Engaging schools to explore meteorological observational gaps

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ABSTRACT

Today, the vast majority of meteorological data are collected in open, rural environments to comply with the standards set by the World Meteorological Organization. However, these traditional networks lack local information that would be of immense value, for example, for studying urban microclimate, evaluating climate adaptation measures, or improving high-resolution numerical weather predictions. Therefore an urgent need exists for reliable meteorological data in other environments (e.g. cities, lakes, forests) to complement these conventional networks. At present, however, high-accuracy initiatives tend to be limited in space and/or time as a result of the substantial budgetary requirements faced by research teams and operational services. We present a novel approach for addressing the existing observational gaps based on an intense collaboration with high schools. This methodology resulted in the establishment of a region-wide climate monitoring network of 59 accurate weather stations in a wide variety of locations across northern Belgium. The project is also of large societal relevance as it bridges the gap between the youth and atmospheric science. To guarantee a sustainable and mutually valuable collaboration, the schools and their students are involved at all stages, ranging from proposing measurement locations, building the weather stations, and even data analysis. We illustrate how the approach received an overwhelming enthusiasm from high schools and students and resulted in a high-accuracy monitoring network with unique locations offering novel insights.

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Introduction

Globally, most regions consist of a complex patchwork of various land use and land cover types with different microclimates. Despite this broad diversity, the overwhelming majority of reliable weather stations are placed in open, rural land types representative of their large-scale environment and thus devoid of any local environmental influence. However, there is a growing need for trustworthy meteorological information characterizing the large diversity of land types. For example, as the world is urbanizing at a high rate and cities are projected to house up to 62.5% of the world population by 2035 (UN-Habitat 2020), urbanized regions increasingly draw the attention of the atmospheric science community. Due to the physical properties of the urban landscape (e.g. materials, form,...) and human activities, the urban climate can differ significantly from that of surrounding rural regions. The best-known illustration is the urban heat island (UHI) phenomenon (Oke 1967) that impacts for example human health (Heaviside et al. 2017) and building energy consumption (Magli et al. 2014). Accurate observations within cities are therefore important to inform urban planners on how to implement climate adaptation measures. A lack of reliable observations is equally found in other land use and land cover environments e.g. in forests as advocated by De Frenne and Verheyen (2016). Weather forecasts would benefit from meteorological measurements in non-traditional locations (e.g., Nipen et al. 2020). During the previous decades numerical weather prediction underwent a 'quiet revolution' as it was called by Bauer (2015). The growth in available computing power has been fueling a gradual increase in the spatial resolution and complexity of the models with increasingly detailed descriptions of the land-atmosphere interactions (e.g., Masson et al. 2013). Such models, currently operationally used at kilometric resolutions, are able to better capture the impact of the land on the atmosphere. The evaluation as well as data assimilation algorithms of high-resolution atmospheric model

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runs might benefit from observations in non-traditional locations.

As described by Muller et al. (2013), operating an observational network is complex, time-consuming, and expensive. Measuring in non-traditional locations makes the task even more cumbersome as it is particularly challenging, both from a practical and organizational point of view, to arrange scientifically-sound, vandalism-proof locations in for instance a city, lake, or nature reserve. Here we report on the VLINDER (Vlaanderen IN DE weeR) project, a successful elaboration of a new strategy for establishing such a network through a close collaboration with schools. Its measurement locations cover a wide range of land types as illustrated by the overview map depicted in Fig. 1. It does not replace but complements traditional and crowdsourced networks. This school-based strategy leads to a region-wide high-accuracy network with detailed metadata in very diverse locations making it, for instance, a valuable reference network for the quality control of crowdsourced data.

Engaging schools to address the need for local weather information

a. Building the VLINDER network together with schools

The weather has always been an appealing subject for the youth and concerns about climate change makes their interest even bigger. Studying the weather together with schools is not a revolutionary idea. For instance, in 1992 the School Weather Network was established (Gonski 1992) and provided meteorological sensors for 57 schools in North-Carolina by bringing together the National Weather Service (NWS), schools, and industry. The resulting data were regularly used in the weather broadcast on television channels. Similar initiatives have been started all over the world such as the GLOBE program (Finarelli 1998; https://www.globe.gov/), the Vancouver Island School-based Weather Station Network

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in Canada (http://www.islandweather.ca/), the Trans-African Hydro-Meteorological Observatory initiative creating a dense measurement network over the African continent (van de Giesen et al. 2014), and the Schools Weather and Air Quality network in Sydney (https://www.swaq.org.au).

Besides the ambition to familiarize young people with atmospheric science through hands-on experience, the VLINDER project aims at answering the researchers' present-day needs for non-traditional meteorological observations. Therefore one crucial innovation of the project forms the scientifically-based selection of station locations. In other words, the weather is measured with schools, but not necessarily at school.

To operate the observational network, a strong and mutually enriching collaboration with the schools is essential. Therefore, we pursue maximal involvement of the schools at all stages of the project as summarized in Table 1. First, we launched a call in the national media, challenging schools to search for interesting locations in very diverse environments, mostly not on their school terrain. The overwhelming response resulted in 450 location proposals from 160 high schools. Their knowledge of the local surroundings may explain the high quality of most proposals. An analysis based on high-resolution land use and land cover datasets led to the assignment of the 59 weather stations available for the project. The measurement locations were selected to maximize the geographical spread and the diversity in environments while minimizing the risk of vandalism. Next, the teachers of the selected schools have been invited for small group sessions in which they were informed about the scientific goals of the project, how to build a weather station, and about the possibilities to integrate the measurements in the science curriculum of the students. At the end of these sessions all components of the weather stations (solar panel, sensors, battery, frame, ...) were

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handed out so that the teachers could build and install the weather station together with their students (Fig. 2). These sessions turned out to be very valuable, not only because the hands-on demo avoided many technical problems while building the weather stations at the schools, but also because the personal contact strongly increased the engagement of the teachers for the project. On the 1st of December 2019, only ten months after launching the call to schools, the network became operational.

b. Specifications of the VLINDER network

The 59 weather stations of the VLINDER network are located in northern Belgium (Fig. 1), a region which is densely populated with Brussels being the largest agglomeration counting about 1.7 million inhabitants. The study region has a nearly flat topography, with only one weather station situated above 100 m altitude. This region is characterized by a temperate maritime climate influenced by the North Sea and Atlantic Ocean resulting in an average maximal and minimal temperature of 5.7 °C and 0.7 °C in January, and 23 °C and 14 °C respectively in July (statistics for the official Uccle station nearby Brussels).

The weather stations use a Davis Vantage Pro 2 unit to measure (passively ventilated) temperature, wind, relative humidity, and precipitation. As some weather stations are installed at remote locations, such as forests and lakes, the stations are powered by a solar panel (240 Wp) charging a battery with a capacity of 206 Wh. The solar panel is mounted under an angle of 50º to maximize the output during the winter season when the cold, short days challenge the power supply. Observations are communicated towards a university server at a frequency of 5 minutes. To guarantee low-power data communication at remote locations the Narrowband Internet-of-Things data communication network is used. All measurements can be consulted in realtime via the existing Weather Observations Website platform (https://wow.meteo.be/) or the dashboard developed for this project

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(https://vlinder.ugent.be/dashboard). The latter one also includes maps and diagrams to visualize the land use and land cover around each weather station such that visitors can interpret the data. All data are open and freely available and an application programming interface (API) is developed to simplify data extraction (https://app.swaggerhub.com/apis-docs/bmesuere/VLINDER/1.0). There is currently no automated quality control but by the choice of the sensors, 'human' quality control, and close contact with local partners we aim at obtaining reliable measurements. The reliability of the data obviously depends on the parameter and the siting as, for example, precipitation measurements in a forest are not representative. The investment cost to initiate this network was covered by a grant from the regional administration to support citizen science such that the initiative was free for the participating schools.

Illustration of the added value of the network: interaction of sea breeze and the urban heat island

During the first half of August 2020 Belgium experienced an intense 12-day heatwave. Fig. 3 (a) presents the minimal temperatures registered by the VLINDER weather stations on the 6th of August 2020, the second day of the heatwave. The UHI is clearly illustrated by the network with the urbanized regions displaying minimal temperatures up to 8 °C higher than nearby rural or forested environments. The highest diurnal minimal values are found in the three largest agglomerations of Brussels, Antwerp, and Ghent. Nevertheless, the UHI phenomenon is also found in mid-sized cities or even small towns. Depicting the same minimal temperatures in a scatter plot in a land cover triangle (Fig. 3 (b)) reveals that large water bodies also have a warming effect on the nocturnal temperatures. This agrees with earlier studies (e.g., Steeneveld et al. (2014)) and illustrates the downside of water bodies in urban regions as a measure against heat stress.

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Fig. 3 (c) presents the temperature evolution for five weather stations, indicated on the map of Fig. 3 (a), on this heatwave day. The selected weather stations include a location in the center of Brussels (station 5) and one at a rural location (station 4) northwest of the agglomeration. Daytime temperature differences between both locations remain limited with station 5 registering even slightly lower temperatures due to the abundant shading by high-rise buildings. However, after sunset a significant difference in the cooling rate is found resulting in a temperature difference of up to 8 °C. In Fig. 3 (c) the short temperature peak around 22 UT forms a striking detail in the otherwise gradually decreasing temperature evolution at station 4. This brief interruption in cooling is explained by the passage of the sea breeze front over the Brussels region roughly 100 km inland (Hamdi et al., 2012). Thanks to the regional scale of the VLINDER network, the slow inland propagation of the sea breeze front can be tracked. The coastal measurement station 1 shows the initiation of a sea breeze around 13 UT. Its slow inland propagation is characterized by sharp temperature drops as noticed at e.g. station 2. After sunset, the sea breeze front results in a short temperature increase (see stations 3 and 4) instead of a decrease as the corresponding increase in wind creates temporally extra mixing. In the urban agglomerations (e.g., station 5) we cannot find this sea breeze fingerprint in the nocturnal temperature evolution.

This example illustrates the potential of a regional monitoring network sampling very diverse landscapes.

Outlook and conclusion

This project can be categorized as a citizen science initiative tailored towards high schools. Citizen science projects are gaining popularity with some very successful examples, yet at the same time there are important challenges as described by Irwin (2018). The key

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challenge for the VLINDER project is undoubtedly to preserve the enthusiasm and find the resources to obtain a long-term reliable measurement network. We are convinced that the strong local anchoring of the project can provide the answer. Owing to their strong involvement and sense of ownership, the high schools act as local ambassadors of the project. As the students and teachers built the weather stations, they know the technical set-up and are therefore skilled partners that play an important role in solving problems and this reduces the operational cost. Together with the schools, we managed to set up a consortium of stakeholders (including cities, companies, nature reserves,...) who are interested in the data and prepared to financially support the project to cover operational costs (e.g. data communication, spare components,...). This strategy further strengthens the local anchoring of the project and creates a unique consortium of local administrations, industry, schools, and scientists which opens new opportunities for collaboration, for example on climate services or smart city applications.

The VLINDER project demonstrates how a close collaboration with schools offers scientists opportunities for obtaining reliable weather measurements that are otherwise unattainable. At the same time, the project contributes to the young generation's scientific knowledge of weather and climate. We hope that our positive experience can encourage colleagues to explore collaborations with schools for future research.

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online dashboard (www.vlinder.ugent.be/dashboard). We are grateful for the remarks and suggestions of the reviewers.

FOR FURTHER READING

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TABLES

Table 1 Overview of the methodology of the VLINDER project. Each of these stages takes around 2 months.

	Stages of the VLINDER project	**researchers**	**teachers**	**students**
1	Call to high schools to propose locations for weather stations	✓	✓	✓
2	Scientists select the best locations	✓		
3	Teachers of selected schools are invited for group sessions	✓	✓	
4	Students build and install the weather stations		✓	✓
5	Network operational, data used by scientists and students, educative material online	✓	✓	✓

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FIGURES

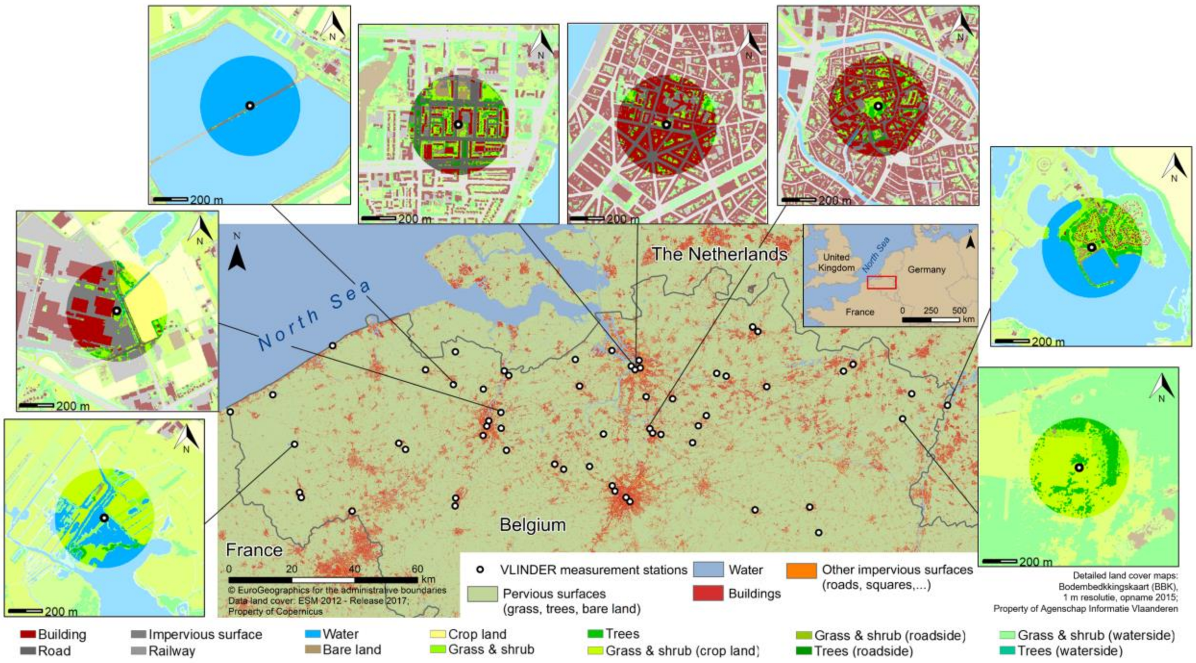

Fig. 1 An overview of the VLINDER network. The detailed land cover of 8 locations is shown in 1.2 km by 1.2 km submaps to illustrate the diversity of the environments. The detailed land cover information for all locations can be consulted on the VLINDER dashboard (https://vlinder.ugent.be/dashboard/).

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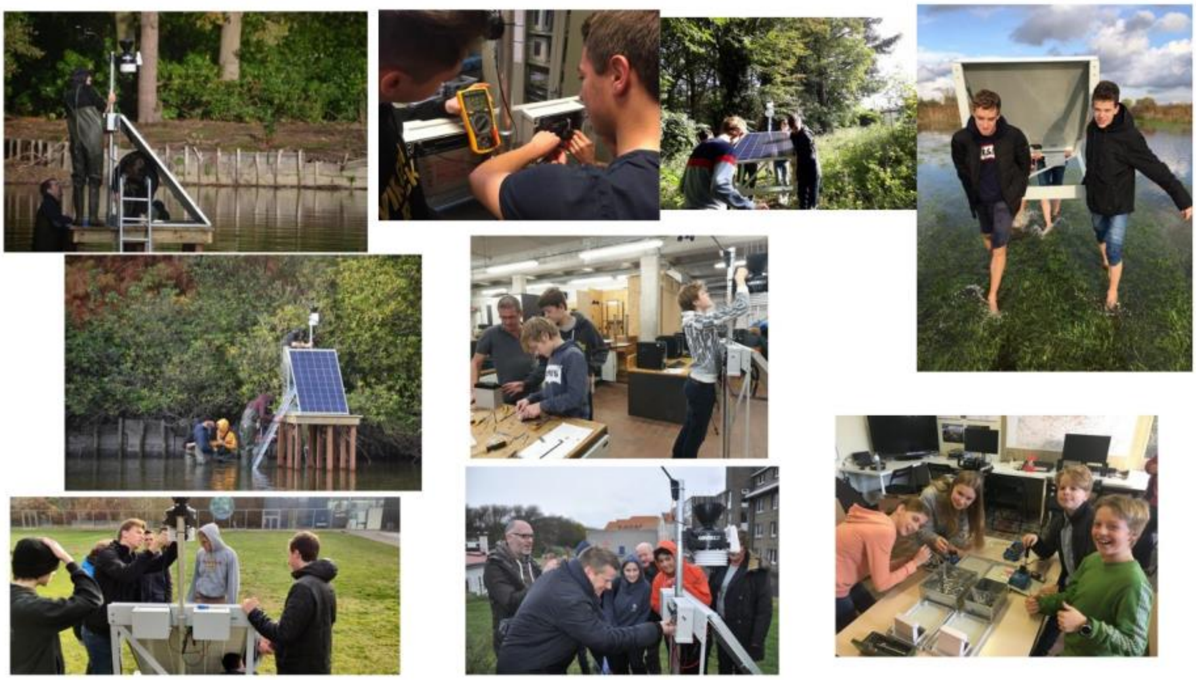

Fig. 2 Pictures of high school students building and installing the weather stations.

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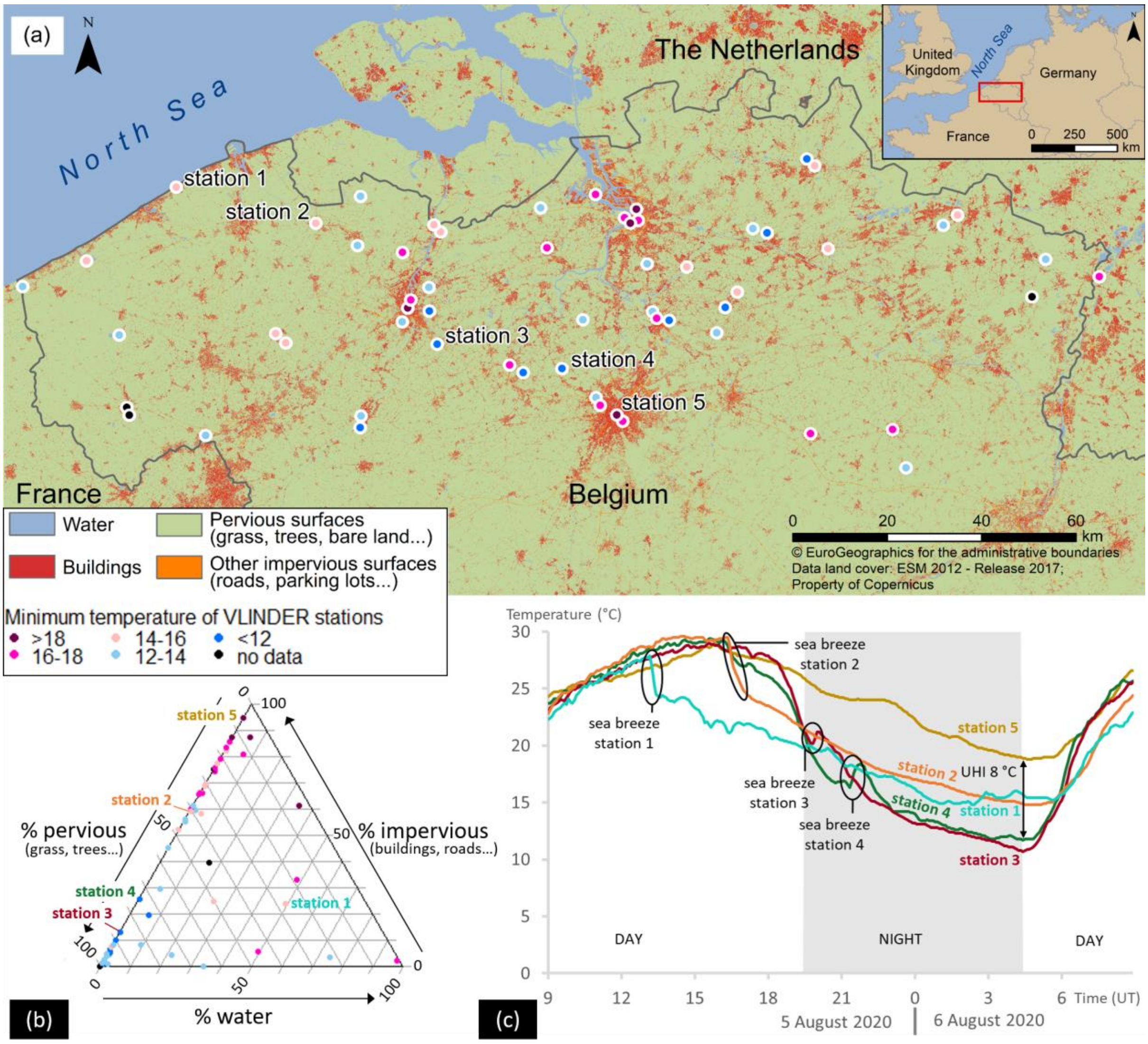

Fig. 3 Minimal temperatures on 06/08/20 registered by the VLINDER network (a). Scatter plot to illustrate impact of land cover (calculated based on a 300 m radius around the locations) on minimal temperatures (b). Depending on the regional siting and local environment of the weather station, the inward progression of the sea breeze causes a different behaviour in the temperature evolution at five VLINDER locations (c).

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