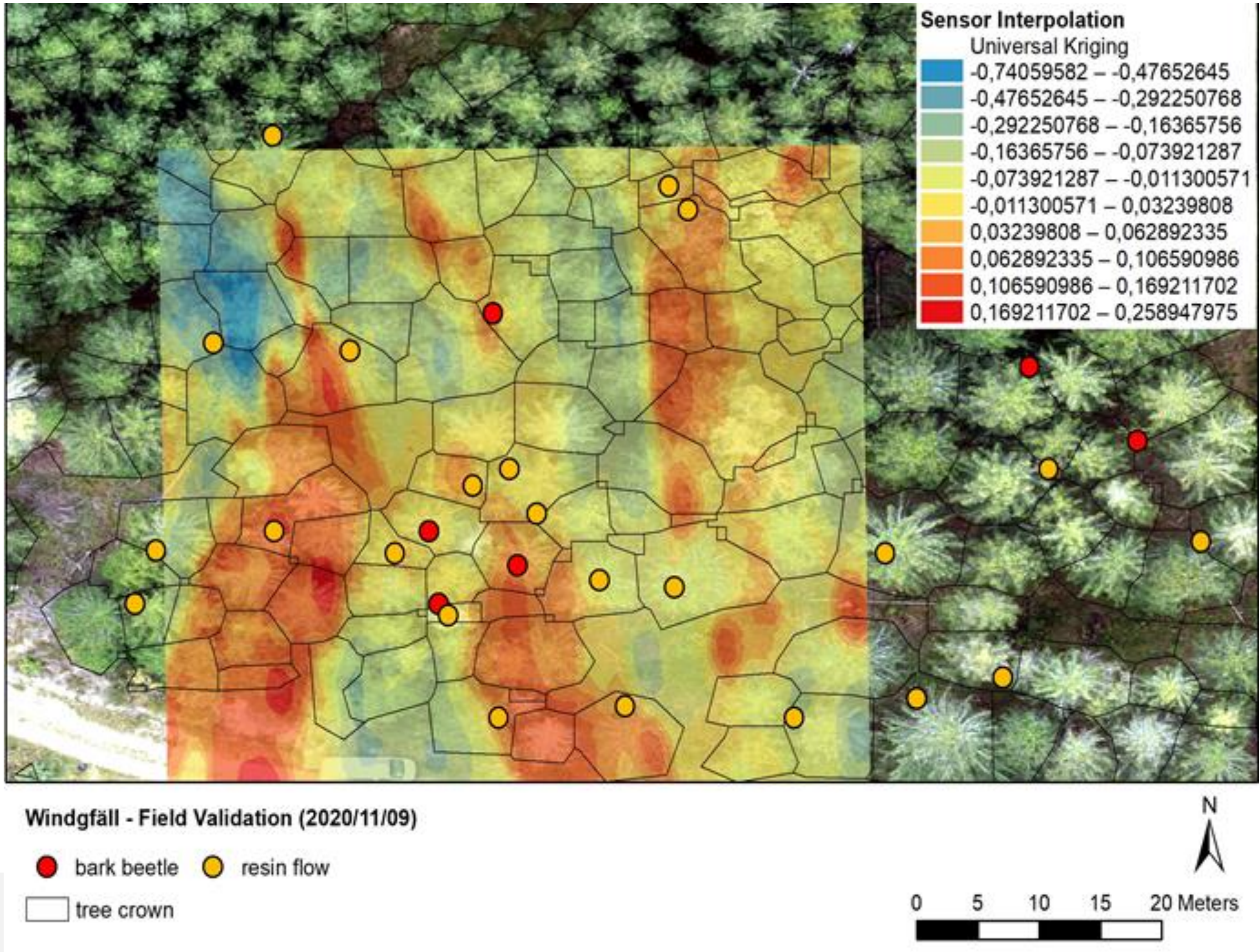
Forest stand assessment

Results

The sensor value interpolation did not allow a localization of the potentially infested trees (red = high VOC concentration)

The wind blew with a mean speed of 4.5 m × s^{-1}

Due to technical restrictions the flight heigth above the canopy varied between 5 and 15 m



Conclusions

The sensor array is able to detect α-pinene and can differentiate between different concentrations

Temperature and α-pinene amount were the main influence factors in a lab test, while different low wind flows and different short distances had no explanatory impact on the results

The drone mounted sensor was able to detect an atificial α-pinene source in 4 m height and showed a much lower response to a prunus tree. It can be concluded that monoterpenes are detected, but a differenciation of different sources is not possible. The sensor array relies on a situation were the only source of α-pinene are infested trees, otherwise false positive identifications are unavoidable

The forest stand assessment was conducted under very unfavorable conditions concerning wind speed, time of the year, temperature and distance to the canopy. The experiments have to be repeated in spring/summer 2021 after improving the drone technology in order to enable the proof of principle test

Thank you very much for your attention !