Virtual weather data for apple scab monitoring and management

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Degree project • 30 hec
Swedish University of Agricultural Sciences, SLU
Hortonomprogrammet/Horticultural Science
Alnarp 2021

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Virtuell väderdata för bevakning och behandling av äppleskorv

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Credits:	30 hec
Level:	Second cycle, A2E
Course title:	Independent project in Horticultural Science, A2E
Course code:	EX0857
Programme/education:	Horticultural Science Programme

Place of publication:	Alnarp
Year of publication:	2021
Cover picture:	Philip Zandelin

Keywords: Apple scab, virtual weather stations, grid-data, decision support system, RIMpro, integrated pest management, leaf wetness

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Acknowledgements

This master thesis would not have been possible without the generosity of Marc Trapman, programming an interface in decision support system RIMpro which allowed me to evaluate virtual weather data for apple scab monitoring.

I would also like to the Swedish board of agriculture and especially Sanja Manduric, for presenting the idea and letting me do it with the help of their resources. Sanja also acted as a valuable sounding board throughout the project.

Thanks to Jan-Eric Englund at the Swedish university of agricultural sciences for helping me with the statistics, constantly thinking of possible ways to look at the data.

Last, but not least, thanks to my supervisor Peter Witzgall. A voice of reason, helping me keep things structured and staying within the boundaries of the project. I mainly wanted support in the writing process, which was exactly what I got.

Abstract

Decision support systems can be used to monitor disease development of apple scab. Decision support systems require weather data to function, which in Sweden is currently provided by conventional weather stations. Conventional weather stations supply reliable weather data if correctly installed and maintained but are costly and require continuous error-checking. Virtual weather data is becoming an increasingly popular option, where the data is calculated based on a combination of observations from local weather stations and weather radar and satellites. In this study, virtual weather data was compared with physical weather stations for apple scab monitoring, to evaluate the suitability of virtual data as a replacement for conventional weather stations. This was done by evaluating differences in predicted apple scab infections using the apple scab model in the decision support system RIMpro for the 2019 and 2020 seasons. Virtual weather data lacks the leaf wetness parameter, which had to be calculated based on other weather parameters. Thus, the use of leaf wetness calculations as an alternative to leaf wetness sensors was investigated.

The study showed that virtual weather data correctly predicted the number and severity of infections, similar to conventional weather stations, with some margin of error especially for low category infections. This indicates that virtual weather data could be a suitable replacement for physical weather stations. With respect to the discrepancies seen in infection severity, few were due to a difference in leaf wetness, demonstrating that leaf wetness calculations may indeed be a suitable option for replacing leaf wetness sensors. This study was carried out after the 2020 apple scab season ended; thus, some crucial aspects were not accounted for, such as checking for errors from the weather stations during the seasons studied. Before implementation of virtual data can take place in Sweden, the virtual data should be evaluated during the growing season.

Keywords: Apple scab, virtual weather stations, grid-data, decision support system, RIMpro, integrated pest management, leaf wetness

Popular scientific summary

Consumers and retailers want undamaged apples. Therefore, apples found in stores are free of apple scab. The reason for this is that apple growers direct a lot of attention at preventing this fungal disease from growing on the apples.

The development of the disease is impacted by multiple factors, where the main ones are rain, temperature, and leaf wetness. To monitor the development of disease, decision support systems have been developed. Data from meteorological weather services and local weather stations are sent to the decision support systems which model the disease development. For apple scab in Sweden, the decision support system RIMpro is used. RIMpro helps growers identify which rain events could potentially lead to disease development, and aids growers in decision making around fungicide spraying.

The weather stations used in the orchards supply reliable weather data if correctly installed and properly maintained. However, as they have a limited lifetime, require both weekly and yearly maintenance to be reliable, and are costly to purchase, another option has started to gain popularity, namely virtual weather stations. In Sweden, there is a virtual weather station every 2.5x2.5 km. The weather data for each virtual weather station is calculated based on both observations from local weather stations and weather radar and satellites. Getting weather data from these virtual weather stations instead of physical weather stations in apple orchards would be less costly and include less work for growers since no maintenance would be required. The question asked in this study was if virtual weather stations in southern Sweden can act as a sufficient replacement for physical weather stations in orchards for modelling apple scab.

The results show that virtual weather stations may become a viable option to in-orchard weather stations. Since multiple fungicide sprayings are usually carried out every season to prevent apple scab, further confirmation is needed to make sure virtual weather stations supply reliable weather data.

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Abbreviations

AROME	Applications of Research to Operations at Mesoscale
DSS	Decision Support System
IPM	Integrated Pest Management
LWD	Leaf Wetness Duration
MESAN	Mesoscale Analysis
PAD	Potential Ascospore Dose
RIM	Relative Infection Measure
RIMpro	Relative Infection Measure program
SJV	The Swedish Board of Agriculture
SLU	Swedish University of Agricultural Sciences
SMHI	Swedish Meteorological and Hydrological Institute
VPD	Vapour Pressure Deficit

1. Introduction

1.1. Apple scab

Apple scab, caused by the fungus *Venturia inaequalis* (Cke.) Wint. (anamorph *Spilocea pomi* Fr.) is globally the most important disease affecting apples when measured by economic loss, the amount of fungicides needed to control scab and effort spent by growers to monitor infestations and to time treatments (MacHardy 1996). Apple scab occurs in all apple growing areas and is especially destructive where spring weather is mild and wet. Commercial apple production largely depends on fungicides for effective apple scab management.

The overwintering form of the fungus are pseudothecia, fungal fruiting bodies, in infected leaves remaining on the orchard ground (MacHardy 1996; Vincent *et al.* 2004). When temperatures are increasing in spring, ascospores, the primary inoculum, are produced in asci that develop within the pseudothecia (Carisse *et al.* 2006). When the ascospores are mature, they discharge during rain events. The spores are dispersed by wind, landing on young leaves, fruit, or sepals where infections occur given the right conditions (MacHardy 1996; Belete & Boyraz 2017).

For ascospores to be released the pseudothecia require wetting (Brook 1969; Singh 2019). The overwhelming majority of ascospores are released when wetting occurs in daylight. Higher temperatures and humidity before wetting also increase the amount of ejected ascospores. The germination of ascospores is dependent on the surface of the tissue being wet, usually referred to as leaf wetness. The number of hours of leaf wetness required for a germination is dependent on the temperature (MacHardy 1996).

Scab lesions that develop from the ascospores produce conidia (secondary inoculum) which can cause further infections on leaves, fruit, and shoots during wet weather for the rest of the season (MacHardy 1996; Belete & Boyraz 2017).

A potential ascospore dose (PAD) is a scab risk assessment for the following season, which can be done after harvest but before leaf-fall. A sequential sampling technique is used where all leaves on 10 shoots from 10 random trees in the orchard are examined for apple scab (Reardon *et al.* 2005). The number of infected leaves can be used to predict the infection risk level for the following season. If the number of infected leaves is between the threshold values for high and low risk, it is necessary to examine another 100 shoots. In low-risk orchards, fungicide applications can be delayed in spring. Sanitation measures during autumn have an important effect on threshold values (Cooley *et al.* 2009).

The risk for apple scab in spring depends on the susceptibility of the apple variety and the level of foliar scab infections at leaf-fall as well as the amount of leaf litter remaining on the ground during winter and spring (MacHardy 1996; Biggs *et al.* 2010). Reducing the amount of apple scab inoculum overwintering on leaves is therefore an important measure to reduce disease pressure (Creemers et al 2002). Although this may not necessarily allow for fewer fungicide applications during the primary infection period (ascospore infections), applications may become more efficient and therefore reduce the need for additional applications during the secondary infection period (conidial infections). Measures taken during the autumn to reduce the inoculum aim to accelerate leaf decomposition, by shredding leaves and spraying urea (Sutton *et al.* 2000; Vincent *et al.* 2004).

Infection risk is highest in spring and early summer since young leaves and fruit are particularly susceptible to *V. inaequalis* infections (Schwabe *et al.* 1984; Jamar 2011). Mature leaves and fruits gain resistance as they age, where young leaves are most susceptible the first 8 days after emergence (Carisse *et al.* 2006). Moreover, failure to control scab during spring is difficult to amend later in the season (Köhl *et al.* 2015). Thus, to avoid a buildup of scab in the orchard, the timing of fungicide application during spring is critical. Using weather-based decision support systems, growers can monitor infection risk to properly time fungicide applications.

Management of apple scab has high priority for growers, since even subtle infections reduces fruit quality. In Sweden apples are sorted according to EU's three quality norm classes for apples (Jordbruksverket 2019). The most desirable is Class Extra, where the apples must be free of any defects, except for insignificant external damage. Second is Class I, where the total surface of apple scab on an apple may not exceed 0.25 cm^2, and finally Class II, where the total surface of apple scab may not exceed 1 cm^2. Each class has a quality tolerance of 5-10% for apples that do not fulfil the criteria. If none of the quality class requirements are met, the apples are sorted as processing fruit (Eneqvist Staflin 2017).

1.2. Decision support systems

Decision-support systems (DSS) are interactive computer-based systems that help growers to make informed management decisions by taking several parameters and large amounts of data into account (Shtienberg 2013). DSSs may also act as a bridge between research and growers to facilitate knowledge transfer, which is often a decisive point in implementing integrated pest management (IPM) strategies.

1.3. RIMpro

RIMpro Cloud Service (www.rimpro.eu) is an interactive DSS for pest and disease management in fruit production developed by Marc Trapman (RIMpro B.V., Zoelmond, NL). Among some of the pests and diseases it contains models for are apple scab, apple sawfly (*Hoplocampa testudinea*), codling moth (*Cydia pomonella*) and powdery mildew (*Podosphaera leucotricha*). RIMpro builds on algorithms that model the biological development of the pests and diseases (RIMpro 2020). The RIMpro simulation models are developed in collaboration with experts for the different pests or diseases. RIMpro is continuously developed based on user feedback, input from working groups and projects, and gains in knowledge of the biology of the respective pests and diseases. To predict the development of diseases and pests, the RIMpro models use weather forecasts from either the Norwegian world-wide weather service YR (www.yr.no) or the swiss meteorological service Meteoblue (www.meteoblue.com). RIMpro also provides a historical record of the development of the pests or diseases based on weather data from either in-orchard weather stations or virtual weather stations. By using user-friendly interfaces RIMpro aids growers and advisers to decide upon and to time applications of pesticides. However, the apple scab model does not calculate an absolute risk since it cannot account for the ascospore potential in the orchard or the susceptibility of apple varieties to apple scab (Trapman 2013). To gain a better understanding of the actual risk level and how to interpret the model output, growers and advisers should first establish the general risk for each specific orchard, before the growing season.

Several other decision support systems have been developed for apple scab, such as Fruitweb, Ag-Radar, NEWA and Skybit (Wallhead & Zhu 2017).

1.3.1. RIMpro Model

The RIMpro apple scab model computes a RIM value which indicates the number of spores germinated. The RIM value increases proportionally with infection risk, where the number of the RIM value can be considered as the percentage of ascospores in an orchard that are likely to cause an infection – divided by 100 (as the number of ascospores are set to 10 000 at the start of the season). For example, a RIM value of 500 indicates that 5% of the ascospores are likely to cause an infection at that given moment. If the orchard was relatively free of scab infections the previous season, fungicide applications for RIM infection values below 300 can possibly be avoided (Trapman 2013). However, at RIM values above 600 it is recommended to spray twice, usually with an application before the predicted infection and one either during the infection or immediately after.

Several factors are of importance for an apple scab infection. Some of the key factors the RIMpro apple scab model takes into account include:

- The impact of rain and leaf wetness on the maturation of ascospores, and delayed maturation of ascospores during dry intervals.
- Rain requirements for discharge of ascospores.
- The effect of light and humidity on ascospore discharge, as adequate humidity and the light condition prior to a rain event increases the amount of dischargeable ascospores. On the other hand, low light and humidity levels, have an opposite effect.
- Leaf wetness requirements for germination of ascospores.
- The effect of temperature on the germination of ascospores, using the "revised mills infection curve" by MacHardy and Gadoury (1989) with some improvement from Stensvand *et al.* (1997) for lower temperatures.
- Survival of ascospores during dry conditions.

Weather data is sent to the RIMpro server where the apple scab model produces new outputs every 30 minutes. The user must provide a starting date, a biofix, when the first ascospores are ready to be discharged (RIMpro user manual, 2013). There are four options in RIMpro for setting a biofix. The preferred approach is petri-plate assay to observe discharge of first ascospores. The second option is to use spore traps in the orchard for detection of the first discharged ascospores. If these methods cannot be used, for lack of time or expertise, it is instead possible to use the date of when the first morphologically mature ascospores under microscope can be seen, or to use the phenological stage green tip.

RIMpro contains another feature in which fungicide applications can be simulated. The apple scab model estimates the coverage and degradation of the fungicide, where the decline of the fungicide cover is estimated based on wash-off by rain and dilution by leaf growth (Wallhead & Zhu 2017). This means growers can verify the timing and efficacy of fungicide applications, and for how long the fungicide residue from a previous application may provide sufficient coverage for the next infection.

1.4. Weather data

1.4.1. Grid data model background

In Sweden, the Swedish Board of Agriculture (SJV) uses RIMpro. Currently, weather data is obtained from in-orchard weather stations at 35 locations. However, SJV is considering to obtain weather data from grid-data instead. Grid-data has a resolution of 2.5x2.5 km in Sweden and is calculated by the Swedish Meteorological and Hydrological Institute (SMHI). The current weather data is calculated for every grid-point by combining weather data from local weather stations and data from weather radar and satellites (SMHI 2019). This is done by the real time analysis model Mesoscale Analysis (MESAN) (Häggmark *et al.* 2000; SMHI 2019). As a starting value, MESAN uses a weather forecast from a numerical weather prediction model called AROME (Applications of Research to Operations at Mesoscale). This forecast is then modified by using observations from local weather stations and data from weather radar and satellites to get a better representation of the actual weather for a grid-point. A method called Optimal Interpolation is used to evaluate how the information given in the observations vary with the distance between the grid-point and the place of the observation. If SJV would eventually switch to using grid-data, LantMet, a database that collects and stores weather data from SMHI and local weather stations, would be used as a provider of the grid-data (Swedish University of Agricultural Sciences 2020b). The LantMet database is managed by Fältforsk, Swedish University of Agricultural Sciences (SLU), and is financed jointly by SLU, SJV and Hushållningssällskapet (Swedish University of Agricultural Sciences 2020a). Due to the large amount of processing power required to store data from all SMHI's grid-points, LantMet has restricted its grid-points to only include those in areas with at least 37% open ground (T. Leuchovius 2020, personal communication, 11 September).

1.4.2. Weather stations

In Swedish apple orchards, Davis' weather stations (Davis Instruments Corporation, Hayward, California) are currently used to collect weather data. For a successful disease and pest warning system weather data needs to be reliable. To attain reliable weather data using weather stations, it is critical to properly install and maintain the equipment and to continuously check for errors (Gleason *et al.* 2008). Physical weather stations require constant maintenance for accurate weather data to be collected (Karlsson *et al.* 2016). As the scab model is highly dependent on rain, humidity, leaf wetness and temperature data, weather stations that are not providing correct data can impact the disease development in the model. For example, the entry hole of the rain bucket funnel is sometimes covered by debris – impacting the amount of water measured by the rain gauge (Hernebring 2008;

Karlsson *et al.* 2016). Other problems concern calibration of the temperature humidity sensor or that the rain gauge is not being leveled. A rain gauge tilted by more than a few degrees may not work properly since it affects the calibration of the rain gauge mechanism (Campell Scientific 2015). In addition, the amount of rain collected from a tilted rain bucket varies with wind direction. Therefore, rain gauge, temperature and humidity sensors need to be checked weekly. A yearly service comprising all parts of the weather station and calibrations is also required (Karlsson *et al.* 2016).

1.4.3. Leaf wetness

The presence of free water on the surface of a crop canopy is defined as leaf wetness (Rowlandson *et al.* 2015). As leaf wetness duration (LWD) is an important factor for infection of apple leaves, apple scab models are dependent on the LWD parameter (Stensvand *et al.* 1997; Leca *et al.* 2015). In Swedish apple orchards leaf wetness sensors are currently used. It is often difficult to measure leaf wetness as there are a variety of different sensors which lack reliable standards. Ehlert *et al.* (2019) showed that several commonly used leaf wetness sensors in Germany did not accurately reflect apple scab infections that occurred during the study period. Angle, orientation and canopy position are other non-standardized factors that influence the readings of a leaf wetness sensor (Rowlandson *et al.* 2015). Calibration and maintenance of the sensors are crucial for reliable LWD data.

RIMpro provide users with the option of using virtual stations, based on weather data from Meteoblue. The meteorological data obtained for the virtual weather stations contain information for parameters such as temperature, air humidity and rain but not for LWD. This means that LWD has to be calculated from the other weather parameters (Trapman 2017). RIMpro uses a model which simulates the wetting and drying of apples leaves developed by Leca *et al.* (2015). It was validated on a large scale in 2016 by asking the RIMpro users each time they used RIMpro whether apple trees were wet or dry in that moment (Trapman 2017). For 74 locations in central Europe, each observation made by the grower was compared to the wetness indicated by the weather station and the virtual leaf wetness. In 81% of the cases, the observation made by the grower agreed with the in-orchard weather station, while the virtual leaf wetness was correct in 73% of the cases. The main discrepancy was that virtual data returned “false wets” in comparison with orchard observations. For 35 locations all primary infections were then compared using both the in-orchard station and virtual data. For the 417 potential infection events that occurred, 88% were calculated by both data types, while 9% of the infection events were calculated only on the orchard station data and 3% only on virtual data. In 65% of the infection events the severity class of the infection was the same between the two types of stations.

In RIMpro, the leaf wetness calculations for the LantMet interface are simpler than the leaf wetness model used for the Meteoblue interface. The LantMet interface uses vapour pressure deficit (VPD) and rain as indicators of leaf wetness. VPD is a combined function of air temperature and relative humidity, calculated by the difference of the amount of moisture in the air and air moisture at saturation point, 100% relative humidity (Medina *et al.* 2019). VPD drives the transpiration of plants. If the air humidity becomes saturated, vapour condenses to form clouds which will lead to condense on leaves (Prenger & Ling). In other words, a low VPD means the relative humidity is high whereas transpiration will be low, which produces leaf wetness.

1.5. Integrated pest management

Integrated pest management (IPM) is an ecologically based pest control strategy which is dependent on natural mortality factors, such as natural enemies or weather (Flint & Bosch 1981). IPM strategies attempts to reduce harmful organisms by disrupting the natural control mechanisms as little as possible. Pesticides may still be used, but only after careful monitoring of both pest populations and natural control factors. It is therefore necessary to adopt a holistic view (Barzman *et al.* 2015). A holistic view requires continuous collection of information about different parameters such as natural enemies, other pests, and cultural practices used. These parameters must then be evaluated with respect to interactions between the different factors and the impact of control actions (Flint & Bosch 1981). The consideration of all available plant protection methods to reduce the development of harmful organisms includes even the option to take no action. It is therefore central for IPM strategies to reduce pesticide usage to levels that are both economically and ecologically justified. This is best achieved by resorting to pesticides only when other management tools are insufficient (Barzman *et al.* 2015; European Commission 2020).

As of 2014 professional pesticide users throughout EU must comply with eight general principles of IPM (Directive 2009/128/EC). These include: (1) Prevention and suppression, (2) monitoring, (3) decision making, (4) non-chemical methods, (5) pesticide selection, (6) reduced pesticide use, (7) anti-resistance strategies and (8) evaluation (Barzman *et al.* 2015).

An example of the first principle, “prevention and suppression”, of apple scab is shredding leaves. Decision support systems (DSS) can be of great value for IPM as it helps growers determine the level of disease and pest incidence and estimate potential economic loss (BiPRO GmbH 2009; Barzman *et al.* 2015). This can be done by using scientifically sound DSSs, such as RIMpro, to monitor pests and diseases, such as apple scab, since DSSs provide a simulation of the development of the pest or disease in relation to weather conditions (Shankar & Abrol 2012).

Monitoring provides the basis for the third principle, decision making. By evaluating the information from the monitoring methods, ecological and economical costs can be considered, and appropriate action can be taken. Choosing the most appropriate management strategy avoids unnecessary pesticides use, thus reducing a detrimental effect on environment and human health and even saving economic expenditure for the grower (Jordbruksverket 2020). A prime focus in IPM is threshold-based interventions (Barzman *et al.* 2015). Thresholds are however rarely universal. RIMpro provides risk-levels, but growers need to individually evaluate the situation in their respective orchards before taking action (Trapman 2013). This is done by assessing the amount of apple scab during the previous season, which sanitary measures were taken during the fall, and how susceptible the varieties grown are.

The fourth IPM principle, non-chemical methods, means the grower should avoid using pesticides if other alternatives are available (BiPRO GmbH 2009). Non-chemical methods such as biological methods are not available against apple scab. Preventative measures, such as scab-tolerant cultivars, are the only option to potentially avoid chemical methods (Carisse *et al.* 2006).

Principles five, six and seven, are all related to the pesticide use which greatly depend on DSSs. Using pesticides may cause undesired side effects on beneficial organisms, increasing the risk for pest outbreaks (Reddy 2016).

When pesticides are deemed necessary, pesticides with minimum impact on human health, non-targeted organisms and the environment should be prioritized (BiPRO GmbH 2009; Barzman *et al.* 2015; European Commission 2020). The pesticide application frequency, dose and area should be the lowest possible. As RIMpro models the development of the disease, and contains a fungicide simulation feature, the user may lower the application dose and frequency, based on the information provided by RIMpro. In addition to adverse health, economic, and environmental effects, the risk of resistance is another important reason why the use of fungicides should be limited (European Commission 2020). The seventh principle, anti-resistance strategies, depends on the fungicide chosen.

The fungicide resistance action committee (FRAC 2019) classifies apple scab as a plant pathogen showing high risk for the development of resistance to fungicides. Using systemic fungicides with a curative mode of action may result in resistance development, while contact fungicides with a protectant quality have a lower risk of developing resistance (Wenneker & Jong 2018; Chatzidimopoulos *et al.* 2020). The protectant fungicides primarily affect spore germination while systemic ones are absorbed by the plant and then affect the fungal growth. Due to the high risk of resistance development of systemic fungicides, it is recommended to primarily use contact fungicides. An example of a multisite contact fungicide is dithianon (quinone class), which FRAC classifies as a low risk of resistance development. Dithianon has been used for almost 50 years and yet there are no reports of reduced sensitivity (Stammler *et al.* 2013). The grower can prioritize protectant fungicides by applying fungicides with the correct timing based on the information provided by DSSs.

The final principle, evaluation, demands that the grower evaluates the success of the plant protection measures taken.

1.5.1. The role of SJV in integrated pest management

The Swedish Board of Agriculture (SJV) is the authority in Sweden that is responsible to inform about IPM and to facilitate implementation, although other agencies are also involved (Nyrén 2013).

SJV can offer assistance to apple growers practicing IPM. They have used RIMpro for 35 orchards in southern Sweden during the past decade, providing information about different diseases and pests, including apple scab. This service is provided to the public for free as a part of the government-funded goal to reduce the effects of pesticide use on public health and the environment (Swiergiel *et al.* 2019). SJV sends weekly updates on the current situation of pests and diseases in Sweden. Alerts are sent to growers when the scab model exceeds warning thresholds for their orchards.

It is essential that governmental institutions play a leading the role in IPM by providing salient information about IPM and supporting projects working to improve IPM-strategies, for example by making DSSs easily accessible.

Currently 33 out of 35 weather stations used by SJV for RIMpro are situated in Scania, where most of the commercial apples are grown (www.fruitweb.se). However, switching to virtual weather data would give new opportunities to expand the area which is currently covered and to include more orchards. Moreover, virtual weather data would render installation and maintenance of weather stations superfluous.

1.6. Objective

The aim of this project was to evaluate if grid weather data can replace physical weather stations in the RIMpro apple scab disease model for Swedish apple growers. To evaluate this aim, two main questions needs to be answered:

- Is the leaf wetness model and calculation used for virtual weather stations sufficient to replace the leaf wetness sensors used by the in-orchard weather stations?
- Will virtual weather stations produce similar outcomes in apple scab disease development when compared to the physical weather stations?

2. Material and methods

2.1. Software and weather data

To evaluate grid data for apple scab decision support systems, the cloud-based decision support system RIMpro (RIMpro B.V., Zoelmond, NL) was used. An interface for LantMet (http://www.ffe.slu.se/lm) (cooperation between SLU, SJV and Hushållningssällskapet) grid weather data was created by Marc Trapman in RIMpro. Since grid data from LantMet does not include leaf wetness measurements, vapor pressure deficit (VPD) was used as the leaf wetness parameter in the grid data model. The model assumed that trees were wet when the amount of rain was greater than 0.0 mm or when VPD was smaller than 2.5 hPa. As RIMpro users already have the option of adding virtual weather stations based on data from Meteoblue (Meteoblue AG, Basel, Switzerland), an extra set of virtual stations were created for every orchard to compare the use of Meteoblue versus LantMet.

2.2. Site selection and experimental design

For ten commercial apple orchards, virtual weather stations were created based on weather data from both LantMet and Meteoblue. The ten sites selected were based on the geographical distribution of apple orchards in Scania (Figure 1). A requirement was that the orchard had a functional weather station with few data gaps for the previous two seasons. The orchards where divided into three regions, West, Northeast, and Southeast.

RIM values were gathered for each infection event for the primary scab infection period of 2019 and 2020. To compare infections between the different types of stations, infections were determined by the rain events which caused the main ejection of ascospores. When rain occurred within 5 h from each other at different stations they were considered to be part of the same rain event. When multiple rain events stretching over several days contributed to an infection, it was difficult to separate which of the rain events had the greatest impact. For an infection to be considered the same in these instances, at least one rainfall with a meaningful contribution of ejected ascospores had to occur at the different stations. Additionally, an overlap in the RIM value infection period was required.

Figure 1. The location of the ten selected orchards in Scania, Sweden. Source: https://www.google.com/maps

2.3. Statistical analysis

All data was processed and analysed using Minitab 19 (v. 19.2020.1.0) for statistical analyses and Microsoft Excel (v. 16.0.13328.20356) for the numerical comparisons.

To simplify the comparison between weather sources and stations, the RIM infection values were categorized from 0-4 based on the infection risk levels as defined by RIMpro graphical outputs (Table 1).

Table 1. Categorization of RIM values based on risk levels from graphical outputs in RIMpro.

RIM value	Category	Risk levels in RIMpro
0-9	0	No infection risk
10-99	1	Sligh infection risk
100-299	2	Medium infection risk
300-599	3	High infection risk
600+	4	Extreme infection risk

2.3.1. Comparison of infection events

To compare infection events between the stations, principal component analysis (PCA) was carried out for the seasons 2019 and 2020 for all three regions. As this study aimed to compare three different types of stations, the difference in infection severity between the different stations at every infection event was the main interest. This means comparing different infection events was of no interest. To eliminate this difference in the PCA, the infection values for the different stations at each infection event were standardized to have an average of zero. This was done by subtracting the mean of the three stations infection value from each individual station's infection value.

The PCA was also complemented with Pearson correlation matrices for every region for the 2019 and 2020 seasons. Additionally, a simple numerical comparison of each stations infection category for every infection event was carried out (see Appendices 1 for example).

2.3.2. Causes of differences between stations

The main cause of categorical differences larger than one between two stations was further investigated. This was done by carefully comparing RIMpro's graphical output and weather data for each of the three types of station for every infection event. Since multiple factors may contribute to differences between stations, the investigation of the differences was evaluated in the following order: 1) rain, 2) available mature spores, 3) leaf wetness duration and temperature, and 4) relative humidity. Only the highest ranked difference observed was counted for each infection event. Rain differences included both differences in rain amount and timing of the rain, while mature spores included differences in both available mature spores during the season and when spores were depleted at the end of the season.

2.3.3. Impact of distance between grid-point and weather station

The distance between LantMet grid-points and weather stations in orchards was measured using google maps (www.google.com/maps). To determine if the distance of a LantMet grid-point and a weather station had any effect on the output, a Pearson correlation matrix was produced containing distance and the percentage of infections differing between LantMet and weather stations.

2.3.4. Regional differences in infection events

The average number of infections per orchard, each year, for the different stations and regions were calculated. This was done to investigate potential differences in performance for the different type of weather sources between the two seasons studied.

3. Results

Three different weather data sources, for the 2019 and 2020 seasons, were investigated for the RIMpro apple scab model in southern Sweden. This was done for primary infections, which is caused by the sexually reproduced spores (ascospores). The weather data sources used were from in-orchard, physical weather stations, Meteoblue and LantMet grid-data.

A typical output of the RIMpro apple scab model is shown in figure 2. The RIM infection value is represented by the red line. This project was carried out after primary infection period ended, and therefore, a forecast was not included in the study. The graph shows only historical data which can be obtained by RIMpro with weather data from either an in-orchard weather station or a virtual weather station. During the ongoing primary infection period, both historical and forecasted infections are represented in the graphical output.

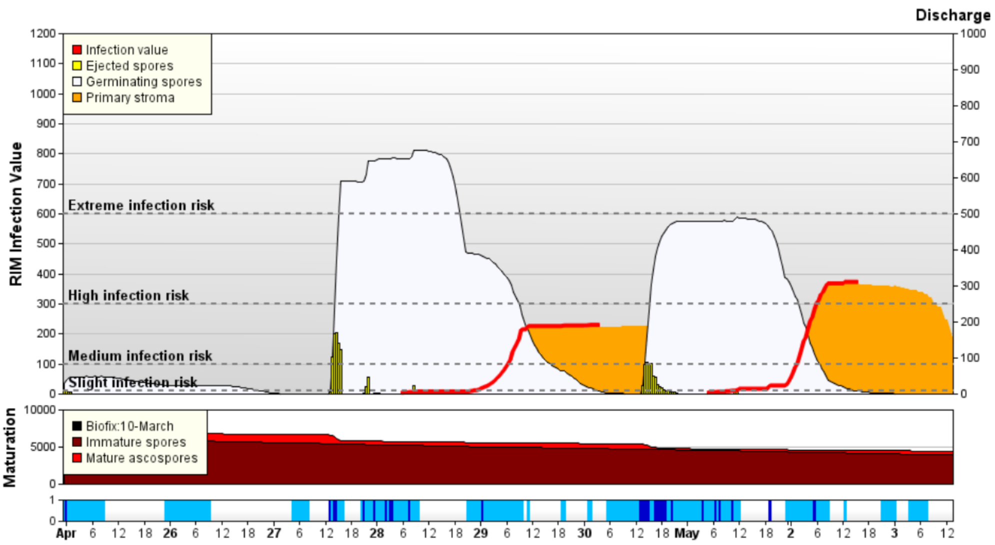

Figure 2. Graphical output of the RIMpro apple scab model. The bottom axis shows rain (dark blue) and leaf wetness (light blue) over the growing season. Above, the proportion of mature spores (light red) and immature spores (dark red) are shown. The main graph shows the number of spores ejected during rain events (yellow bars), the number of spores germinating (white area), while the red lines represent the RIM infection value. The orange area indicates scab lesions that were initiated by infection from the germinating spores and are incubating in the leaf after which scab lesions will become visible. Used by permission of RIMpro B.V., Netherlands.

3.1. Numerical comparison of infection events

For the primary infection period of apple scab in 2019, there were 130 predicted infection events (Table 2). In 11% of the events, all three stations produced unique RIM category infections, while in 19% of the cases all three stations produced the same RIM infection category. As seen in table 2, in 62% of the events, the RIM infection categories were the same for weather stations and LantMet grid-data. The weather station and Meteoblue data predicted the same RIM infection category for 29% of events. When comparing the virtual stations based on LantMet and Meteoblue, the two produced the same RIM infection category for 37% of the infection events. Differences between the weather station and LantMet did not exceed two categories during any infection event, while the comparison of Meteoblue compared with either the weather station or LantMet showed differences of three to four categories. For the 2020 season, 100 infection events were predicted, 30 less than 2019. Again, the weather station and LantMet gave the highest percentage of the same category infections at 53%. For the weather station and Meteoblue 39% of the infection events had the same category and for LantMet and Meteoblue, 35% were the same. For 2020 there were no category 4 differences between any stations (Table 2).

Table 2. Predicted primary infection events of apple scab 2019 and 2020 by different weather stations compared against each other for 10 Swedish apple orchards. "Δ" shows differences in infection severity. n = 130 for 2019; n =100 for 2020.

Year	Stations compared	Δ0	Δ1	Δ2	Δ3	Δ4
2019	Weather station - LantMet	62%	33%	5%	0%	0%
	Weather station - Meteoblue	29%	52%	13%	3%	3%
	LantMet - Meteoblue	37%	44%	14%	4%	2%
2020	Weather station - LantMet	53%	45%	2%	0%	0%
	Weather station - Meteoblue	39%	48%	11%	3%	0%
	LantMet - Meteoblue	35%	51%	12%	3%	0%

3.2. Principal component analysis of predicted infections

For the principal component analyses (Figure 3), all three regions in both years, with the exception of the West region during 2020, produced similar outputs. For the five plots with similar output, the first component explained the difference in data between Meteoblue and the other two stations, with a variance explained between 60.1- and 77.4%. The second component in these five analyses showed the difference between LantMet and the weather stations with a variance explained between 22.6- and 39.4%. The PCA of the Western region in 2020 differed from the others where the two components are similar in variance explained, and no large differences were seen between the three different weather data sources.

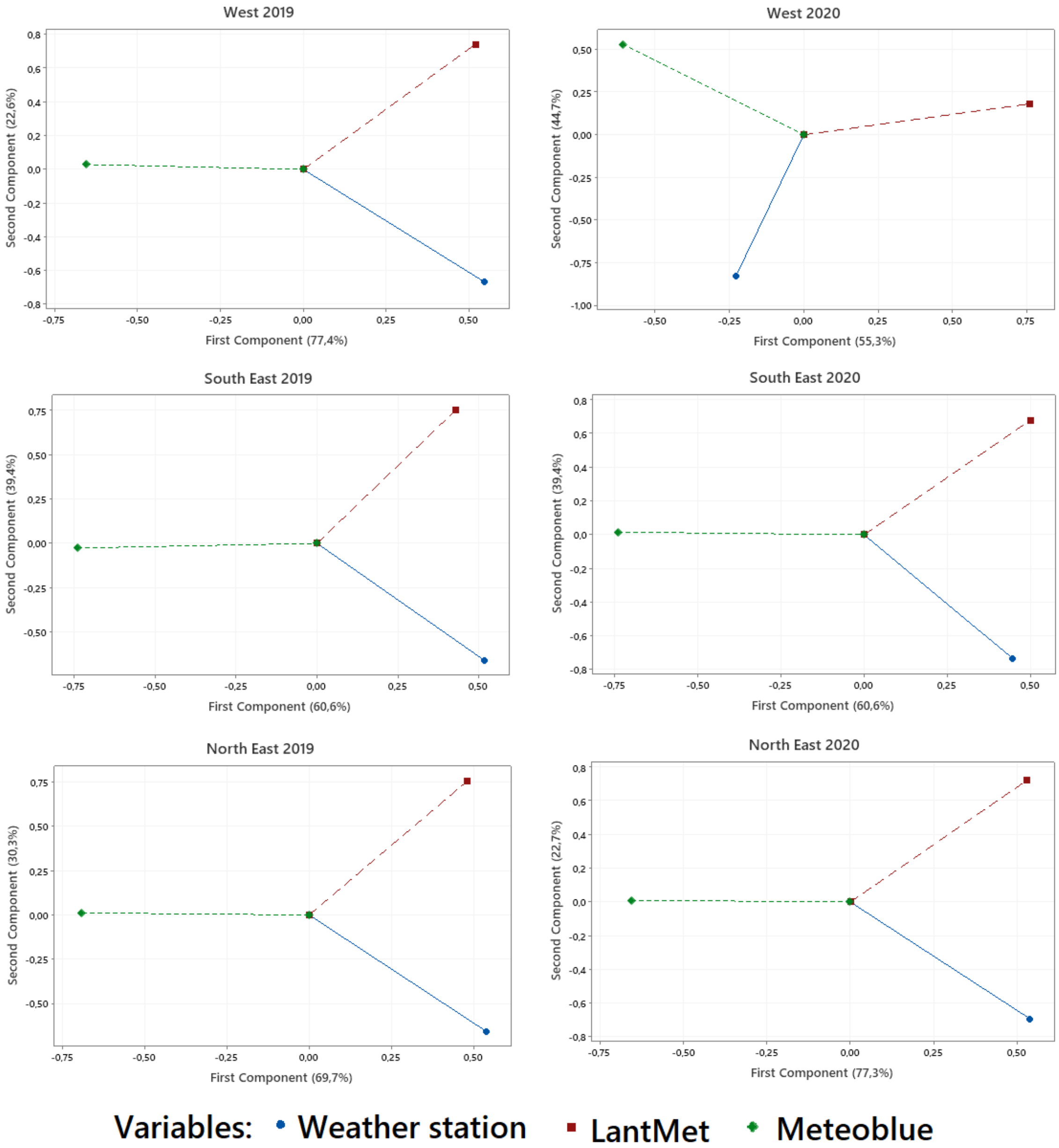

Figure 3. Loading plots from principal component analysis for standardized RIM infections for the 2019 and 2020 apple scab season. Within parentheses of the different components are the percentage of variance explained. For all but the West region 2020, the first component shows the difference between Meteoblue and both the weather station and LantMet. The second component then explains the difference in variance between the weather station and LantMet. For the West region in 2020, there was no large difference between any of the stations.

The PCA was complemented with correlation matrices for every region both 2019 and 2020 (Figure 4).

Correlations 2019 W

	Weather station	LantMet
LantMet	0,899	
Meteoblue	0,451	0,574

Correlations 2020 W

	Weather station	LantMet
LantMet	0,859	
Meteoblue	0,881	0,828

Correlations 2019 SE

	Weather station	LantMet
LantMet	0,838	
Meteoblue	0,675	0,716

Correlations 2020 SE

	Weather station	LantMet
LantMet	0,889	
Meteoblue	0,757	0,778

Correlations 2019 NE

	Weather station	LantMet
LantMet	0,815	
Meteoblue	0,447	0,479

Correlations 2020 NE

	Weather station	LantMet
LantMet	0,907	
Meteoblue	0,557	0,552

Figure 4. Pearson correlation matrices for each region in 2019 and 2020. For all regions and both years, excluding 2020 West, the correlation between the weather station and LantMet is stronger. For 2020 West, there are smaller differences between the different weather sources.

3.3. The number of predicted infections

There were both regional and station-type differences associated with the number of infections per orchard in both years (Table 3). For all three regions, except West 2019, the weather stations predicted more infections than Meteoblue. On average, weather stations and LantMet predicted infections differed between 0- and 1, while it differed between 0- and 2.7 for the weather station and Meteoblue.

Table 3. The average number of infection events per station, region, and year. West n=4, Southeast n=3, Northeast n = 3.

Year	Region	Weather station	LantMet	Meteoblue
2019	West	10.0	9.0	10.0
	Southeast	11.3	11.3	11.0
	Northeast	12.0	12.0	9.3
2020	West	6.0	6.5	5.5
	Southeast	7.7	6.7	6.3
	Northeast	7.0	8.0	6.0

3.4. Causes of differences in predicted infection

There were 87 infection events in total for 2019 and 2020 where a categorical difference in infection larger than one could be seen between two stations, of which eight involved the weather station versus LantMet (Table 4). The four causes of differences were rain, leaf wetness, mature spores, and relative humidity. Rain differences were the most common cause, contributing to 69% of the differences. Both mature spores and leaf wetness were found to cause 15% of the total differences. Relative humidity caused only one categorical difference larger than one. Temperature caused no observed differences.

Table 4. Primary causes of categorical differences greater than 1 arranged by stations against each other for each region and year.

Year	Region	Stations	Rain	Mature spores	LW	RH
2019	West	Weather station - LantMet	2	0	0	0
		Weather station - Meteoblue	7	1	2	0
		LantMet - Meteoblue	7	0	2	0
	Southeast	Weather station - LantMet	2	0	0	0
		Weather station - Meteoblue	1	0	3	0
		LantMet - Meteoblue	1	0	4	0
	Northeast	Weather station - LantMet	1	0	1	0
		Weather station - Meteoblue	8	2	1	0
		LantMet - Meteoblue	10	1	0	0
2020	West	Weather station - LantMet	1	0	0	0
		Weather station - Meteoblue	1	0	0	0
		LantMet - Meteoblue	2	1	0	0
	Southeast	Weather station - LantMet	0	0	0	1
		Weather station - Meteoblue	2	1	0	0
		LantMet - Meteoblue	1	3	0	0
	Northeast	Weather station - LantMet	0	0	0	0
		Weather station - Meteoblue	8	2	0	0
		LantMet – Meteoblue	6	2	0	0

3.5. Distance between weather sources

The distance between the in-orchard weather station and the LantMet grid-points ranged between 0.4- and 4.1 km. The correlation between the percentage of infections differing between physical weather stations and LantMet and the distance between the grid-points and the in-orchard weather station was not significant ($r = 0.151$).

4. Discussion

The scope of this study was to compare different sources of weather data, two sources of virtual weather data and physical weather stations, feeding into the apple scab forecast provided by the decision support system RIMpro. This study compares 10 apple orchards in Southern Sweden, during the 2019 and 2020 seasons. The amount and severity of infections using weather data from in-orchard weather stations and LantMet grid-data in southern Sweden correlated to a higher extent when compared to Meteoblue and the weather station. The results show that replacing in-orchard weather stations with LantMet grid-data in Sweden could be a viable option.

4.1. Numerical comparison of infections

The categorical infection did not exceed a difference of two between the weather station and LantMet at any infection event, while it was in some instances as large as three or four when comparing Meteoblue and the weather station. Thresholds for when treatment is necessary are impacted the apple variety grown, the level of scab recorded in the orchard the previous season, and the phenological stage of the tree. As these factors were not recorded for any of the stations and are not accounted for in the RIMpro model (with the exception of phenological stage), threshold values for treatment were not verified. However, category 4 infections are recommended to always be sprayed twice, while several factors impact the spraying decisions for the lower categories (Trapman 2013; Veens 2014). If the orchard had low amounts of scab the previous season, category 1 and 2 infections might not need treatment. This indicates that large categorical differences between stations will likely result in different management decisions.

In 42% and 63% of the cases in 2019 and 2020, respectively, when a categorical difference of one was observed, one of the two stations had a category 1 infection while the other had no infection. This suggests a correlation between low categorical differences and a low severity of infection. Protection may not be recommended for infections of low severity and in some cases, fungicide residue from previous applications might be enough to protect the plant from these infections.

The categorization of the infections was necessary in order to enable statistical analyses. A potential problem with this categorization is that the difference in absolute RIM infection values between two stations may vary greatly (see Appendices 2). This means that two stations with different categories could be very similar in absolute RIM values, and therefore be treated the same way. Meanwhile two stations with the same category could have a larger difference in absolute RIM values, leading to a difference in treatment.

4.2. Principal component analysis and correlations of infections

The variation of infection severity between stations was mostly ascribed to differences between Meteoblue and the weather station or LantMet when running a principal component analysis. Only one region in one year was found to have similar variation between all stations. The amount of scab infections per orchard were 28-43% lower in 2020 than 2019 and infections were particularly mild in the West region, which may explain the similarities between weather data sources for that region. The differences seen between the stations were supported by correlation matrices.

The observed differences between Meteoblue and the in-orchard weather station contradicts Trapman (2017). This is most likely due to the geographical factors, since the study by Trapman (2017) was carried out in central Europe where Meteoblue is based. The weather data for Meteoblue does not seem to have the same accuracy in southern Sweden as in central and southern Europe. For all three locations in the Northeast region 2020, Meteoblue had the same rain data despite a distance of 12 km between the orchards. This had some major impacts on the result, as two rain events were reported for all three Meteoblue stations, but not reported for either the weather stations or LantMet stations in that region. These two rain events caused a categorical difference in infection of two and three between the Meteoblue stations and the other two. For 2019, there was one rain event on May 20th that gave an infection on all ten weather stations, whereas seven out of ten LantMet stations and zero Meteoblue stations predicted any infection.

4.3. Categorical differences of infections

Of categorical differences larger than one in predicted infections between the different weather sources, 65% was mainly due to differences in rainfall prediction. This was also where most of the difference between the weather station and LantMet was seen. This is not surprising since rainfall measurements are susceptible to errors (Gleason *et al.* 2008; Hernebring 2008; Michael Pollock *et al.* 2014; Campell Scientific 2015; Karlsson *et al.* 2016).

The in-orchard weather stations register rain at 0.2 mm while LantMet does already at 0.1 mm. Because the RIMpro model requires a minimum of 0.2 mm rain for ascospores to be discharged, this will not have any direct impact on the number of spores ejected. The different cut-offs for registering rain may have had some effect on the leaf wetness duration, but as infections require multiple hours of leaf wetness in order to occur, it is unlikely that the impact is significant. Indeed, leaf wetness caused a difference between the weather station and LantMet predictions only once. This suggests that the leaf wetness calculations done for the LantMet weather data could be a sufficient replacement for the leaf wetness sensors used for the in-orchard weather stations. The reason for leaf wetness causing a difference in predicted infections between weather stations and Meteoblue six times, were likely due to the lower accuracy of weather data obtained by Meteoblue rather than the leaf wetness model itself. It is possible that for category 1 differences, which was not further investigated, that potential problems with the LantMet leaf wetness calculations would become more apparent.

There was no occasion where the weather station and LantMet differed with respect to differences in mature spores, while it occurred in 16% of the predicted infections involving Meteoblue data. Most of these cases involved Meteoblue not recording rain on days where the other two data sources did (or the opposite), leading to a discrepancy in when the available mature spores were ejected. One could therefore argue that rain ultimately caused the difference for most of these cases, as rain differences led to the discrepancies in mature spores (except for a few occasions at the end of the season when one of the stations spores was depleted).

On no occasion did temperature impact an infection difference between any of the stations. This is not surprising since temperature usually doesn’t vary greatly between data sources (Trapman *et al.* 2008).

4.4. Distances

The distance between the LantMet grid-points and the in-orchard weather stations, and the number of infections differing between the two stations showed a very weak correlation. It can therefore be inferred that areas with a less dense grid-network should be able to use LantMet, assuming that the distance does not exceed 4 km, which was studied here. No investigation was made of the difference in infections between orchards using the same grid-point, but this should be studied for future reference. If similar results are achieved between stations surrounding the same grid-point and the in-orchard stations, it might be possible for SJV or farmers to collectively use a single RIMpro source for multiple surrounding orchards. This would open the possibility to decrease cost and to cover larger areas.

4.5. Potential problems and future directions

The primary infection period of apple scab in 2019 and 2020 were compared in retrospect. This means the infections compared here is based on the outcome of the historical data. However, one should be aware that when the tool is used during an ongoing season, most of the fungicide application decisions are based on predicted infections from weather forecast data, and not historical. Weather forecasts can change rapidly and the expected RIM may change from a high-risk infection to low-risk infection in just a short period of time. The forecasts of infections are only as good as the weather forecasts used. Unreliable forecasts are what growers consider one of the most difficult aspects of scab management.

Unfortunately, as this study was conducted after the primary infection period of 2020, no comparison of the forecasted infections and the actual predicted infection of the models had been done. However, when it comes to forecasts differences are not expected between the in-orchard weather station and LantMet since they would both use YR as a weather forecast source. Meteoblue has its own forecast system, which can also be used for the other two stations for an additional fee. Weather data from Meteoblue forecasts would not be the same as historical Meteoblue weather data. Thus, the lower accuracy of historical data from Meteoblue in southern Sweden compared to LantMet seen in this study, would not necessarily be the case when comparing weather data from Meteoblue forecasts and YR forecasts.

As the grower sometimes must take decisions days before the expected infection event due to the weather impacting when application can be made, they are dependent on the forecast being as similar to the outcome as possible. Since the number of fungicide applications per season is limited, spraying fungicides based on a forecasted infection which does not turn into an infection will not only reduce the number of possible applications for the season, but also be costly as well as having an environmental impact.

As weekly checkups of the weather stations and scab evaluation in the orchards were not carried out in this project, the accuracy of the predicted infections for the different stations cannot be evaluated. However, multiple studies from the past few years have confirmed the legitimacy of RIMpro as a decision support tool for apple scab, where several of these studies have showed the potential of decreasing the number of fungicide applications during a season compared to standard farming practices, such as calendar-based sprays (Wallhead *et al.* 2017; Acimovic *et al.* 2019; Garofalo 2019; Chatzidimopoulos *et al.* 2020). This means if the weather source is accurate then the predicted infection value by RIMpro can be assumed to be reliable. The weather stations were calibrated by a service technician before the season started for both years. Maintenance and recalibrations were not done by an expert until the next season unless some apparent problem emerged with the station. It was accordingly up to the grower to check the stations every week, especially with respect to rain measurement. Since this may not have been carried out by the growers during the seasons studied, the data from the weather stations may not be fully reliable. This means the weather data provided by the weather stations should not be considered as flawless. Thus, the infections provided by the weather stations are not necessarily more accurate than the virtual data.

If weather stations are handled correctly, they provide reliable orchard-specific weather data. For this to occur, correct positioning of the weather station and its different parts is required as well as weekly and yearly maintenance and calibration, and reliable internet connection for data to be sent (unless the stations are using SIM-card for data transferring). Add to this the cost and limited lifetime of the weather station. Meanwhile, grid weather data requires no maintenance, no purchase cost and can easily be added to new orchards. However, the potential benefits of grid-data are of no importance if the weather data supplied by the grid system is not representative of the weather in the orchard. Incorrect weather data may lead to inefficient fungicide applications, which ends up costing more for the grower while also having an unnecessary impact on the environment.

Apple scab and other fungal pathogens are more difficult to model than many insect pests, as they are more dependent on parameters such as rain and leaf wetness, which are harder to predict and measure. For the simulation of insect biology, such as the codling moth model, virtual data is easier to implement because of its primary dependence on temperature, which varies less between data sources when compared to rain (Trapman *et al.* 2008).

4.6. Conclusion

The aim of this study was to evaluate if grid weather data can replace physical weather stations in the RIMpro apple scab model for Swedish apple orchards. For a potential implementation of grid-data, similar outcomes of the apple scab infection predictions calculated by RIMpro were considered necessary. Additionally, as leaf wetness is not obtained directly from the grid-data, the additional calculations needed to obtain leaf wetness values had to be considered a sufficient replacement to leaf wetness sensors. The results from this study shows promising results for implementing grid-data from LantMet as few infections differed between the stations from LantMet and in-orchard weather stations by more than one category.

The leaf wetness was only causing a difference in infection between LantMet and the weather stations once, implying the leaf wetness calculations done for LantMet would be a satisfactory replacement. Ideally this study would have been conducted with forecasts included during ongoing season. In addition, regular check-ups of the weather stations should be made to make sure reliable data is collected.

Providing more Swedish apple growers with the opportunity of using a DSS, can aid in the process of improving integrated pest management. On multiple occasions during the conducted study, spores were ejected after a rainfall but the conditions following the ejection were not sufficient for an infection to occur. This means unnecessary applications can be avoided by following the development of the disease. Gridded weather data would give multiple growers an opportunity to start using RIMpro for a lower cost than currently, as no weather stations would be required.

Before a full implementation can be applied, forecasts should be tested during another season, where weather stations are continuously checked and maintained.

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Appendices 1

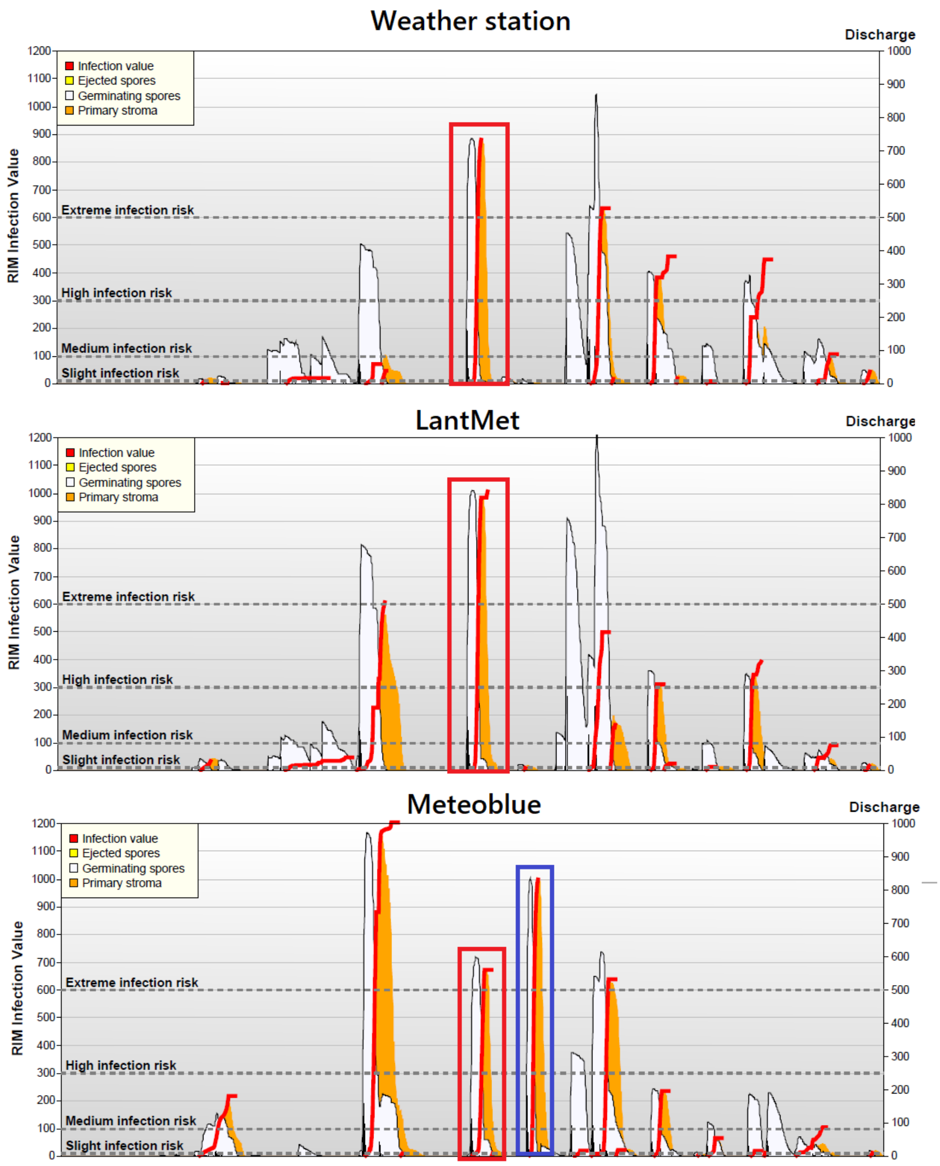

Figure 5. Graphical outputs from the same orchard for the same period but with different weather sources used (weather station, LantMet and Meteoblue). Highlighted in red is a predicted infection event which occurred on all three weather sources, with the same infection severity. Highlighted in blue is a predicted infection event which occurred only on the Meteoblue weather source. The RIM-value of this predicted infection passed the threshold for the highest severity risk, giving a category 4 infection. As the other two weather sources did not predict any infection for this event, a category 4 difference in infection severity were seen between Meteoblue and the other two weather sources. Used by permission of RIMpro B.V., Netherlands.

Appendices 2

Table 5. RIM infection value for all 10 stations for the primary infection period of apple scab 2019. Organized in color by region.

Northeast 1			
Month	RIM ws	RIM lant	RIM meteo
April	18	53	134
May	307	424	849
May	727	844	404
May	242	307	0
May	0	0	54
May	64	19	3
May	363	405	411
May/June	645	523	21
June	428	139	106
June	13	18	5
June	221	144	109
June	72	75	12
June	12	0	0

Northeast 2			
Month	RIM ws	RIM lant	RIM meteo
April	60	131	223
May	75	197	0
May	405	301	950
May	748	790	475
May	207	254	0
May	0	0	134
May	55	11	11
May	551	265	398
May/June	390	411	28
June	288	67	50
June	6	62	6
June	75	51	0
June	85	10	48
June	53	26	5
June	10	0	0

Northeast 3			
Month	RIM ws	RIM lant	RIM meteo
April	4	33	133
May	49	281	0
May	245	263	855
May	808	779	451
May	629	288	0
May	0	0	360
May	23	17	15
May	615	352	403
May/June	400	470	10
June	371	88	31
June	3	20	6
June	328	154	109
June	76	117	14
June	10	0	0

Southeast 1			
Month	RIM ws	RIM lant	RIM meteo
April	72	168	139
May	170	125	0
May	348	523	633
May	787	923	740
May	86	197	0
May	33	50	33
May	727	1010	931
May/June	501	344	392
June	36	171	33
June	158	412	122
June	443	195	128
June	0	32	21

Southeast 2			
Month	RIM ws	RIM lant	RIM meteo
April	255	153	113
May	801	688	93
May	1170	1060	510
May	110	0	5
May	6	202	89
May	675	769	871
May/June	477	621	326
June	31	126	17
June	168	383	166
June	175	130	15
June	10	7	98
June	58	37	31

Southeast 3			
Month	RIM ws	RIM lant	RIM meteo
April	92	167	146
May	50	34	0
May	893	664	79
May	0	0	12
May	799	1080	682
May	461	607	118
May	442	702	866
May/June	580	425	120
June	131	121	132
June	233	299	53
June	6	66	10
June	11	25	0
June	15	7	60
June	88	21	33

West 1			
Month	RIM ws	RIM lant	RIM meteo
April	217	141	190
May	901	800	469
May	852	878	602
May	133	0	0
May	169	114	902
May	708	592	556
May/June	287	502	254
June	11	2	223
June	260	324	13
June	0	0	67
June	7	3	13
June	0	0	10

West 2			
Month	RIM ws	RIM lant	RIM meteo
April	13	34	211
May	21	47	0
May	118	607	1217
May	881	1007	682
May	15	0	0
May	0	0	1001
May	652	664	685
May/June	480	336	233
June	9	13	72
June	449	393	33
June	107	91	109
June	44	17	11

West 3			
Month	RIM ws	RIM lant	RIM meteo
April	30	94	202
May	18	33	0
May	376	805	443
May	675	797	431
May	120	244	0
May	0	85	888
May	552	457	445
May/June	479	396	186
June	20	19	214
June	395	284	13
June	0	0	70
June	27	22	0
June	20	1	1

West 4			
Month	RIM ws	RIM lant	RIM meteo
April	47	83	198
May	33	7	0
May	319	405	808
May	841	995	680
May	29	0	0
May	0	0	740
May	0	0	71
May	567	393	420
May/June	349	308	205
June	0	0	69
June	375	469	24
June	65	83	72
June	14	22	7

Table 6. RIM infection value for all 10 stations for the primary infection period of apple scab 2020. Organized in color by region.

Northeast 1			
Month	RIM ws	RIM Lant	RIM Meteo
April	0	10	0
April	0	26	3
April/May	1005	1357	287
May	0	0	317
May	1346	975	514
May	548	484	551
June	52	35	0
June	182	121	382
June	0	17	0
June	0	0	132
June	54	0	0

Northeast 2			
Month	RIM ws	RIM lant	RIM meteo
April	0	18	0
April	21	15	0
April/May	898	1160	340
May	0	0	376
May	715	890	665
May	706	455	519
June	163	59	0
June	106	67	422
June	0	0	127
June	73	17	0

Northeast 3			
Month	RIM ws	RIM lant	RIM meteo
April	0	11	0
April	3	14	0
April/May	823	1223	332
May	0	0	396
May	777	996	546
May	386	504	550
June	131	40	0
June	280	123	357
June	0	0	105
June	106	13	0
June	22	0	0
June	19	0	0

Southeast 1			
Month	RIM ws	RIM lant	RIM meteo
April	20	0	0
April/May	1110	1316	869
May	0	32	0
May	1096	930	380
May	388	410	546
June	61	49	0
June	69	84	48
June	0	0	91
June	59	19	0

Southeast 2			
Month	RIM ws	RIM Lant	RIM Meteo
April	24	0	0
April/May	486	1008	275
May	1420	740	214
May	286	713	574
May	76	56	0
June	11	67	43
June	0	92	0
June	0	0	21
June	0	0	104
June	18	0	0
June	40	0	14
June	34	0	0

Southeast 3			
Month	RIM ws	RIM lant	RIM meteo
April/May	864	1404	453
May	3	58	0
May	862	932	314
May	909	558	544
June	49	34	0
June	96	132	23
June	55	36	13
June	2	0	133
June	10	0	0
June	0	0	18

West 1			
Month	RIM ws	RIM Lant	RIM Meteo
April/May	997	1424	718
May	16	0	5
May	584	756	392
May	0	13	0
May	490	278	409
June	170	69	106
June	0	0	96
June	62	14	0
June	12	0	0

West 2			
Month	RIM ws	RIM lant	RIM Meteo
April	0	26	0
April/May	878	1501	701
May	1058	1233	434
May	424	495	538
June	0	86	0
June	62	109	142
June	30	0	186
June	12	0	0
June	0	0	15

West 3			
Month	RIM ws	RIM lant	RIM meteo
April	0	206	0
April	235	263	186
April/May	366	668	609
May	723	915	755
May	250	319	357
June	214	242	137
June	4	71	71
June	24	0	0

West 4			
Month	RIM ws	RIM Lant	RIM Meteo
April	0	10	0
April	39	0	0
April/May	1143	927	963
May	763	814	517
May	373	370	494
June	54	53	86
June	0	14	0
June	0	33	0
June	0	0	127
June	9	57	0