TECHNICAL NEWSLETTER
#45- September 2018

WHEN FROST BITES

A new way of assessing winterkill insurance risk

INTRODUCTION

The agricultural industry is faced with a plethora of risks, and some of its major loss drivers are weather-driven natural catastrophes. In contrast to many other industries, for agriculture it's not just the occurrence of a certain type of event that is important, but also its timing. Even a very intense typhoon cannot cause losses if there are no crops in the field, and reduced rainfall in a two-week period coinciding with critical stages of plant development may cause far more damage than a one-month dry period close to harvest. Different parts of the world face different weather-driven perils, and one way to classify them is by their geographic extent. Localised events, such as hail, vary in frequency and severity from year to year, but a single event affects only a restricted area. Perils which affect very large geographic regions simultaneously are what we call "systemic risks" or "cat events" and can cause large losses, sometimes even spanning multiple countries. Here we examine one such catastrophic peril: winterkill.

Winterkill is caused when a plant is damaged through exposure to low temperatures in the winter, particularly when there is little or no snow to protect it. Many different types of plants can be affected by this phenomenon, such as pastures and orchards, but here we restrict our attention to broadacre crops. Winterkill on crops occurs in regions where, on average, winters are sufficiently mild to plant winter crops but can occasionally also be severe enough to cause extensive damage. Such regions are typically in the mid-latitudes, for instance Lithuania or the Midwest of the United States. The photographs in figures 1 and 2 show examples of winterkill damage caused to winter wheat and rapeseed, respectively.

FIGURE 1: THE EFFECTS OF WINTERKILL DAMAGE ON A FIELD OF WINTER WHEAT IN LITHUANIA AFTER AN EVENT IN THE WINTER OF 2010/2011. THE PHOTOGRAPH WAS TAKEN IN APRIL AND SHOWS THAT PLANTS WERE NOT ABLE TO RECOVER FROM THE DAMAGE – THE ENTIRE FIELD NEEDED TO BE PLOUGHED UNDER.

FIGURE 2: A FIELD OF DAMAGED WINTER RAPESEED AFTER A WINTERKILL EVENT. THE DENSITY OF THE DAMAGED LEAVES IS AN INDICATION THAT THE PLANTS WERE ABLE TO DEVELOP SUFFICIENTLY BEFORE THE ONSET OF WINTER.

Photo courtesy of Vereinigte Hagel

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The potential for winterkill damage over a large area can be demonstrated with an example. From the end of January to the beginning of February 2012, a cold spell swept through much of Europe. From central France through to Ukraine and Turkey, cold days with winterkill potential occurred, causing widespread losses to winter crops (MARS Bulletin 2012). This event was further aggravated by a preceding period of high temperatures and a lack of snow. Of course, events may also have more localised impacts, so for example the 2012 event did not cause damage to winter crops in Lithuania as there was a sufficient protective snow layer in the region. On the other hand, the country experienced losses in 2011 when other parts of Europe were not affected. See the info box for more details on this event.

THE CATASTROPHIC WINTER OF 2010/2011

The winter of 2010/2011 was truly catastrophic for both farmers and the agricultural insurance industry in Lithuania. To make matters worse, it was the second winter in a row with winterkill events. As shown in Figure 3, over 80% the country's insured area of winter barley, rapeseed and rye was damaged completely. This left the farmers with no choice but to plough the fields and re-plant them with lower-yielding summer crops.

Through optimal management practices, farmers can improve the chances of their crops surviving winter. These include choosing suitable crop varieties, applying growth regulators to prevent plants from over-developing, or seeding at an appropriate time. However, none of these management strategies is enough when a truly catastrophic event occurs, as it did in in the winter of 2010/2011. For example, although the majority of rapeseed was planted at optimal dates in autumn 2010 and was sufficiently prepared for winter, it was not spared by this event. Even winter wheat and triticale, some of the hardiest winter crops, suffered losses of over 50% of the area sown.

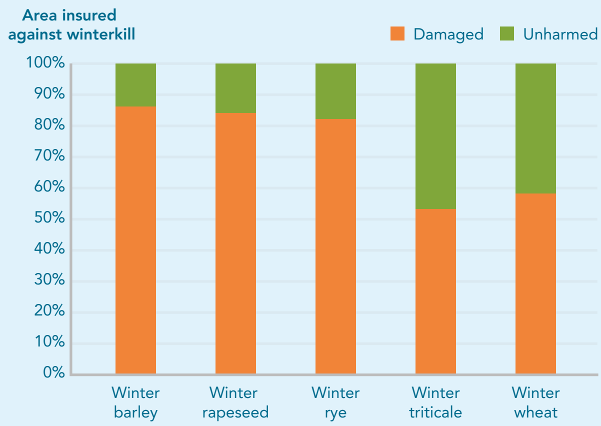


FIGURE 3: THE PERCENTAGE OF THE INSURED AREA IN LITHUANIA THAT NEEDED TO BE PLOUGHED UNDER AND RE-SOWN IN THE SPRING AFTER THE WINTER OF 2010/2011

Source: Vereinigte Hagel own data

In this study we examine the winterkill phenomenon in Lithuania. We have chosen to do so as winter crops constitute over 40% of the planted area of the country[1], and in the last 10 years alone it has experienced three winterkill events (in 2009/2010, 2010/2011 and 2013/2014), all of which had negative impacts on yields and caused large losses to both farmers and the insurance industry. Although nothing can be done to prevent damaging meteorological events from occurring, certain actions, such as buying insurance, can be taken to mitigate their effects. To design appropriate insurance products, it is imperative to understand the frequency and severity of winterkill events. Below we present a methodology for looking at winterkill from a weather perspective and for relating it to plant damage. Although we do this by examining winterkill in Lithuania, the methodology can also be adjusted and applied to other geographies exposed to this risk.

1. Years 2015 and 2016, data accessed via Eurostat on 3 April 2018 (2017 and 2018 data incomplete at the time of writing).

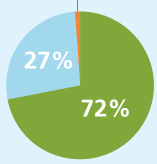
THE REPUBLIC OF LITHUANIA AT A GLANCE

Population

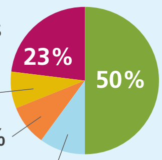
3.0 million

Agricultural area[2]

30,000 km²



Main crops[3]



Surface area

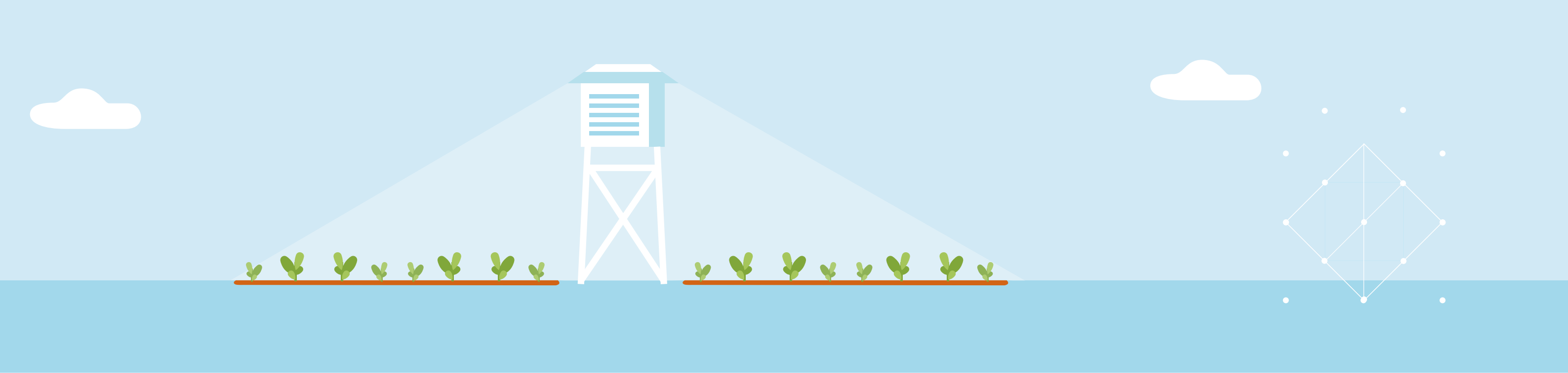
65,300 km²

Lowest air temperature on record
(on 1 February 2015 in Utena)

-42.9°C

FIGURE 4:. LOCATION OF LITHUANIA

2. Food and Agriculture Organization of the United Nations. (2015). FAOSTAT Database. Rome, Italy: FAO. Retrieved 11 April 2018 from http://www.fao.org/faostat/en/#country/126
3. Percentage of sown area in 2016, according to Eurostat statistics available at http://ec.europa.eu/eurostat/data/database.



IDENTIFYING MECHANISMS OF WINTERKILL

In this study, we wish to define winterkill purely in terms of weather. To do this, we need to first identify ways in which damage occurs, and the drivers affecting the amount of damage caused.

HOW CAN DAMAGE OCCUR?

The term "winterkill" is general, and damage can be caused through a range of different mechanisms, acting on their own or in combination with others. In this study, we have chosen to describe four types of winterkill. The list below is by no means exhaustive, and is an attempt to classify the types of events thought to have the most damage potential in Lithuania:

1. **Prolonged freeze** A period of prolonged low temperatures, with frost close to the ground, without a protective, insulating snow layer. Damage is a result of how long the event lasts, as a single day of such low temperatures would not harm the plant.

2. **Intense freeze** Very low temperatures without a protective snow layer; also harmful when they occur for only a short time. The length of time these last also plays a role, but to a lesser extent than for a prolonged freeze event.

3. **Freeze-thaw cycles** Alternation between warm and cold weather over several days without a protective snow layer, which leads to soil displacement and drying out.

4. **Suffocation and rotting** High temperatures occurring for a period of time when there is a thick blanket of snow on the ground. The snow begins to melt, and the runoff water suffocates the plant and can result in its rotting.

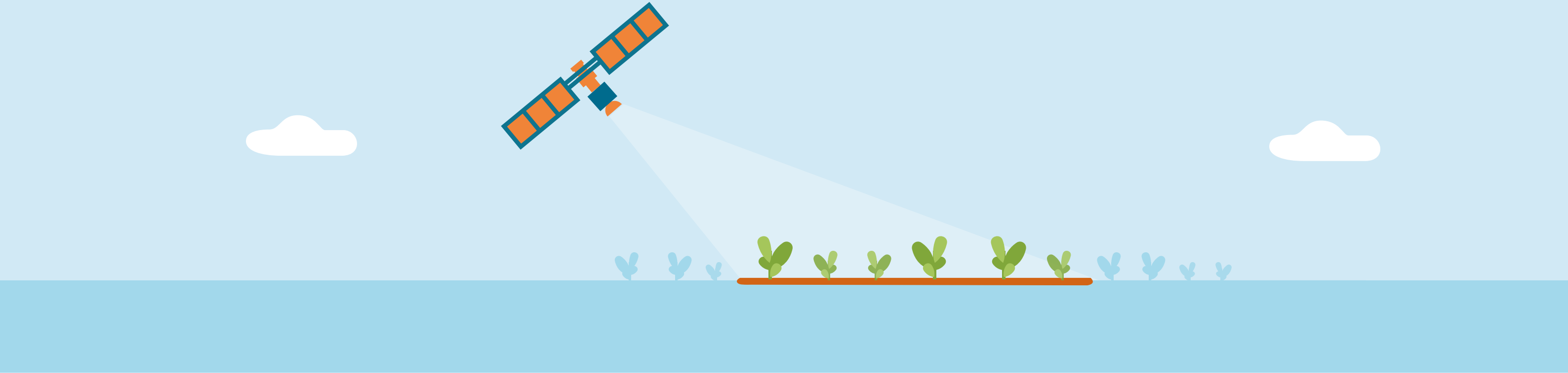
WHAT ARE THE FACTORS IMPORTANT FOR WINTERKILL?

Several factors influence the damage caused on the field. As seen above, when describing the ways in which damage can occur, three factors stand out: temperature, snow cover, and the length of an event, but there are others too. For instance, the type of plant and its intrinsic tolerance to cold temperatures will determine the critical temperature threshold for damage. Winter wheat can withstand temperatures of down to -20°C without a protective snow blanket, whereas for winter rape this is around -15°C. These critical temperatures also depend on plant variety, as well as plant type, soil type, and the plant's stage of development during an event.

Weather conditions prior to an event are also very important. The process of hardening, during which a plant undergoes a series of bio-physiological changes to prepare for winter, can drastically increase its cold tolerance. For instance, killing temperature for a variety of winter wheat called Norstar goes from -3°C prior to hardening to -19°C when it is fully hardened[4]. For hardening to occur, cool (but not killing) temperatures are necessary, and if it is not sufficiently cold in the winter, unhardening can occur. In the 2012 European event described above, the drop in temperatures in late January was preceded by anomalously warm temperatures, which meant plants were not sufficiently hardened for winter, which in turn further aggravated damage.

There are also other factors influencing the extent of damage, such as soil and air moisture, length of day, insolation, wind speeds, and farm management practices, to name a few. In this study, for simplicity we choose to examine only three main drivers: temperature, snow cover, and the length of an event. We also make the assumption that farm management practices are uniform in Lithuania, which although is a gross simplification, is possible due to the country's relatively small area. This approach allows us to examine the frequency of winterkill events in Lithuania.

4. Fowler, D. B. 2002. Winter wheat production manual. [Online] Available at: https://www.usask.ca/agriculture/plantsci/winter_cereals/winter-wheat-production-manual [11 April 2018].



HOW CAN WE DEFINE AN EVENT?

DEFINING WINTERKILL

As illustrated above, due to the large number of mechanisms causing plant damage and factors influencing its extent, defining a winterkill event in terms of meteorological variables is tricky. **We have chosen to examine four mechanisms for damage and do so in terms of three parameters: the length of an event, snow cover, and temperature.** We examine the period between 15 November and 30 April each year, which corresponds to the dates after planting when a plant is most at risk during the winter. In Table 1 we summarise the critical threshold values of the parameters we have chosen for event definition. Note that the thresholds presented in the table reflect values adjusted both for Lithuanian conditions and for use in combination with gridded data, which tends to smooth extremes. See the next section for details on the gridded data used. Different threshold values may need to be chosen for similar studies in other regions.

To define the period of an event, which is shown in the "Event window" column of the table, we use a rolling window approach where, on any given date, we consider the date and the days following it to determine whether an event occurs. We require that within this event window, our conditions defined in terms of snow depth and temperature occur simultaneously on a certain minimum number of days, indicated in the "Days occurring" column. For the temperature, we set thresholds for both the minimum and maximum daily temperatures, and both thresholds need to be satisfied.

• For **prolonged freeze** events, we say that any day within the risk period between 15 November and 30 April was affected by a winterkill event if, on at least 10 of the 15 days starting on that day: the snow cover was less than 10cm deep, and the minimum temperature was below -6°C, and the maximum temperature was no more than 0°C. For instance, to determine whether such an event occurred on 1 January, we would consider the risk period from 1 to 15 January inclusive. If on at least 10 days the snow and temperature requirements are satisfied, we say an event occurs on 1 January, otherwise it does not. We then repeat the process for 2 January, and consider the period between 2 and 16 January inclusive and continue in this manner until we consider all the days of every winter[5].

• For an **intense freeze** event to occur, we require a shorter event window and fewer days occurring within it than for a prolonged freeze event, but for fixed snow depth and maximum temperature thresholds, we require the minimum temperatures to be lower to reflect the different severity of the event.

• For **freeze-thaw cycle** events, damage is driven by the alternation between low (at night) and high (during the day) temperatures, and so although we relax our minimum temperature threshold compared to prolonged and intense freeze events, we require the maximum temperature to be at least 4°C.

• And finally, for **suffocation and rotting** events, we extend the event window to 18 days, on at least 12 of which we require the snow depth to be over 17cm, and the minimum temperatures to be above freezing, causing the snow to melt. In this case, we make no requirement for the maximum temperature.

Winterkill type	Risk time period	Event window	Days occurring	Snow depth threshold	Minimum temperature threshold	Maximum temperature threshold
Prolonged freeze	15 November to 30 April	15 days	10	< 10cm	< -6°C	≤ 0°C
Intense freeze		6 days	4	< 10cm	< -11°C	≤ 0°C
Freeze-thaw cycles		6 days	3	< 10cm	< -4°C	≥ 4°C
Suffocation and rotting		18 days	12	> 17cm	> 0°C	-

TABLE 1: CRITICAL THRESHOLD VALUES OF THE PARAMETERS USED FOR DEFINING WINTERKILL EVENTS

Source: SCOR

5. Note that here and in subsequent parts of the newsletter, the term "winter" refers to the risk period between 15 November and 30 April each year.

DATA USED

For analysis, we use two gridded weather datasets[6], one for snow depth, and one for temperatures.

We use the GlobSnow dataset to obtain the snow depth. The data comes from a combination of satellite and ground-based synoptic weather stations, and has a resolution of approximately 25 km. It is provided for terrestrial non-mountainous regions of Northern Hemisphere from 1979 to the present, and is produced on a daily, weekly, and monthly basis. For more information, see Pulliainen (2006) and Takala et al. (2011). For this study, we use the weekly sliding average data of the snow water equivalent (SWE), a parameter indicating the water column that would theoretically result should the whole snow pack melt instantaneously, defined as a product of the snow layer's depth and density. We obtain the snow depth by assuming a constant snow density of 240 kg/m^3. We exclude the winters of 1981/1982, 1986/1987, 1987/1988 and 1991/1992 from our analysis due to gaps in data. This leaves us with a total of 34 winters between 1979/1980 and 2016/2017[7].

We use the minimum and maximum air temperature at a height of 2 m from the Climate Forecast System Reanalysis[8] (CFSR) created by the National Center for Environmental Prediction (NCEP) (Saha et al., 2010; Saha et al., 2014). CFSR spans the entire globe and is available from 1979 to the present at a 6-hourly resolution. The minimum and maximum 2 m air temperatures are available at a resolution of roughly 50 km. We interpolate these to the same 25 km resolution grid for which snow data is available and aggregate it to a daily time resolution.

WEATHER DATA ANALYSIS AT SCOR

At SCOR we have the capabilities and the technical know-how for a range of different analyses involving weather data, whether we are looking at winterkill in Lithuania, drought in South America or flooding in Asia. We have developed STRATUS, a tool for quickly and efficiently viewing and extracting worldwide weather data from various sources, and which further allows us to link weather and insurance perspectives using methodologies developed in-house. This approach gives us deeper insights into perils of interest and their return period estimates, and is especially valuable for insurance programs with short, unavailable, unreliable, or even non-existent loss histories.

For more information on this and other types of analyses at SCOR, see the technical newsletter Guide to Agriculture Insurance – Part III – Risk Modelling Aspects, which is available on our website.

WINTERKILL HAZARD MAPS

The methodology and data described above are used to obtain winterkill hazard maps for each type of winterkill in Lithuania. These are maps indicating which regions are most susceptible to winterkill and highlighting any geographic differences in the expected frequency of the peril. We obtain the maps by determining the average number of days per winter on which a particular winterkill event type occurs and call this the winterkill index.

These hazard maps are presented in Figure 5. We see that prolonged freeze is the most commonly occurring event in the country, with up to 10 days expected per winter in the eastern regions of Lithuania. This is closely followed by intense freeze, with up to 6 days expected in the same regions. The other two events, although they have occurred historically, are not as common and are expected only on at

6. Gridded data refers to geospatial data which is provided for each point in space defined by a grid. It can be obtained, for example, by interpolating point data (e.g. from weather stations) to a grid.

7. Data for the season 2017/2018 was not available at the time of writing.

8. A reanalysis is a dataset which provides a complete, global view of the state of the atmosphere by initialising a Global Circulation Model (representing the dynamics of the atmosphere) with observational data coming from a range of possible sources such as satellite measurements and station data.

most 0.8 days (freeze-thaw cycles) and 0.2 days (suffocation and rotting) each winter.

The hazard maps indicate that there is an east to west gradient, with the eastern, coastal regions being less exposed to the risk of prolonged and intense freeze events than the western regions, which are more affected by cold and dry continental weather. Due to the limited occurrence of freeze-thaw cycles and suffocation and rotting events, it is difficult to draw similar conclusions about them.

Such hazard maps allow us to compare how the risk of winterkill differs between regions, but it is difficult to draw any conclusions about the expected frequency/severity of events. Events which are rare, but long (i.e. they are less frequent, but more severe), produce similar maps to relatively frequent but much shorter (i.e. less severe) events. We address this issue next by looking in more detail at when events occur and how long they last.

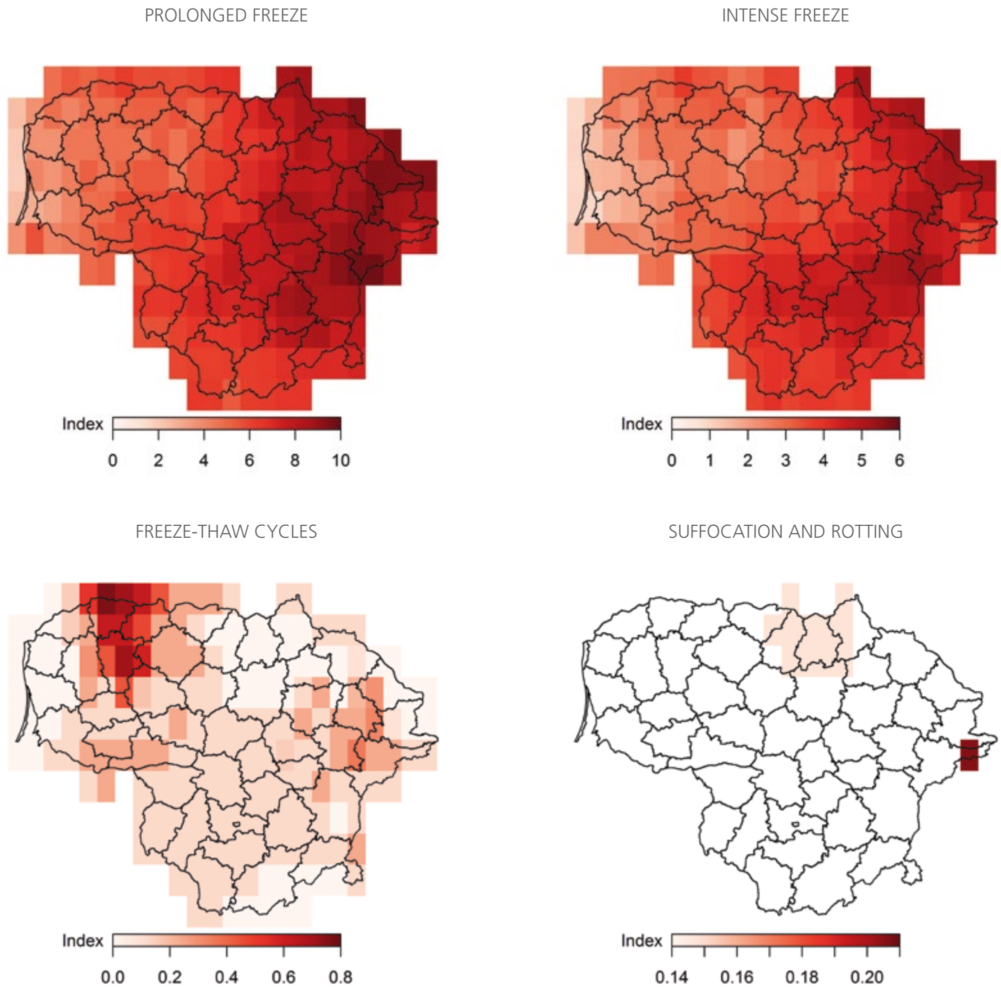
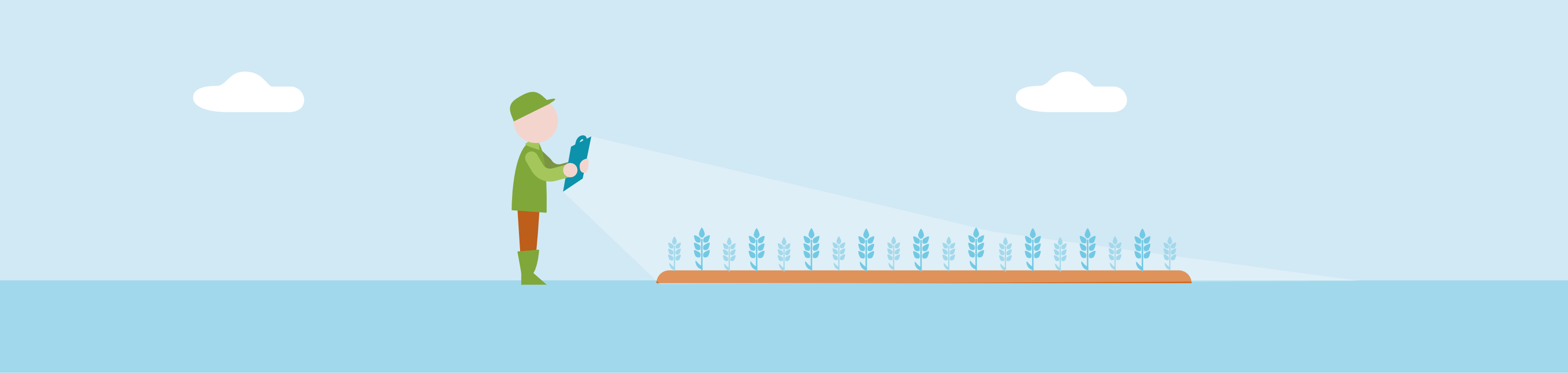


FIGURE 5: WINTERKILL HAZARD MAPS FOR EACH OF THE FOUR TYPES OF WINTERKILL FOR THE TIME PERIOD 1979/1980 TO 2016/2017. NOTE THAT FOUR SEASONS HAVE BEEN EXCLUDED WITHIN THIS TIME PERIOD DUE TO DATA LIMITATIONS

Source: SCOR



WHEN AND WHERE HAVE WINTERKILL EVENTS OCCURRED HISTORICALLY?

We now examine in more detail when and for how long each type of winterkill has occurred historically. We do this by determining if an event occurs on each day, of each winter, at each grid point, as we did in the previous section. We then examine events per municipality (*savivaldybės*) in Lithuania[9]. To do this, we determine which grid points fall into each municipality, and for each day of each season determine what proportion of the area of this municipality was affected by a winterkill event. If this is over 50%, we say that a winterkill event has occurred in that municipality, otherwise we say it has not. We apply this restriction on the extent of the event in order to detect only the large events with catastrophic damage potential. The results of this analysis are shown for the Joniškis municipality, the location of which is shown in Figure 6. We have chosen this region as it contains some of the most fertile soils in Lithuania.

In the upper left-hand panel of Figure 7 we indicate the dates between 15 November and 30 April (x-axis) on which winterkill events occurred. The y-axis corresponds to each winter considered. For each winter, we indicate the occurrence of the four types of winterkill events with coloured bars. In the right-hand panel, we also show the total number of days affected by a winterkill event per winter, and in the bottom panel we show the frequency of occurrence on each date.

We see that prolonged and intense freeze events are most common, as was already seen in the hazard maps. We also see that very often these two types of events occur simultaneously, which is not surprising given the similarities in their definition. In Joniškis a suffocation and rotting event has never occurred (at least in the period for which data is available since the winter of 1979/1980), and a freeze-thaw cycle has occurred only once, in the winter of 1980/1981. Winterkill has most often occurred between mid-January and mid-February, but earlier and later events are also possible, especially for prolonged freeze.

Figure 7 allows us to estimate the return periods of specific winters and of events of a certain length. For example, the winter of 2010/2011 had almost 20 days, occurring between the end of November to mid-December, on which prolonged freeze occurred. A winter like this occurred only once in the 34 years we consider, and so we assign a return period of 34 years to it. The winter of 2002/2003 had the second highest amount of days affected by prolonged freeze, and so we assign it a return period of 17 years (which is equal to 34 years divided by 2 events of this magnitude or more). We can continue in this way for all winters and event types and can also apply this approach to single events of specific length, not only to whole winters, and as well as to combinations of events.

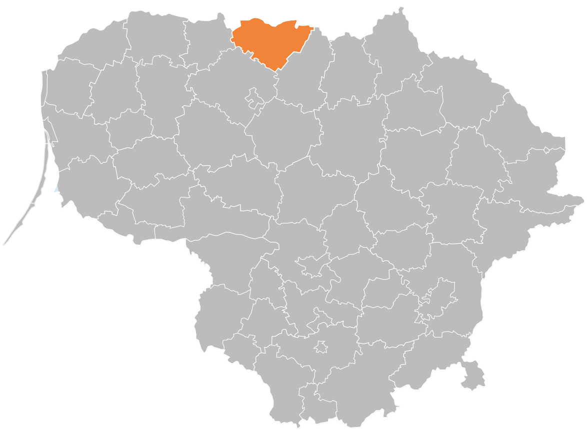
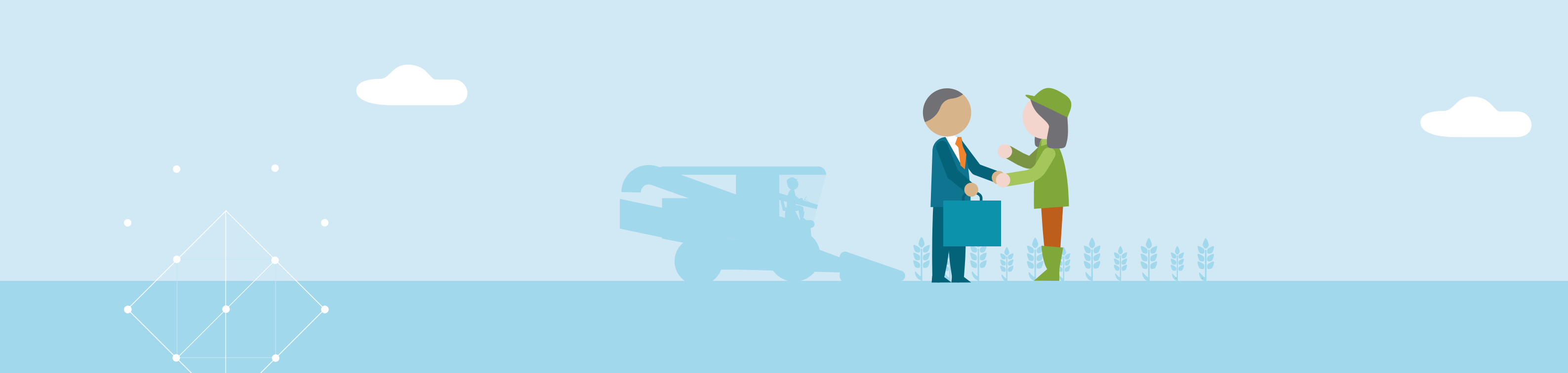


FIGURE 6: LOCATION OF THE MUNICIPALITY JONIŠKIS IN LITHUANIA

9. On average these are around 1400 km².



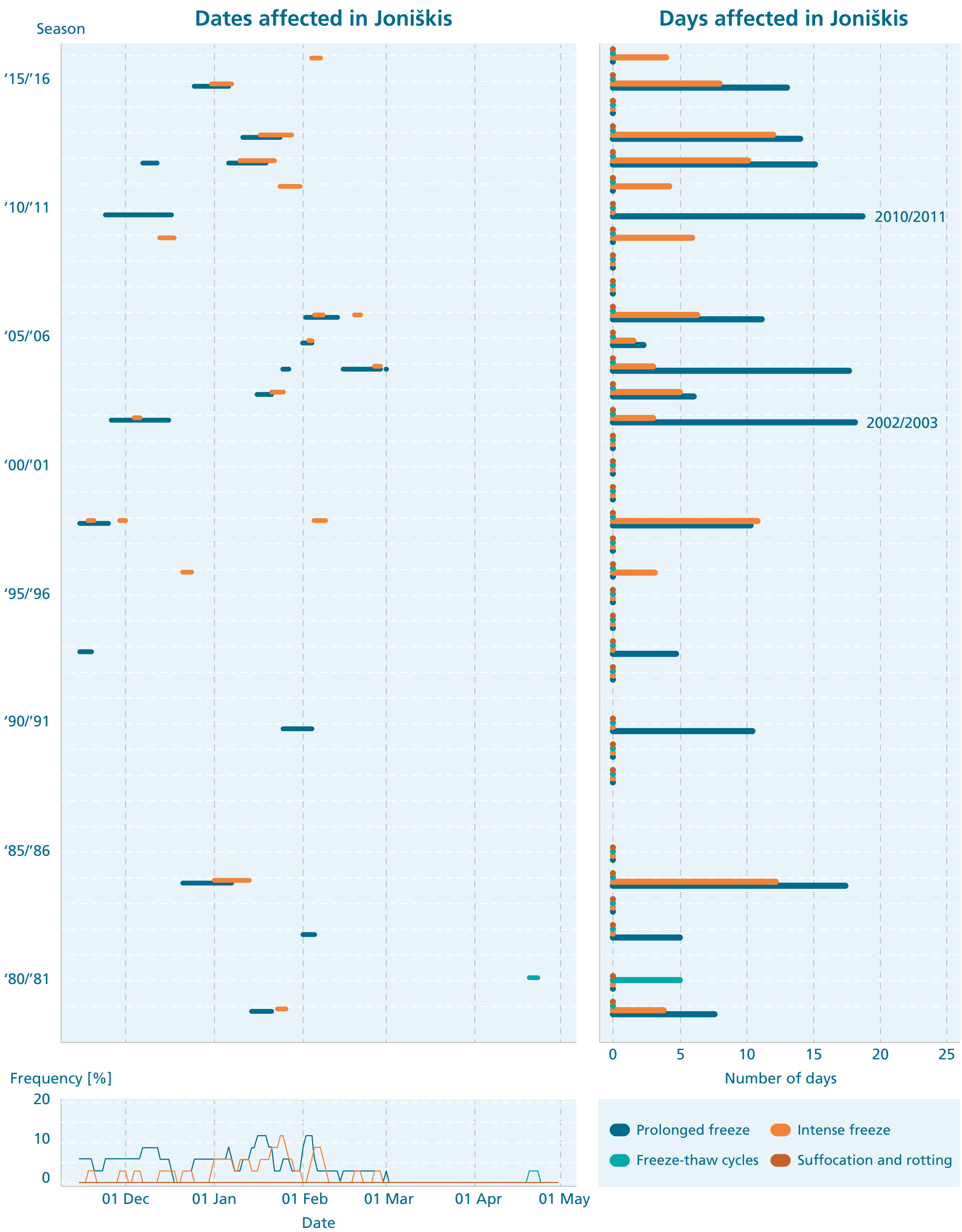


FIGURE 7: RESULTS SHOWING WHEN AND HOW OFTEN WINTERKILL EVENTS ARE EXPECTED TO OCCUR IN LITHUANIA FOR THE JONIŠKIS MUNICIPALITY

Source: SCOR

MODELLING OF WINTERKILL LOSSES IN LITHUANIA FROM A CROP INSURER'S PERSPECTIVE

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Vereinigte Hagel is a German insurer specialized in the coverage of weather-related crop loss. Dr. Nöhles has been working for Vereinigte Hagel since 1999 and supports, together with her fellow team members, the development and pricing of insurance products for various EU countries.

There is an increasing awareness of weather risks among farmers in the modern market-oriented agriculture industry in Lithuania. The demand for coverage of weather-related crop loss is growing continuously and is further boosted by government / EU premium subsidies of up to 65%. Due to the influence of the continental climate, the risk of frost damage in the period of dormancy ("winterkill") is particularly high for crops such as winter cereals and winter rapeseed. Only a small amount of historical data is available about winterkill-related crop loss in Lithuania, thus one needs to rely on alternative sources of information. Launching "long-term" insurance solutions on the Lithuanian market requires demand-oriented product development, profound loss adjusting expertise and, most of all, in-depth risk assessment that allows for the setting of insurance premiums which reflect local production conditions.

The development of a risk model to quantify winterkill-related crop loss in Lithuania can make a significant contribution here. Identifying major winterkill events (e.g. in the 2010/2011 winter season) and their return periods, and taking into account regional differences – also in case of minor and moderate winterkill damage (e.g. in the winter seasons 2009/2010 or 2013/14) – all play a major role in this context. In agriculture insurance, the insured farmers typically have a good understanding and long-term experience when it comes to weather-related crop loss at individual farm level. In view of this, pricing the insurance as accurately as possible is indispensable to counter the asymmetry of information (adverse selection) and to create insurance products featuring stable premium rates that ensure market acceptance in the long run.

However, it should be noted that loss models which simulate the impact of extreme weather events should be carefully interpreted and cannot be used to fully replace an individual (on-site) assessment. There are several reasons for this, especially when talking about crop insurance:

Complex yield formation

Yield formation largely depends on weather conditions during the growing season. Even though extreme frost events can cause significant damage, the actual impact on crop yield is extremely difficult to quantify. Adverse weather events of a comparable nature may result in different levels of yield loss and indemnity payments subject to weather conditions in previous and subsequent periods, choice of crop variety, farming practices (e.g. date of sowing, crop management) as well as local geographical factors (e.g. soil type, soil moisture). The modelling of winterkill losses therefore requires accurate identification and quantification of the parameters influencing crop yield.

Data quality and model validation

The quality of the simulation model can only be validated by comparing its results with actual loss events. Portfolio and yield loss data gained from Lithuanian winterkill insurance are good indicators in this respect. Insurance practice has proven that snow cover during cold weather periods (especially snow depth and regional distribution) is an essential parameter for the impact of winterkill; even snow cover of a few centimetres may have a significant effect on plant survival. In this context, it needs to be examined whether exact results can be obtained from the available weather data.

Climate change

Weather-based loss models only allow for a retrospective assessment of winterkill. These models do not consider whether and to what extent the number of winterkill losses will increase or decrease in the future. At first glance, global warming may seem to reduce winterkill events; however, losses in recent years (as in the 2010/11 winter season) have been a good reminder to be cautious. Warm spells in winter (de-hardening of winter crops) and reduced snow cover during cold spells (no insulating effect) are adverse effects of global warming.

Weighing up opportunities against potential risks

Even though there are still some uncertainties in the modelling of winterkill events in Lithuania, the results obtained from it are very valuable, especially in view of insufficient historical data. These findings not only provide an overview of comparable weather conditions, their spatial extent and return periods; they also help to identify areas at high risk of winterkill and allow us to set premium rates tailored to the actual risk.

CONCLUSIONS AND OUTLOOK

We have shown above how defining the winterkill peril from a weather perspective gives us insights into the frequency and location of the event. **Through our methodology we have been able to identify historical loss-causing events, and to assign return period estimates to them. This knowledge can be used by insurers to design products that help farmers to mitigate their exposure to risk.**

The methodology presented here is just a first step for linking meteorological analysis and on-field know-how, and still has several challenges to overcome. For instance, we have seen that there are many different mechanisms for winterkill damage, and so defining a winterkill event is challenging. Furthermore, there are many factors affecting the severity of damage, and selecting the most important ones, which also allow us to capture the non-binary nature of winterkill, is non-trivial. Data availability and limitations are also a problem. Gridded data may be too coarse to capture very local phenomena, and detailed loss data, which is not always available, is necessary to validate the model. In general, it is very important to work with clients who have on-field experience to validate the model and adapt it to the situation on the ground.

There are several ways in which the model can be extended to more realistically model winterkill. For example, a measure of severity beyond simply looking at the number of days affected by an event can be included. As the condition of a plant prior to the event is crucial to its survival, the model can be extended to include a proxy for this. This could be done either by looking at plant development in the autumn before the onset of winter, or at the meteorological conditions directly prior to an event that could cause a plant to unharden.

Overall, the model is a first and important step for understanding winterkill and can greatly assist with risk assessment in the absence of long data histories. We have already started looking at ways of further extending it to more realistically model the risk of winterkill.

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