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CONTRIBUTIONS

IMPACTS OF WEATHER AND CLIMATE ON MORTALITY AND SELF-HARM IN FINLAND

REIJA RUUHELA

FINNISH METEOROLOGICAL INSTITUTE
CONTRIBUTIONS
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Impacts of Weather and Climate on Mortality and Self-harm in Finland

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Whoever would study medicine aright must learn of the following subjects. First he must consider the effect of each of the seasons of the year and the differences between them. Secondly he must study the warm and the cold winds, both those which are common to every country and those peculiar to a particular locality.

Hippocrates, ‘‘Airs, Waters, Places’’,
ca. 400 B.C.E.

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Abstract

Human beings are able to adapt to their climatic normal conditions, but weather extremes may pose a substantial health risks. The aims of this dissertation were to model the dependence of all-cause mortality on thermal conditions in Finland, and to assess changes in the relationship over the decades and regional differences in the relationships between hospital districts. Another aim was to assess impacts of weather and climate on committed and attempted suicides Finland. Various methods were applied in these studies.

Time series of all-cause mortality in three age groups in Helsinki-Uusimaa hospital district were made stationary, and thus the weather impacts were comparable over the 43-year long time period regardless of changes in population and life-expectancy. The increase in relative mortality due to hot extreme was more than due to cold extreme, when compared to seasonally varying expected mortality. However, a decrease in relative mortality in extreme temperatures over the decades was found in all age-groups, even among the 75 years and older, indicating decreased sensitivity to thermal stress in the population.

Regional differences in temperature–mortality relationships between 21 hospital districts were studied using distributed lag non-linear models (DLNM), and the differences were assessed by meta-regression with selected climatic and sociodemographic covariates. Regional differences in the relationships were not statistically significant indicating that the same temperature-mortality relationship can be applied in different parts of the country. On the other hand, the meta-regression suggested that the morbidity indices and population in the hospital districts could explain part of the small heterogeneity in the temperature–mortality relationships.

The study on committed suicides on the basis of 33-year long time series showed a significant negative association between suicides and solar radiation in the period from November to March, thus, a lack of solar radiation would increase suicide risk in winter. Men appeared to be more sensitive to variation in solar radiation than women. The study on weather dependence of attempted suicides in Helsinki on the basis of two shorter periods showed another difference between genders. The risk of suicide attempts of men increased with decreasing atmospheric pressure, while the risk of suicide attempts of women increased with increasing pressure.

The outcomes of this thesis can be utilized e.g. in preparedness to weather extremes in health sector and in further studies on impacts of climate change on human health.

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Tekijä
Reija Ruuhela

Nimeke
Sään ja ilmaston vaikutukset kuolleisuuteen ja itsetuhoisuuteen Suomessa

Tiivistelmä

Ihmiset sopeutuvat ilmastonsa tyypillisiin olosuhteisiin, mutta äärevät säätilanteet voivat aiheuttaa merkittäviä terveysriskejä. Tämän väitöstyön tavoitteena oli mallittaa kuolleisuuden riippuvuutta lämpöolosuhteista Suomessa ja arvioida siinä tapahtuneita muutoksia vuosikymmenien kuluessa sekä selvittää mahdollisia alueellisia eroja sairaanhoitopiireittäin. Lisäksi tavoitteena oli arvioida sään ja ilmaston vaikutuksia itsemurhiin Suomessa ja itsemurhayrityksiin Helsingissä. Tutkimuksissa sovellettiin useita erilaisia menetelmiä.

Helsingin ja Uudenmaan sairaanhoitopiirin kuolleisuuden 43 vuoden mittaiset aikasarjat kolmessa ikäryhmässä muunnettiin stationaarisiksi, jolloin lämpötilan vaikutukset kuolleisuuteen olivat vertailukelpoisia väkiluvussa ja eliniässä tapahtuneista muutoksista huolimatta. Kun kuolleisuusriskiä verrattiin vuodenajan odotusarvioihin, kuumuuden aiheuttama kuolleisuuden nousu oli suurempi kuin kylmyyden. Kuolleisuusriski äärilämpötiloissa on kuitenkin alentunut vuosikymmenien aikana kaikissa ikäryhmissä – jopa yli 75-vuotiaiden keskuudessa, mikä viittaa siihen, että väestön herkkyys äärilämpötiloille on pienentynyt.

Kuolleisuuden lämpötilariippuvuuden eroja 21 sairaanhoitopiirin välillä tutkittiin käyttäen viiveellisiä epälineaarisia malleja (DLNM), ja eroja arvioitiin meta-regression avulla käyttäen kovariaatteina valittuja ilmastollisia ja sosiodemografisia tekijöitä. Tutkimuksen mukaan alueelliset erot eivät olleet tilastollisesti merkitseviä, joten samaa kuolleisuuden lämpötilariippuvuutta voidaan käyttää eri puolilla Suomea. Toisaalta meta-regressio antoi viitteitä siitä, että sairaanhoitopiirien sairastavuusindeksit ja väestömäärät voivat selittää pientä heterogeenisyyttä kuolleisuuden lämpötilariippuvuudessa.

Tarkasteltaessa 33 vuoden ajanjaksoa Suomessa toteutuneiden itsemurhien ja globaalisäteilyn välillä oli negatiivinen korrelaatio marras-maaliskuun välisellä jaksolla, eli auringonvalon vähäisyys lisäisi itsemurhien riskiä. Miehet olivat herkempiä auringonsäteilyn vaihtelulle kuin naiset. Tutkimus Helsingin itsemurhayritysten sääriippuvuudesta kahdella lyhemmällä jaksolla toi esiin toisen sukupuolten välisen eron. Miesten itsemurhayritysten riski kasvoi matalapaineen vallitessa, kun naisten itsemurha-yritysten riski kasvoi ilmanpaineen myötä.

Näitä tutkimustuloksia voidaan hyödyntää muun muassa terveydenhuollon varautumisessa sään ääri-ilmiöihin ja tutkimuksissa ilmastonmuutoksen vaikutuksista ihmisten terveyteen.

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Preface

My interest in health impacts of weather and climate originates around year 2000, when Ministry of Health and Social Affairs made an initiative to the Finnish Meteorological Institute (FMI) to develop weather service for pedestrians in order to reduce and prevent winter-time slipping injuries. During that work my original ambivalence on the health impacts of weather and climate turned into enthusiasm – I realized how important and wide, yet underrated, a topic it was. Ever since I've been looking for new possibilities to do human biometeorological research. I am grateful to Prof. Timo Partonen, Prof. Timothy Carter and Docent Kirsti Jylhä for their interest to include health-impact studies into their projects and, in practice, arranging possibilities for me to conduct this research. I am also grateful to the Vilho, Yrjö and Kalle Väisälä Foundation for providing me a grant to collate research findings into this dissertation and putting the outcomes in a wider context of current scientific knowledge on the health impacts of weather and climate. Without this grant, I doubt if I would ever have had the possibility to find enough time to finalize the dissertation. My supervisors, Prof. Heikki Järvinen and Docent Ari Venäläinen helped me in setting the structure for my thesis and encouraging me to finalize it even though my path has never been straightforward.

Making health-impact research has been and is challenging but also very rewarding. Throughout the process I have learned so many new interesting things. I like to thank especially Prof. Andreas Matzarakis, who greatly helped by sharing German biometeorological expertise with me, and made my visit in the Research Center of Human Biometeorology at the German Meteorological Service (DWD) in the spring of 2016 both useful and fun. In Finland I have had good collaboration with many experts in the health sector: I would like to thank all my co-authors from the National Institute for Health and Welfare (THL) with special thanks to Laura Hiltunen, Timo Partonen, Timo Lanki and Pekka Tiittanen for their patience in explaining to me the complex issues related to health and epidemiological research. My co-authors in FMI – Ari Venäläinen, Pentti Pirinen, Kirsti Jylhä and Otto Hyvärinen – I would like to thank for following me to "unknown" and helping me to clarify both aims and results from the meteorological point view and supporting me in my moments of doubt. I am grateful to Curtis Wood for checking my English language and the interesting discussions it lead to and Sanna Luhtala for valuable advices for both Finnish and English expressions. Finally, I would like to thank all my colleagues at the FMI, especially in our unit – a good workplace boosts innovative thinking and easy-going collaboration is a joy in our daily affairs.

However important and meaningful the work is, family and friends are far more important and carry longer than any career. My parents have always encouraged me for further education and have showed a good example on how curiosity to life maintains a good quality of life. My son, Tarek, has been keeping my mind young by challenging me continuously with new ideas and viewpoints. Enjoyable and refreshing leisure time with friends provides also inspiration for the scientific work. Thank you being in my life.

Helsinki, October 2018

Reija Ruuhela

Contents

List of original publications

I Ruuhela R, Jylhä K, Lanki T, Tiittanen P, Matzarakis A, 2017. Biometeorological Assessment of Mortality Related to Extreme Temperatures in Helsinki Region, Finland, 1972–2014. Int. J. Environ. Res. Public Health 14(8), 944. doi:10.3390/ijerph14080944.

II Ruuhela R, Hyvärinen O, Jylhä K, 2018. Regional Assessment of Temperature-Related Mortality in Finland. Int. J. Environ. Res. Public Health 15(3), 406. doi:10.3390/ijerph15030406.

III Ruuhela R, Hiltunen L, Venäläinen A, Pirinen P and Partonen T, 2009. Climate impact on suicides rates in Finland from 1971 to 2003. Int J Biometeorol 53:167-175. doi:10.1007/s00484-008-0200-5.

IV Hiltunen L, Ruuhela R, Ostamo A, Lönnqvist J, Suominen K and Partonen T, 2012. Atmospheric pressure and suicide attempts in Helsinki, Finland. Int J Biometeorol 56:6, 1045-1053. doi: 10.1007/s00484-011-0518-2.

In articles I – II the author conducted all the analysis and wrote the articles taking into account the comments of the co-authors. In article III the author conducted the analysis and wrote most of the article. In article IV the author conducted synoptic analysis and preliminary statistical analysis for more detailed analysis and participated in writing the article as an expert in meteorology.

1. Introduction and objectives

Impacts of weather and climate on human health have been considered important since Hippocrates' times in antiquities, but have been underrated in the 20th century when fast progress in modern medicine has taken place. The awareness on adverse health impacts of weather and climate started to increase especially after the heatwave in 2003, that caused about 70 000 extra deaths in Europe (Robine et al., 2008). In the future, heatwaves will become longer and more intensive due to climate change, while cold stress is expected to decrease because of climate change (Smith et al., 2014).

Depressive disorders are a major public health problem worldwide (WHO, 2017a). Weather and climate also affect the mood of people, and seasonal affective disorder is a recognized mental condition especially in high-latitude areas (Magnusson, 2000). Seasonality of suicides with a peak in late spring or early summer is well known but the reasons for this seasonal pattern are not fully understood. Typically it has been connected with increasing amount of sunshine in spring.

This thesis focuses on direct health impacts of weather and climate in Finland via different mechanisms. Both heat stress and cold stress lead to physiological responses that may contribute to mortality. The impacts of heat and cold stress were studied by comparing daily climate data and all-cause mortality in hospital districts.

The aims were to:

- Model the relationship between mortality and thermal environment using various modelling methods and biometeorological indices for thermal comfort.
- Study changes in the mortality related to temperature extremes over decades, 1972–2014, in various age groups.
- Assess regional differences in temperature-related mortality in Finland.

The mental health impacts of weather and climate were studied by comparing climate factors and deaths from suicide in Finland over three decades (1971–2003), and weather impacts on suicide attempts in Helsinki for two shorter periods.

The aims related to the mental health impacts were to:

- Explore the role of meteorological variables in the variation of number of deaths from suicides in Finland.

- Study the role of weather as a trigger for suicide attempts in Helsinki.

In Finland the research and awareness on health impacts of weather and climate has been quite limited – notwithstanding the studies of a few forerunners. This thesis aims also for raising awareness about health impacts of weather and climate and enhance the basis for further multi-disciplinary research collaboration. Furthermore, themes of this dissertation are relevant in planning climate change adaptation measures in the health sector. An important motivation for health impact studies is a need to understand how climate change will affect health risks together with the socio-demographic changes, such as aging population and urbanization, that will take place in Finland in the future.

2. Background

The scientific articles included in this thesis focus on weather and climate dependence of mortality and self-harm. There are numerous studies on the relationships between mortality and temperature and less on weather-related morbidity and the impacts of weather on symptoms of the chronically ill (Oudin Åström et al., 2011; Bunker et al., 2016). However, weather-related morbidity and disease exacerbation of weather-sensitive individuals may lower the quality of life and increase need for health services, and thus research on weather and climate impacts on morbidity is relevant. Therefore this Background chapter begins with a wider discussion on the adaptation of people to climatic conditions, and generic weather sensitivity, followed by more detailed discussion on relationships between meteorological factors and mortality and mental health.

2.1. Human adaptation to variation of climate and amount of light

Human beings have successfully adapted to various thermal environments and spread to live in almost all climatic zones on the globe. Adaptation to climatic conditions of the living environment can take place through various behavioural (housing, clothing) and physiological processes on different time scales.

Genetic adaptation takes place over a long period of time. Skin colorization and basal metabolic rate (energy consumption at rest) are typical examples of genetic adaptation to regional climatic conditions (Jablonski and Chaplin, 2000; Leonard et al., 2002; Hancock et al., 2011). The best cold-adapted people are found in Arctic areas and the best heat-adapted people in tropical areas.

Seasonal acclimatization takes a few weeks in the beginning of the hot or cold season (Koppe and Jendritzky, 2005; De Freitas and Grigorieva, 2015). The physiological changes related to this short-term acclimatization are not permanent, and they take place annually or when people move to stay in new climate zone.

People have developed sophisticated biological mechanisms, circadian clocks, to adapt to daily (circadian) and seasonal variation in light (Coomans et al., 2015; Honma, 2018). The hypothalamic suprachiasmatic nucleus in the brain acts as the principal circadian clock and synchronizes the functions of other clocks in peripheral tissues. Disturbances in the circadian rhythms have been suggested to be associated with both physical and mental health problems such as cardiovascular, metabolic and neuropsychiatric diseases (Hastings et al., 2003;

Karatsoreos, 2015; Preußner and Heyd, 2016). However, it is not clear up to date if circadian disruption is a symptom or reason for diseases. Recently Liberman et al. (2018) presented a model to investigate mechanisms how circadian clock genes lead to mood and circadian disorders.

2.2. Weather sensitivity

In spite of human's adaptation capability, weather and climate affect human health and quality of life. The impacts depend on exposure to particular weather types and relevant individual characteristics such as age, body size and composition, fitness, health, medication and behaviour. Possibilities to reduce the exposure and recover from adverse impacts depend also on a range of socioeconomic factors such as education, income, social isolation, health care provision and urban design (Carter et al., 2016; Benmarhnia et al., 2015).

Weather and climate have some impact on all people, at least on the behaviour and outdoor activities, but some individuals are more sensitive to weather than others. Generic weather sensitivity, meteorosensitivity, has been studied mainly through surveys, where people themselves report the impacts of weather on their well-being and their weather-dependent symptoms. In surveys conducted in Germany and Canada, about 55% and 61% of the population (Von Mackensen et al., 2005) reported that weather affects their well-being. Among the most frequent weather-related symptoms that were listed were e.g. headache and migraine, sleep disturbances, fatigue, pain in joints and depression. Most common weather types that cause problems for well-being are related to cold or stormy weather. Typically women are more sensitive to weather than men and weather sensitivity increases with age. According to a German survey, within the group of people who consider themselves weather sensitive 76% had chronical illnesses (Koppe et al., 2013).

The chronically ill are sensitive to different weather variables. The majority of studies report on the significant relationship between temperature and total or cause-specific morbidity including cardio-vascular and pulmonary diseases and diabetes, as well as emergency transport and hospital admissions (Ye et al., 2012). A high risk of epileptic seizures has been associated with low atmospheric pressure and high relative air humidity, whereas high ambient temperatures seem to decrease seizure risk (Rakers et al., 2017). Strokes have been associated with short-term changes is both high and low temperatures (Lian et al., 2015). A statistically

significant association has not been found between strokes and atmospheric pressure or humidity (Cao et al., 2016).

Quality of life and mental health have a clear seasonality. For example Jia and Lubetkin (2009) investigated the general Health Related Quality of Life (HRQoL) among the U.S. population and found out that physical HRQoL was best during the summer and worst during the winter, but the worst mental health occurred during the spring and fall. Grimaldi et al. (2008) found out that in a Finnish population lower HRQoL and more severe mental ill-being were associated with greater seasonal changes in mood and behaviour and poor illumination experienced indoors.

In Finland, surveys on impacts of hot and cold on symptoms and thermal sensations have been conducted in context of national FINRISK-surveys. Almost half of the subjects (46%) reported some kind of cold-related symptoms (Näyhä et al., 2011); particularly people with pre-existing medical conditions experience cardiovascular, respiratory or musculoskeletal symptoms in the cold. About 80% of adult population perceive heat-related general cardiorespiratory or psychiatric symptoms even during a normal summer, and 26°C was on average considered as hot. Most symptoms increase by age, except feelings of thirst declines with age, and the symptoms are more prevalent in women than men (Näyhä et al., 2014). The prevalence of heat-related cardiorespiratory symptoms was 12% varying between 3% and 60% depending on several factors. Heat-related cardiorespiratory symptoms are most common among people with pre-existing lung or cardiovascular disease, agricultural workers, unemployed, pensioners, and people having only basic education (Näyhä et al., 2017).

Many of the weather-related symptoms cannot be correlated to any single meteorological variable, but rather to a weather type, which poses challenge to study methods. Furthermore, a weakness of survey-based research method is that even though a big share of the variation of the symptoms would be explained by weather variability, the causal pathways cannot always be well explained. The best-understood responses to weather conditions are the consequences of exposure to heat or cold.

2.3. Human responses to variation in thermal conditions

Physiological responses to the heat and cold stress can be described with the human energy balance model. The model development has started in early twentieth century, but current scientific understanding on thermal comfort is firmly based on the studies conducted in sixties and seventies, and a classic work of Fanger (1970).

The energy balance model is based on thermoregulation of humans: the body aims to maintain a core temperature of about 37°C, which is vital for the function of internal organs. If the subject is exposed to cold stress, the blood vessels contract, and the blood circulation in the outer parts of the body is reduced and skin temperature decreases. The body begins to react to cold exposure also by e.g. shivering in order to start producing heat through muscular work. Conversely, when the subject is exposed to heat stress, the blood vessels enlarge, and the blood circulation in outer parts of the body increases in order to transfer excess heat from the core of the body. Excess energy is also used for sweating and evaporation of the sweat. Severe heat or cold stress can lead to severe symptoms or even death.

Thermal stress or thermal comfort of humans depends not only on ambient temperature but also on humidity, wind speed and radiation. The energy exchange between environment and the human body can be described with a heat budget model as follows (Jendritzky and de Dear, 2008):

$$M - W - [Q_H(T_a,v) + Q^*(T_{mrt},v)] - [Q_L(e,v) + Q_{SW}(e,v)] - Q_{Re}(T_a,e) \pm S = 0, \qquad (1)$$

where M is metabolic rate of the subject, W is mechanical work of the subject, S is the storage term describing the change in heat content of the body. Other energy terms in the equation are also functions of meteorological factors. $Q_H(T_a,v)$ describes the turbulent flux of sensible heat that depend on air temperature (T_a) and wind velocity (v). $Q^*(T_{mrt},v)$ is radiation budget, where the mean radiant temperature (T_{mrt}) describes the temperature as a consequence of short- and long-wave radiation fluxes. Turbulent fluxes of latent heat by diffusion of water vapour (Q_L) and sweat evaporation (Q_{SW}) depend on water vapour pressure (e) and wind velocity (v). Energy loss in respiration (Q_{Re}) depends on air temperature and water vapour pressure.

The complex energy transfer between the core and outer parts of the body and the insulation of clothing are not explicitly mentioned in this equation while putting the emphasis of meteorological factors, but these factors are essential and embedded into the energy terms

(Parson, 2003). The energy exchange between the environment and human body depend also on individual characteristics such as age, weight, gender, health and acclimatization, and environmental factors e.g. in the built environment (Rupp et al., 2015). The role of beige and brown fat in individual differences and thermoregulation in cold may be substantial. Brown adipose tissue (BAT) contributes to energy expenditure and cold-induced thermogenesis in humans, and thus, impacts on the responses of humans to cold exposure (Kiefer, 2017; Yoneshiro et al., 2016).

There are only a few rational thermal indices i.e. that are based on human energy balance. The state-of-the-art in the field is UTCI (Universal Thermal Climate Index, Blazejczyk et al., 2012; Blazejczyk et al., 2013). However, e.g. in comparative study of Morabito et al. (2014), it was found that UTCI did not perform as well as expected in health impact studies. Yet, they concluded that thermal indices, which include air temperature, humidity, wind speed and solar radiation, correlate best with health impacts. In Article I of this thesis, daily mortality is compared to values of Physiologically Equivalent Temperature, PET (Höppe 1993; 1999). PET is also based on an energy budget and its values are given in degrees Celsius. PET-values in the selected thermal environment are equal to similar thermal conditions indoors described by temperature. Since it is impossible to calculate the heat stress at an individual level in a larger population, the PET-values are typically calculated using standard values for light activity (work metabolism 80W) and thermal resistance of clothing (0.9), which could be described as clothes that people wear on cool summer day. The meteorological input variables need to be transferred to the height of typical person: mass centre (1.1m) (Höppe, 1999; Matzarakis et al., 1999).

Earlier, hundreds of different thermal indices have been developed for assessing indoor or outdoor thermal comfort (e.g. review of Taleghani et al., 2013). Quite often in research on health impacts of weather and climate, only temperature or simple empirical indices are used. Simple indices are typically combinations of two or more meteorological variables.

2.4. Temperature dependence of mortality

The heatwave of 2003 in western and central Europe caused about 70 000 excess deaths (Robine et al., 2008) and the heatwave of 2010 over Russia about 55 000 excess deaths (Barriopedro et al., 2011). Both of these heatwaves extended also to Finland. According to Kollanus and Lanki (2014), the number of non-accidental extra deaths was over 200 in 2003 and more than 300 in

2010. The impacts were most severe among the elderly, aged 75 years and older, as the daily mortality increased on average by 21%. An exceptional heatwave took place in Finland in 1972 causing about 800 extra deaths. After that, remarkable heatwaves with increased mortality occurred also e.g. in 1973, 1978, 1988, 1995 and 1997 (Näyhä, 2005).

The relationship between thermal environment and mortality is widely studied and well understood. The temperature–mortality relationship can be described as U-, V- or J-shaped (Armstrong, 2006; Kovats and Hajat, 2008; Gosling et al., 2009). The mortality increases towards both extremes of the temperature distribution, and the range of the minimum mortality temperature (MMT) varies according to the latitude and geographical area (Basu and Samet, 2002; Curriero et al., 2002). People living in cold climates are more sensitive to hot weather and are better acclimatized to cold conditions than people living in warmer climates. This is reflected in the shape of the temperature–mortality relationships.

The MMT describes the optimal thermal conditions that the population is acclimatized to and it is lower in cool climates than in warm climates. The MMT is typically found around 75th percentile of the annual daily mean temperature distribution, varying between the 66th and 80th percentiles (Guo et al 2014). In Finland the mortality is lowest when the daily mean temperature is at the range of 12–17°C (Figure 1) while in Mediterranean countries the same is true at 22–25 °C (Keatinge et al., 2000; Näyhä, 2005; Näyhä, 2007). The MMT may vary even within a country like reported e.g. by Tobias et al. (2017) from Spain and Curriero et al. (2002) in the USA. A small difference in MMT between southern and northern Finland was also suggested by Keatinge et al. (2000).

Otherwise, there are contradicting results on the climate dependence of the shape of temperature–mortality relationships, thus in steepness of the slopes around minimum mortality. For instance, Curriero et al. (2002) and Gasparrini et al. (2012) found a clear association of the temperature–mortality relationship with latitude in US cities, while climate-zone dependence has not been found in studies of Keatinge et al. (2002) or Guo et al. (2014). Meta-analyses across European and US cities (Baccini et al., 2008; D'Ippoliti et al., 2008; Medina-Ramón and Schwartz, 2007) have indicated heterogeneity in the relationships. The risk varies by community and country and differences in vulnerability and sensitivity of the population to temperature extremes depend also on non-climatic environmental and socioeconomic factors such as level of urbanization, buildings, share of elderly, income, education, lifestyles, access to health care and social structures (Hondula et al., 2015; Bao et al., 2015; Carter et al., 2016).

Especially the elderly and people with pre-existing medical conditions such as cardiovascular or respiratory diseases, diabetes or chronic mental illnesses are found to be vulnerable to temperature extremes (Kovats and Hajat, 2008; Kollanus and Lanki, 2014).

The impacts of thermal stress depend also on the exposure time and they may appear with a delay. The impacts of cold on mortality are more complex than the impacts of hot due to different causal pathways. Heat stress leads to enlarging skin vessels and sweating which increase cardiac work and blood viscosity, and also the risk of thrombosis. Cold stress causes constriction of skin vessels which increases blood pressure and the risk of thrombosis. Furthermore, breathing cold air increases the risk of respiratory infections which are associated to increase in mortality (Näyhä, 2005). The impacts of hot weather on mortality typically appear on the same day and last for a couple of days, whilst the increase in cold-related mortality can be found with a delay varying from days up to weeks (Anderson and Bell, 2009; Rocklöv and Forsberg, 2008; Yu et al., 2012). Most of the temperature-related mortality burden is attributable to cold—even in tropical and sub-tropical areas (Gasparrini et al., 2015a). On the other hand, recently e.g. Ebi and Mills (2013) have questioned the assumption that the seasonal variation with higher mortality in winter than in summer would be attributable only to temperature. Higher winter mortality may also be related to other factors that vary seasonally such as influenza epidemics and solar radiation.

Prolonged heatwave or cold spell seems to cause an additional increase in mortality time series. However, according to Guo et al. (2017) no added heatwave effect on mortality was found in most of the studied countries. The excess mortality during the heatwaves is rather a cumulative effect of hot days.

Short-term mortality displacement, so called harvesting effect, causes difficulties in assessing overall attribution of heat and cold stress on mortality. The number of deaths increases in the beginning of the heatwave and after a few days number of deaths may decrease even below the baseline level. This harvesting effect may vary from one location to another. E.g. according to comparative study of Hajat et al. (2005) the heat-related short-term mortality displacement was higher in London than in Sao Paulo or Delhi. However, epidemiological studies have suggested that regardless of mortality displacement, the thermal stress increases the number of deaths in annual level. Based on data from 12 countries, Armstrong et al. (2017) concluded that most of the deaths associated acutely with heat and cold extremes shortened lives by at least one year. In Finland, Kollanus and Lanki (2014) did not find a decrease in mortality in the months

following the heatwaves in 2003 and 2010, either. Thus, the excess deaths indicated life shortening rather than short-term mortality displacement.

Exposure to heat or cold stress may vary remarkably even in a small area due to mesoscale or microscale climatic variation. In densely populated areas the urban heat island (UHI) may cause an additional heat stress during heatwaves, and affect the spatial distribution of relative risk of mortality (e.g. Taylor et al., 2015; Ketterer and Matzarakis, 2015). Especially in urban areas, poor-air-quality episodes may take place simultaneously with heat waves or cold spells causing an additional health burden. As a consequence of the heatwave 2010 almost 11 000 excess deaths took place in Moscow. It has been assessed that statistically interactions between high temperatures and air pollution from wildfires contributed to more than 2000 deaths during the heatwave (Shaposnikov et al., 2014).

2.5. Mental health and climate

According to WHO depressive disorders are ranked globally as the single largest contributor to non-fatal health loss (WHO, 2017a). A climate-dependent type of depressive disorder, seasonal affective disorder (SAD), is characterized by the onset of a depressive illness during the winter months, when there is less natural sunlight, and improved mood during the spring and summer. SAD symptoms have been significantly associated with sunshine hours of the same and previous week, and global radiation of the previous week (Sarran et al., 2017). On a monthly level, more SAD symptoms have been associated with higher precipitation in the same and previous month, and on the other hand, people had less depressive symptoms in areas with sunnier conditions (O'Hare et al., 2016). There are also hypotheses that over-activated brown adipose tissue might induce disrupted thermoregulation and disrupted circadian rhythm, and might contribute to lowered mood and pronounced depressive behaviors (Partonen, 2012). Patients with affective disorders are at higher risk to commit suicide than general population (Bostwick and Pankratz, 2000).

In Finland almost 40% of population experience some changes in mood and behaviour routinely during wintertime, while about 9% report actual winter depression symptoms (Grimaldi et al. 2009b). Seasonal affective disorders are linked also to physical health problems. People tend to be physically less active and gain weight, which may lead also to health problems such as metabolic syndrome (Grimaldi et al. 2009a).

Suicides accounted for 1.4% of all deaths worldwide, making it the 17th leading cause of death in 2015 with incidence of 10.7/100,000 (WHO, 2017b). In eastern European countries the incidence is highest and South-America lowest. In Finland over 700 persons committed suicide in 2015 which means incidence of 13.3/100,000, which is higher than in EU-countries on average. The median age of men who committed suicide was 48 years and of women 51 years. About 10% of suicides were committed by younger than 25 years (OSF, 2015a).

The seasonal variation of suicides is well-known and reported all over the world both in northern and southern hemisphere, and also in Finland (e.g. Christodoulou et al., 2012; Woo et al., 2012; Hakko et al., 1998, Partonen et al., 2004). The suicide rate is typically highest in late spring or early summer, and smallest in winter. Some studies have reported a secondary peak in women suicides in autumn. Seasonality is stronger in suicides of men than women. Different suicide methods have different seasonality (Räsänen et al. 2002) and suicides with violent methods – hanging, shooting and jumping from high – have stronger seasonality than non-violent methods such as poisoning. Based on earlier diagnoses, seasonality in suicides is found with people suffering from severe depression, alcoholism, schizophrenia or other mental health illness. However, according to the review of Ajdacid-Gross et al. (2010) the seasonality in suicides has diminished in western countries on the basis of long time series of suicides. The seasonality of attempted suicides is not as clear as with deaths from suicide. However, a peak in spring and early summer is also the most typical seasonal pattern in attempted suicides (Coimbra et al., 2016). In Finland the incidence of attempted suicide was found to be lowest in December and highest in April (Haukka et al., 2008).

Up to date causal pathways of this seasonality are not fully understood but it has been associated with a rapid increase in sunshine in springtime (Petridou et al., 2002; Partonen et al., 2004). In an Austrian study a positive correlation was found between suicides and sunshine hours up to 10 days prior to suicides while more sunshine 14 to 60 days earlier was associated with lower suicide rate (Vyssoki et al., 2014). Lambert et al. (2002) found that the rate of production of serotonin by the brain was related to the prevailing duration of bright sunlight, and thus would explain the seasonality of mood and seasonal affective disorder.

According to review of Thompson et al. (2018) high ambient temperatures have a range of mental health effects with strongest evidence for increasing suicide risk. For instance, daily mean temperature has been positively associated with suicides in East Asian countries (Kim et al., 2016), while in the United States no correlation was found between temperature and suicide

rates (Dixon et al., 2007). However, possibly due to varying study methods there is little consensus on impacts of weather factors on suicide rate other than seasonal variation, and higher suicide risk has not been associated to specific weather conditions so far (Deisenhammer, 2003).

2.6. Impacts of climate change on temperature–related mortality and mental health

Climate change is projected to increase heat-related mortality especially due to more intense heatwaves and to decrease cold-related mortality due to fewer cold extremes (Smith et al., 2014). Therefore the seasonal pattern in mortality is also expected to be gradually altered. Ballester et al. (2011) assessed that in Europe the rise in heat-related mortality would start to compensate for the reduction of deaths from cold during the second half of the century. A wide multi-country study (Gasparrini et al., 2017) on projected temperature-related mortality under climate change scenarios, assuming no adaptation or population changes, concluded that in temperate climates such as in northern Europe a large decrease in cold-related excess deaths would lead to marginally negative or null net change in mortality, and cold-related mortality would remain higher than hot-related mortality even in high emission scenario. In warmer regions a sharp increase in heat-related mortality would lead also to large net increases in mortality, up to 12.5% (−4.7 to 28.1) in central America by the end of the century. However, there is still ongoing discussion if climate change will substantially decrease cold-related mortality in future because excess winter mortality is not entirely attributable to cold (e.g. Ebi and Mills, 2013). For instance Staddon et al. (2014) also concluded that temperature dependence of winter mortality has disappeared in the UK in recent decades and therefore winter mortality would not decrease because of future climate change.

Only few studies have included scenarios for acclimatization and changes in sensitivity or demographic changes (Huang et al., 2011) into projections on mortality in future climates. In a European-wide multi-country study (Kendrovsky et al., 2017) projected changes in population were included in an assessment of attributable heat-related deaths in two climate change scenarios. The outcomes indicated an excess of almost 47 000 and 120 000 attributable deaths per year by the end of the century under the Representative Concentration Pathways (RCP) 4.5 and 8.5 scenarios respectively. For Finland additional attributable deaths per year were almost 90 and about 290 respectively by the end of the century.

The long-term adaptation of population to a gradually warming climate and changes in sensitivity of people to extreme temperatures cause substantial uncertainty in projected changes in mortality. Based on past data, several studies have shown a decrease in population susceptibility to heat over time, but a similar decrease in susceptibility to cold is not found (Arbuthnott et al., 2016). For instance in Stockholm the relative mortality risk associated with heat extremes has decreased but a similar decrease in cold-related mortality risk was not found (Oudin Åström et al., 2013). Furthermore, the minimum mortality temperature has increased over the course of the 20th century, suggesting that autonomous adaptation has taken place in the Swedish population (Oudin Åström et al., 2016). In the study of Donaldson et al. (2003) a decrease in heat-related mortality since 1971 was found in three climatically diverse regions including southern Finland.

Muthers et al. (2010) concluded that heat-related mortality would increase significantly in Vienna by the end of the 21st century also in an approach where long-term adaptation was included. Ballester et al. (2011) suggested that if societies effectively adapt to a warmer climate, at the end of the century the total mortality due to thermal stress might decrease in Europe, when increases in heat-related mortality, decreases in cold-related mortality and acclimatization are taken into account. The discussion of how to include adaptation and changes in sensitivity into assessments of temperature-related mortality under climate change scenarios has only just started. The method substantially affects the outcomes and the uncertainties of the outcomes, but both shift in threshold (adaptation) and reduction in slopes (sensitivity) should be included in climate change impact assessments (Gosling et al., 2017).

In high-latitude countries people presumably can adapt to gradually changing average thermal conditions, and the health risks will be attributable to hot and cold extremes of the future climate. In countries with hot climate already now, there is a risk that limits of human thermoregulation will be exceeded. According to Mora et al. (2017) about 30% of the world's population is currently exposed to climatic conditions exceeding this deadly threshold for at least 20 days a year. By 2100, this percentage is projected to increase to 48% in the scenario with low greenhouse gas emissions and to 74% in a high emission scenario. Technical solutions such as air-conditioning would be vital for adaptation in such climatic conditions, otherwise migration to cooler climate would be necessary.

Studies on impacts of climate change on mental health and specifically on suicides are less than on physical health. In causal pathways of impacts on mental health, the emphasis has been on

post-traumatic stress disorders as a consequence of weather-related hazards. Indirect impacts such as mental exhaustion due to heat stress, decreasing wellbeing in communities due to climate change impacts, and related anxiety or concerns have also arisen (Berry et al., 2010; Doherty and Clayton, 2011; Trombley et al., 2017). Impacts of decreasing solar radiation on seasonally affective disorders in high-latitude regions has been mentioned in few articles without deeper studies (Berry et al., 2010). Based on analysis on relationships between suicides and temperature variations, Williams et al. (2015) concluded that it is very difficult to predict how climate change will affect the risk of suicide. Impacts of changes in solar radiation on suicides under climate change scenarios were not considered.

3. Material and Methods

3.1. All-cause deaths

For research on the relationship between mortality and thermal conditions, daily number of all-cause deaths and annual population in 21 hospital districts in Finland from 1971 to 2015 were obtained from Statistics Finland. The data included the number of all-aged deaths and the number of deaths in two age groups: 65–74 years and 75 years or older. The daily number of deaths in additional age groups such as younger than 65 years were calculated from these data. Daily population values were interpolated from the annual population values for each age group. The life-expectancy in Finland over the study period has increased markedly. In 1980, the median age at death was 68.2 years for men and 75.4 years for women. In 2015, the corresponding values were 76.8 and 85.3 years, respectively (OSF, 2015b).

Study I concentrates on changes in the temperature–mortality relationship in the most populated Helsinki–Uusimaa hospital district and the whole time series of mortality by age group were utilized in that study. Study II on regional differences in temperature–mortality relationships across hospital districts is based on all-aged number of deaths in a shorter period, 2000–2014. Finland is a sparsely populated country and the characteristics of hospital districts vary substantially. The highest population, about 1.5 million is in the Helsinki–Uusimaa hospital district. In five hospital districts the population is less than 0.1 million and in the rest of the hospital districts the population varies between 0.1 and 0.5 million. Daily number of deaths in the Helsinki–Uusimaa hospital district varied between 11 and 57 with a median of 30 deaths per day during our study period. In the smallest hospital district the median of daily deaths was less than five while in most of the hospital districts the median of daily deaths was about 10 with maximum around 20 deaths per day. Typically the share of deaths in age group 75+ was more than 50% of the all-aged deaths, while the share of elderly (75+) in the population varied from 5% to 10% in hospital districts, and was highest in eastern Finland. Morbidity indices in hospital districts were also used as covariates to explain potential differences in mortality–temperature relationships between hospital districts. Morbidity indices describe the generic population health status and in the indices the weight of prevalence of selected disease groups are based on their significance for mortality, disability, quality of life and health-care costs in the population (THL's morbidity index, 2016). The morbidity indices in hospital districts varied between 66 and 147 and were highest in eastern Finland.

3.2. Suicides and suicide attempts

The daily number of deaths from suicide for the period 1969–2003 were obtained from Statistics Finland for study III. From the total 43 393 suicides, 33 993 were men and 9400 women. Data on attempted suicides are not collected systematically. Therefore data that were originally collected for other studies (Billie-Brahe et al., 1995) were used in study IV on attempted suicides in Helsinki. The para-suicide data of men and women included two separate periods: the first period was from 1 January 1989 to 31 July 1990 (19 months) and second period from 15 January 1997 to 14 January 1998 (12 months). Altogether 3945 suicide attempts were made during these two periods, about half of them were men.

3.3. Meteorological data

Various meteorological datasets were used in the studies. Selection of data was based on the research questions and prior understanding on potentially relevant meteorological factors that may have impact on health impact in question.

In study I, that concentrates on mortality in the Helsinki–Uusimaa hospital district, two indicators for exposure to thermal stress were used, namely the daily mean value of PET (Physiologically Equivalent Temperature) in Helsinki–Vantaa weather station and spatially averaged daily mean temperature (Tavg) in the hospital district. Station-wise synoptic temperature, relative humidity, wind speed and global radiation data were used as input to calculate PET for the study period 1971–2014, and PET daily values we calculated from these 3-hourly data. The calculations were made with the RayMan model (Matzarakis et al. 2007; Matzarakis et al. 2010). Values of Tavg were derived from the gridded 10 km × 10 km dataset of the Finnish Meteorological Institute (Aalto et al. 2013).

In study II about regional differences in temperature–mortality relationships in Finland, the number of deaths were compared to spatially averaged daily mean temperatures (Tavg) in the hospital districts in the period 2000–2014.

In study III, deaths from suicide in Finland were compared with global radiation, sunshine hours, temperature and precipitation in the time period 1971–2003. Temperature and precipitation were spatially averaged values based on the gridded database, but for solar radiation station-wise data from Jokioinen in south-western Finland was used instead, because

gridded data were not available. About 80% of suicides in Finland take place in southern and central part of the country.

In study IV, suicide attempts in Helsinki were compared to daily mean, maximum and minimum temperatures, daily precipitation, global solar radiation, sunshine hours, and atmospheric pressure from Helsinki–Kaisaniemi weather station. Furthermore, the deviations of temperature and global solar radiation from their climatic normal values from the period 1971–2000 were also considered. A descriptive analysis of weather types on peak days of attempted suicides were based partly on synoptic weather charts, as well.

3.4. Methods

3.4.1. Assessing temperature–mortality relationship

Study I aimed to assess changes in temperature–mortality relationship 43-year-long study period in the Helsinki–Uusimaa hospital district. Demographic changes were taken into account by calculating daily mortality values as number of deaths / 100,000 inhabitants for each age group. Expected mortality was used as a baseline mortality: daily expected mortality values were calculated from the mortality data applying Gaussian smoothing with a filter of 365 days for the whole study period. The time series of expected mortality include the seasonal cycle but day-to-day variability is smoothed out. Relative mortality is then the deviation of mortality from the expected mortality as a percentage. The time series of relative mortality are stationary, which makes it possible to compare impacts of thermal extremes over the decades regardless of demographic changes or lengthening life-time. The smoothing method shortens the mortality time series from both ends and comparisons of relative mortality to the meteorological data were made for the time period 1972–2014. Figure 1 clarifies this method that was developed by Koppe and Jendritzky (2005).

The impacts of the thermal conditions on the relative mortality were studied by comparing the daily mean values of PET and Tavg with the mean value of relative mortality in the same and following day, thus applying a 1-day lag. Generalized additive model (GAM) was applied to visualize the relationships and the analysis was done for the whole study period and separately for two 21 year-long sub-periods, 1972–1992 and 1994–2014. The R-package "mgcv" (Wood, 2016) was used for modelling.

Quantitatively the relationships between relative mortality and the thermal indices were calculated in 12 percentile categories of the PET and Tavg frequency distributions. Then the

mean values of relative mortality with 95% confidence intervals were calculated in these percentile categories were calculated for the age groups: all ages, <65, 65–74, ≥ 75 years. In order to assess potential changes in the relationships between relative mortality and the thermal indices during the study period, we applied linear regression to explore linear time trends of the mean relative mortality in each percentile category. Furthermore, the changes in relative mortality were concretized by calculating relative mortality mean values in the percentile categories in the two sub-periods: 1972–1992 and 1994–2014 using the percentile categories that were defined from the whole study period. The statistical significance of differences in the relative mortality between the sub-periods were tested by a Welch Two Sample t-test and the Shapiro–Wilk test was used to check the normality of the distributions.

The dependence between mortality and thermal conditions varies depending on the time window. Therefore, the relationships were calculate also for longer time windows using 7- and 14-day averages of relative mortality and thermal indices without lag considerations.

The main aim of *study II* was to assess regional differences is temperature–mortality relationships across 21 hospital districts in Finland. The research was conducted using daily all-aged mortality data in the 15-yearlong study period, 2000–2014 and the exposure to thermal stress was described by spatially averaged daily mean temperatures in hospital districts, calculated from gridded temperature data.

In modelling the relationship between the daily deaths and mean temperatures in the hospital districts, different versions of distributed lag non-linear model (DLNM) were applied (Gasparrini et al., 2010; Gasparrini, 2011; Gasparrini and Leone, 2014). The daily number of deaths follow quasi-Poisson distribution and the general model definition is as follows:

$$g(\mu_t) = \alpha + s(x_t; \beta) + \sum_{j=1}^{J} h_j(c_{ti}; \gamma_j) \qquad (2)$$

where g is a log link function of the expectation $\mu_t \equiv E(Y_t)$, with Y_t being the time series daily mortality counts in hospital district, α is an intercept, $s(x_t;\beta)$ is an exposure–response function to temperature (x_t) defined by β and it is chosen as quadratic B-spline defined by internal knots. The cross-basis matrix of coefficients also describes lag effects of temperature, defined by knots for lag on a logarithmic scale. Delayed effects of temperature on mortality were studied with a lag of up to 25 days. Confounding factors (c_{ti}) were day of the week and time from the beginning of the time series. Day of the week is modelled as a categorical variable and elapsed time as a

natural cubic spline with 7 degrees of freedom (df) per year to control seasonal variation and long-term trend.

Simple model versions without delayed temperature impacts (lag = 0) and with 4 internal knots for temperature distribution, were first applied for each hospital district (HD) separately without confounding factors. After this first-stage modelling, meta-regression analysis (Gasparrini et al., 2012) was conducted to assess if there is heterogeneity, thus significant differences, in temperature–mortality relationship across the hospital districts. In this method the effects of random variation on the relationships is reduced by calculating best linear unbiased predictions (BLUP) for the relationship. These BLUP estimates converge the HD-specific relationships towards a pooled, averaged exposure–response relationship. A Cochran Q test and I^2 were used to study heterogeneity across the BLUP estimates of the relationships in hospital districts.

Climatological mean temperature, ranges of daily mean temperatures, morbidity indices, population, and share of elderly (75 years and older) in the hospital districts were used as covariates to explain potential heterogeneity in the temperature–mortality relationship in the hospital districts. An LR test and Wald test were applied to study the statistical significance. Because temperature ranges deviate between the hospital districts, the meta-regression was done on both absolute and relative temperature scales.

For studying the effects of heat stress and cold stress on mortality with a long delay, we applied a more complex DLNM version with lag up to 25 days. Based on the lowest Akaike Information Criteria (AIC) value, the best models in hospital districts had on average three internal knots for temperature and two knots for lag, and these fixed numbers of knots were used in this complex modelling version in all hospital districts. The R packages dlnm (Gasparrini, 2011) and mvmeta (Gasparrini et al., 2012) were used while conducting these studies.

3.4.2. Baseline mortality definitions

The shape of temperature–mortality relationship varies also according to the chosen definition for baseline mortality and how seasonal variation is controlled. Different baseline mortality definitions are used in studies I and II. The consequences of methodological differences needs to be understood when interpreting the modelled temperature–mortality relationships, and they are demonstrated in Figure 1.

In study I the baseline mortality is seasonally varying expected mortality, which is higher in winter than in summer. The deviation of the observed mortality from its seasonal expected value, relative mortality, is then used in modelling the temperature–mortality relationship, as described is 3.4.1. In study II the temperature–mortality relationship is modelled using mortality at the minimum mortality temperature (MMT) as a reference, and relative risk for mortality is then number of deaths at given temperature/ number of deaths at MMT. Different baseline definitions lead to differences in mortality risks in the cold thermal range, while the risks in the warm range are fairly similar and in study I the modelled increase in mortality due to cold stress appears to be smaller than in the study II.

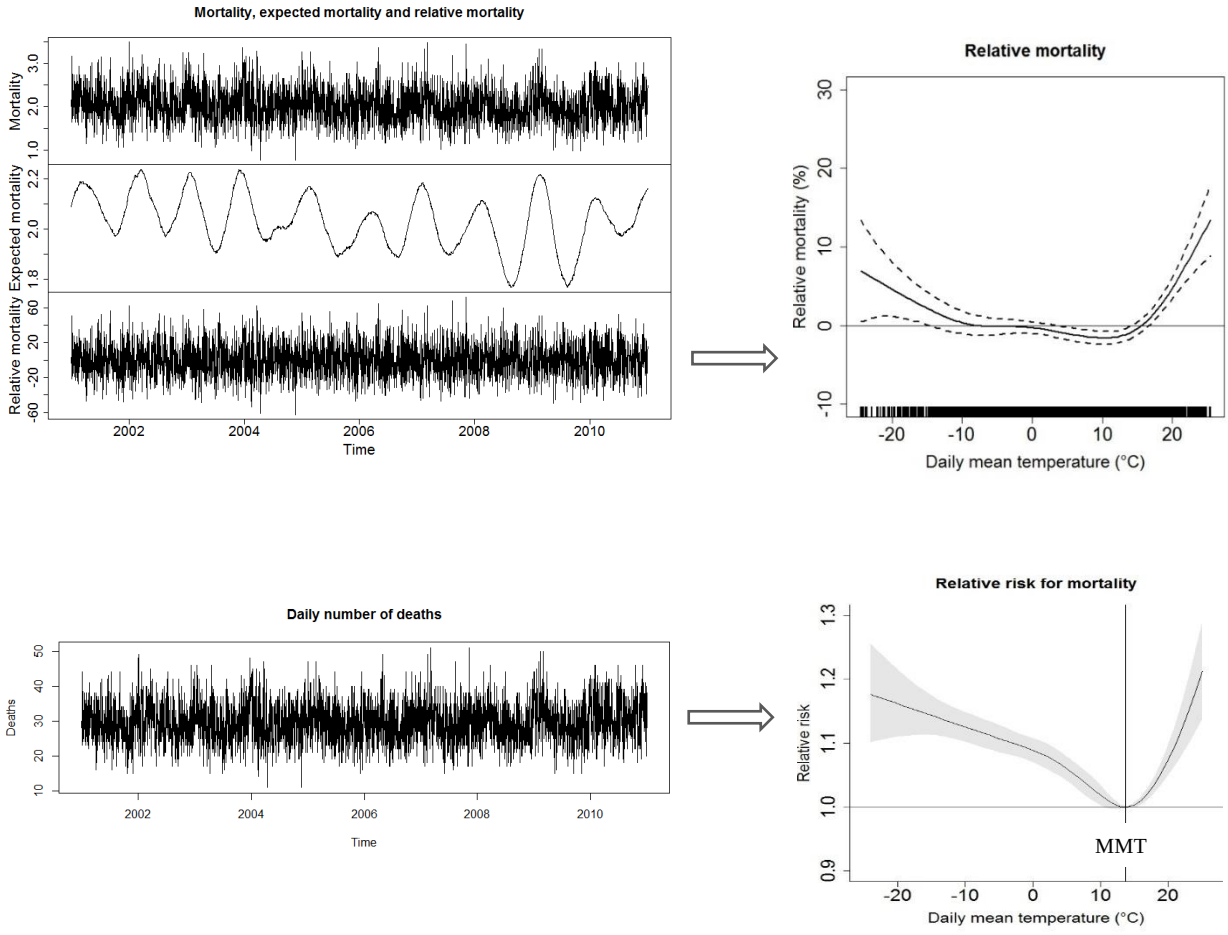

Figure 1. The definition for the baseline mortality effects on the shape of the temperature–mortality relationship. In study I (upper row) the baseline mortality is seasonally varying "expected mortality", while in study II (lower row) the baseline is the mortality at the minimum mortality temperature (MMT, vertical line in the graph).

3.4.3. Assessing impacts of weather and climate on suicides and attempted suicides

The suicide rates and meteorological variables in the time period 1971–2003 were compared in various time windows ranging from monthly to annual level (Study III). For each time window the cumulative values of suicide rates (all, men and women), global radiation, sunshine hours and precipitation were calculated as the sum of daily values for the period in question, whereas temperature was averaged over the period. Delayed climate impacts were not considered in this study.

Both simple and multivariate linear regression analyses were performed. Linear univariate regression models were calculated using the suicide rate as the dependent variable and the measured global radiation, sunshine hours, average temperature or precipitation as the explanatory variable. For the multivariate models global radiation, average temperature and precipitation were included stepwise as the explanatory variables.

The regression analyses were conducted both to the data that included long-term trends, and to the residual data after the trends were removed in order to differentiate impacts of long-term variations and trends (years) and short-term variations in weather variables. The trends were filtered by fitting linear trends both to the suicide and weather data for two sub-periods, i.e., the periods of increasing suicide rates from 1971 to 1990 and of decreasing suicide rates from 1991 to 2003. The regression analyses were also conducted separately to these sub-periods in order to see if the impacts of meteorological factors differ between the time periods of increasing and decreasing suicide trends.

Daily number of suicide attempts in Helsinki during the two shorter study periods (Study IV) were an average two for both women and men, varying between zero and nine for women and between zero and eight for men, and the frequency distributions followed Poisson distribution. Based on weather data and synoptic charts, descriptive case studies were made in the beginning in order to assess if certain weather types prevailed on cluster days with high number of suicide attempts, and days without self-harm. The criteria for a cluster day was defined as the probability for the number of suicide attempts being less than 0.01 according to a Poisson distribution. Altogether 17 days fulfilled the cluster day criteria, either for men, women or both sexes together. The outcomes of these preliminary, descriptive analyses were tested using the

chi-squared test. Similar descriptive analyses were made for cluster weeks and low-self-harm weeks in order to control for day-of-the-week effect.

Poisson regression was used to study statistical association between weather variables and suicide attempts in the whole datasets. The analysis was conducted for women and men separately using weather parameters as independent explanatory variables and daily number of suicide attempts as dependent variable. Daily mean temperature was taken as deviation from its normal value, and global radiation as a proportion of its normal value in the period 1971–2000. Furthermore, Poisson regression was performed separately on violent suicide attempts, which are defined by the method of the suicide attempt, such as hanging or shooting.

4. Summary of results

4.1. Heatwaves in 1972 and 2010

Heat-related mortality is important also in Finland, but intense heatwaves do not take place every summer. In Figure 2 the increases in mortality in the context of two remarkable heatwaves are presented. In the data used in these impact studies in the period from 1971–2015 the highest increase in mortality was found in the heatwave 1972. In context of exceptional the heatwave in 2010, a new heat record was achieved. As a sign of changes in sensitivity of the population to heat stress, the increase in mortality was less than the heatwave 1972. However, the heatwave in 1972 lasted longer than the heatwave 2010 and the impacts are therefore not directly comparable.

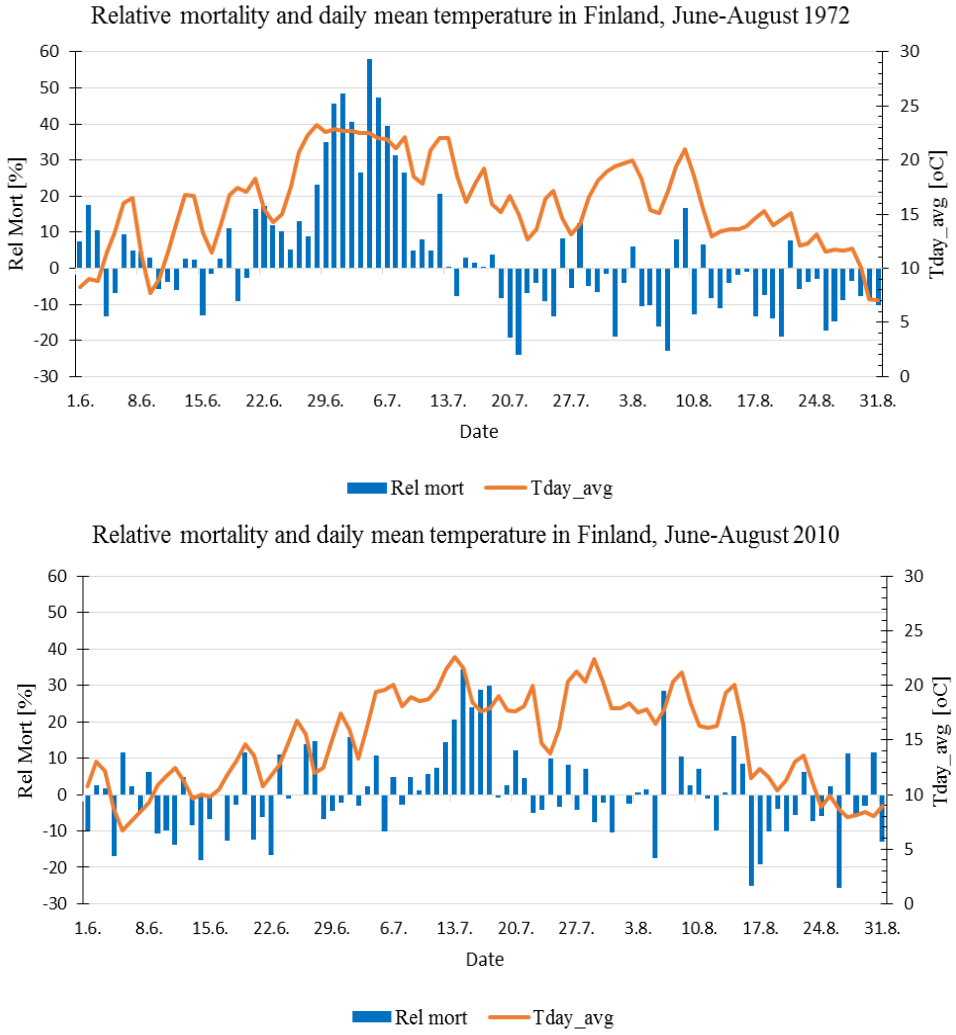

Figure 2. Daily relative mortality (all-aged, all-cause) and mean temperature (spatial average over Finland) in summers 1972 (upper) and 2010 (lower).

In 1972 the heatwave started in late June and lasted for about two weeks. The highest maximum temperature was 33.6°C and the heatwave was most intensive in eastern and northern Finland. The peak in relative mortality was 58% and according to Näyhä (2005) during the heatwave 1972 over 800 extra deaths took place. The heatwave 2010 consisted of two shorter periods in the middle and end of July. The highest measured maximum temperature was 37.2°C and especially people in southern and eastern Finland were exposed to heat stress. The peak in relative mortality was 34% and according to Kollanus and Lanki (2014) the heatwaves in 2010 caused over 300 non-accidental extra deaths.

4.2. Thermal environment and all-cause mortality

4.2.1. Changes in sensitivity to thermal stress over decades

The increase of the relative mortality in the hot extreme end of the thermal distributions is more than in the cold extreme. The increase in relative mortality appears above the 95th percentile of the thermal distribution and is highest above the 99th percentile among those 75 years and older. On the other hand, from the 43-year-long time series of mortality and meteorological data we found a statistically significant decrease in relative mortality in upper percentiles of the thermal distribution, indicating decreasing sensitivity to heat stress over the decades. In Figure 3 the relationship between relative mortality in Helsinki–Uusimaa hospital district and PET in Helsinki–Vantaa airport for all-aged and elderly (≥ 75 years) for the two 21-year sub-periods. The decrease in sensitivity to the hot extreme was statistically significant in upper percentiles: for instance in the highest percentile category (>99^{th} percentile) the all-aged relative mortality decreased from 18% (1972–1992) to 9% (1994–2014). Among the elderly the decrease was from 21% to11 %.

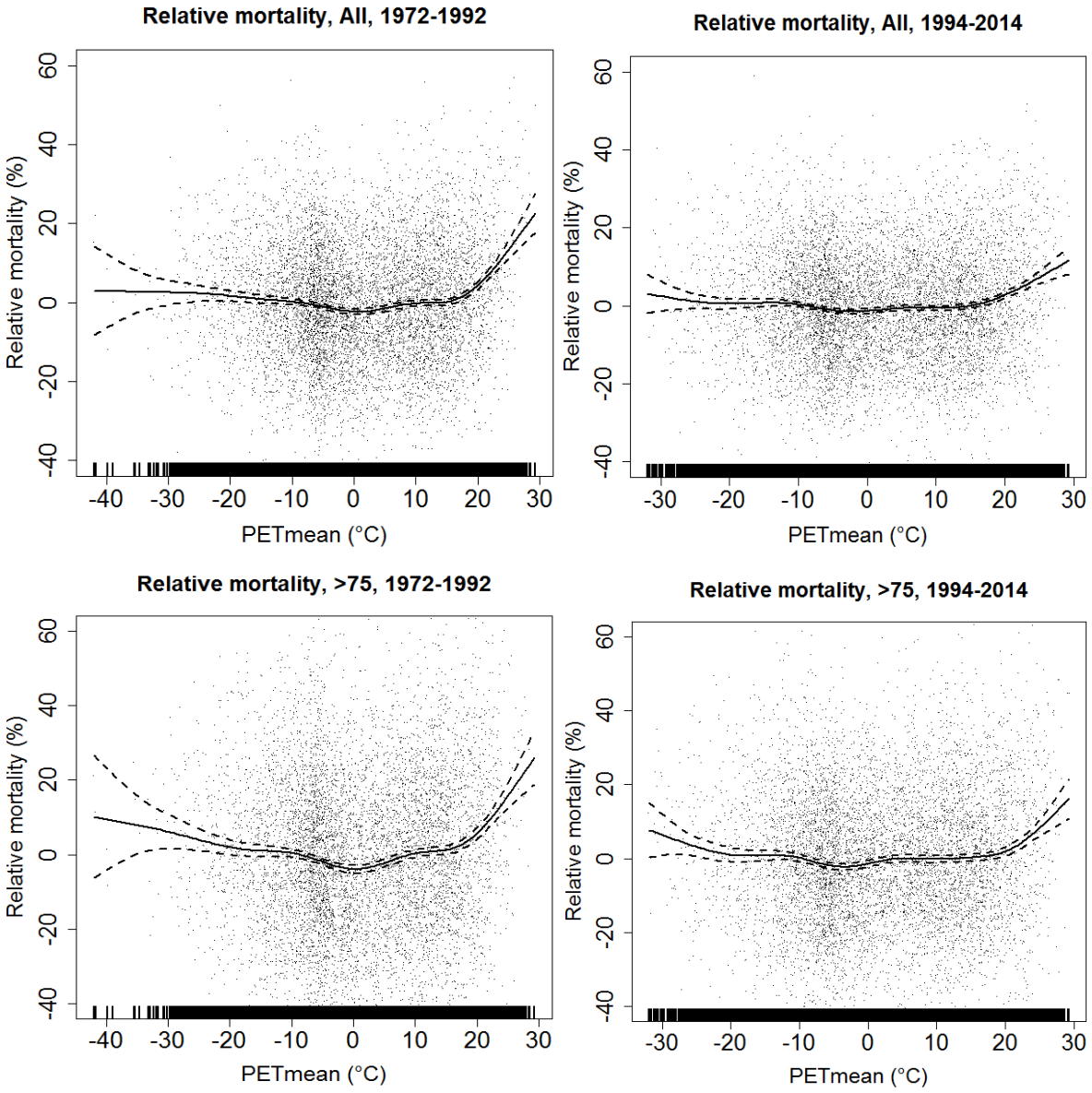

Figure 3. Relationships between relative mortality in the Helsinki–Uusimaa hospital district and daily mean value of PET in Helsinki–Vantaa weather station in the periods 1972–1992 and 1994–2014 for all-aged and elderly, ≥ 75 years. (Adopted from study I Figure 2.)

In addition to the daily mean value of PET at Helsinki–Vantaa weather station, following other thermal indicators were also used: daily max and min values of PET based on synoptic data in Helsinki–Vantaa, station-wise daily mean, max and min temperatures in Helsinki–Vantaa and spatially averaged daily mean, max and min temperatures over the Helsinki–Uusimaa hospital district. Even though quantitatively the relationships between relative mortality and the thermal indicators varied, the shapes of the relationships were fairly similar. In study I the relationship

between mortality and daily mean values of PET and spatially averaged daily mean temperature Tavg were reported. In Figure 4 an example of the impact of thermal indicator on the shape of the relationship between mortality and thermal environment is demonstrated.

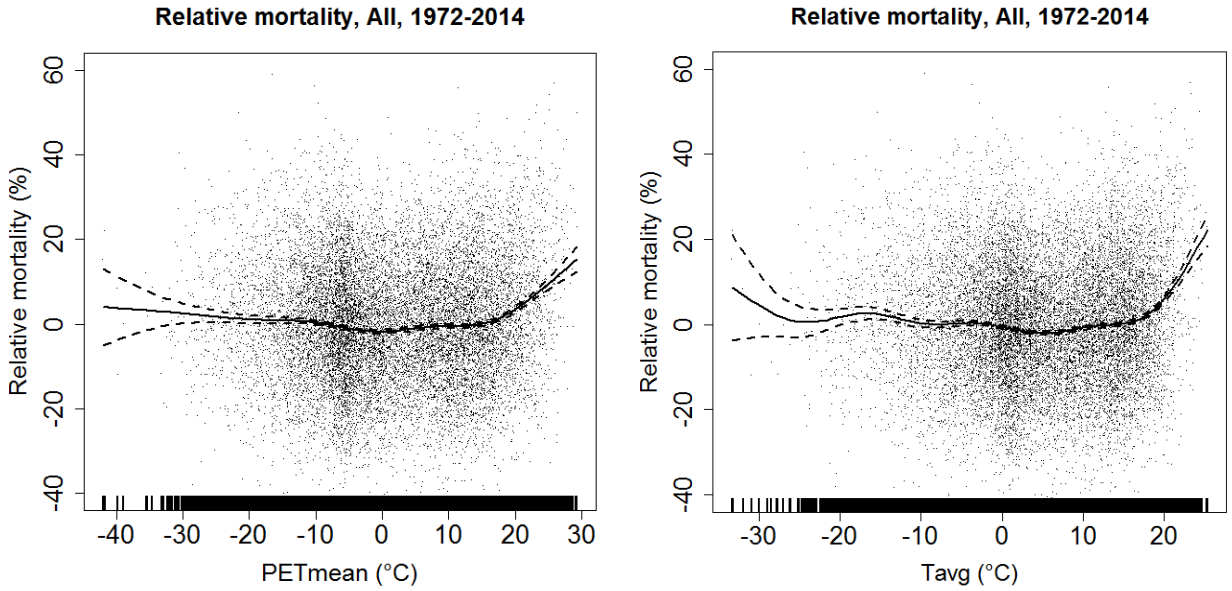

Figure 4. Relative mortality in Helsinki–Uusimaa hospital district as a function of PET daily mean value in Helsinki–Vantaa weather station and spatially averaged daily mean temperature in Helsinki–Uusimaa hospital district. (Adopted from study I, Figure 2 and Figure 3.)

In the Tavg scale, the impact of heat stress appeared to be somewhat stronger than in the PET-scale and the increase in mortality appeared to be also steeper in Tavg. This difference is partly due to the fact that the PET-scale is wider than spatially averaged temperature, because of the role of solar radiation in summer and wind in winter in contributing to PET-values. On the other hand the distribution of spatial average of temperature over hospital district is narrower than station-wise temperature distribution.

Both PET and spatially averaged temperature are feasible indicators in modelling the relationship between mortality and thermal environment – depending on the scope of the study and availability of the data. Based on this conclusion, spatially averaged temperature was used as indicator for thermal stress in study II.

4.2.2. Regional differences in the temperature–mortality relationship

The simple DLNM modelling without lagged effect and without controlling seasonality produced U-shaped relationships in all hospital districts, except for the two least-populated ones, which have populations of less than 50 000. The first-stage modelling showed large differences and variation in the temperature–mortality relationships across hospital districts, especially on the cold thermal range, but the BLUP estimation converges the relationships towards the pooled, average relationship and the differences between hospital districts almost disappear (Figure 5).

According to the meta-analysis there was no statistically significant heterogeneity in mortality–temperature relationships among the hospital districts on an absolute temperature scale. Thus, based on the meta-analysis the same mortality–temperature relationship can be applied in all parts of the country. However, on the relative temperature scale, 21% of variation in the relationships between hospital districts would be explained by heterogeneity. According to the Wald test, morbidity index and population in the hospital districts would explain heterogeneity on a statistically significant level, but the LR tests did not support these findings. Climatological factors – climatological mean temperature and range of daily mean temperature in the hospital districts – did not explain considerably the small heterogeneity.

On the basis of the pooled temperature–mortality relationships, the increase in relative risk (RR) of mortality at a daily mean temperature of 24°C was 1.16 (1.12–1.20; CI 95%) when compared to mortality at 14°C, which is the minimum mortality temperature (MMT) of the pooled relationship. On the cold side, at a daily mean temperature of −20°C, RR was 1.14 (1.12–1.16; CI 95%). The MMT was found at the 79th percentile on the relative scale of daily mean temperature.

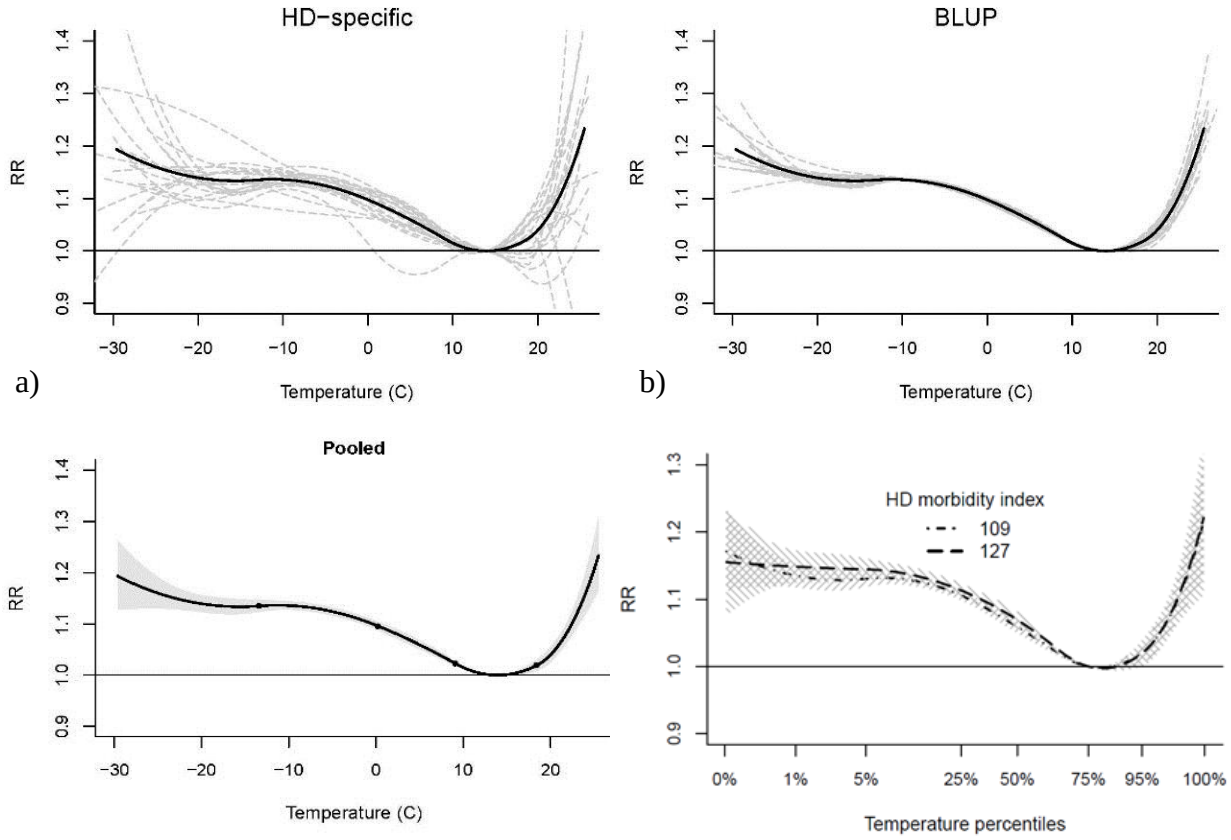

Figure 5. Temperature–mortality relationships based on the model without lag. a) Hospital district (HD)-specific models (dash curves) with the pooled relationship (solid curve), b) best linear unbiased predictions (BLUP) estimates for hospital districts, c) pooled, average relationship (solid curve) with 95% confidence interval (shaded), relative risk (RR) reference at T = 14°C, which is the minimum mortality temperature d) Meta-analysis on relative temperature scale with morbidity index of hospital districts as covariate. (Adopted from Study II, Figure 2 and Figure 3.)

The impacts of heat stress appeared typically on the same day and lasted for a few days while the impacts of cold stress appeared after a few days but lasted for several days or even weeks. Modelling with more complex DLNM with long 25-day lagged effects suggests that including delayed impacts with a long lag may double or triple the estimated overall mortality risk compared to the outcomes of a simple model (Table 2 in Study II). Figure 6 visualizes delayed impacts of heat and cold in the Helsinki−Uusimaa hospital district.

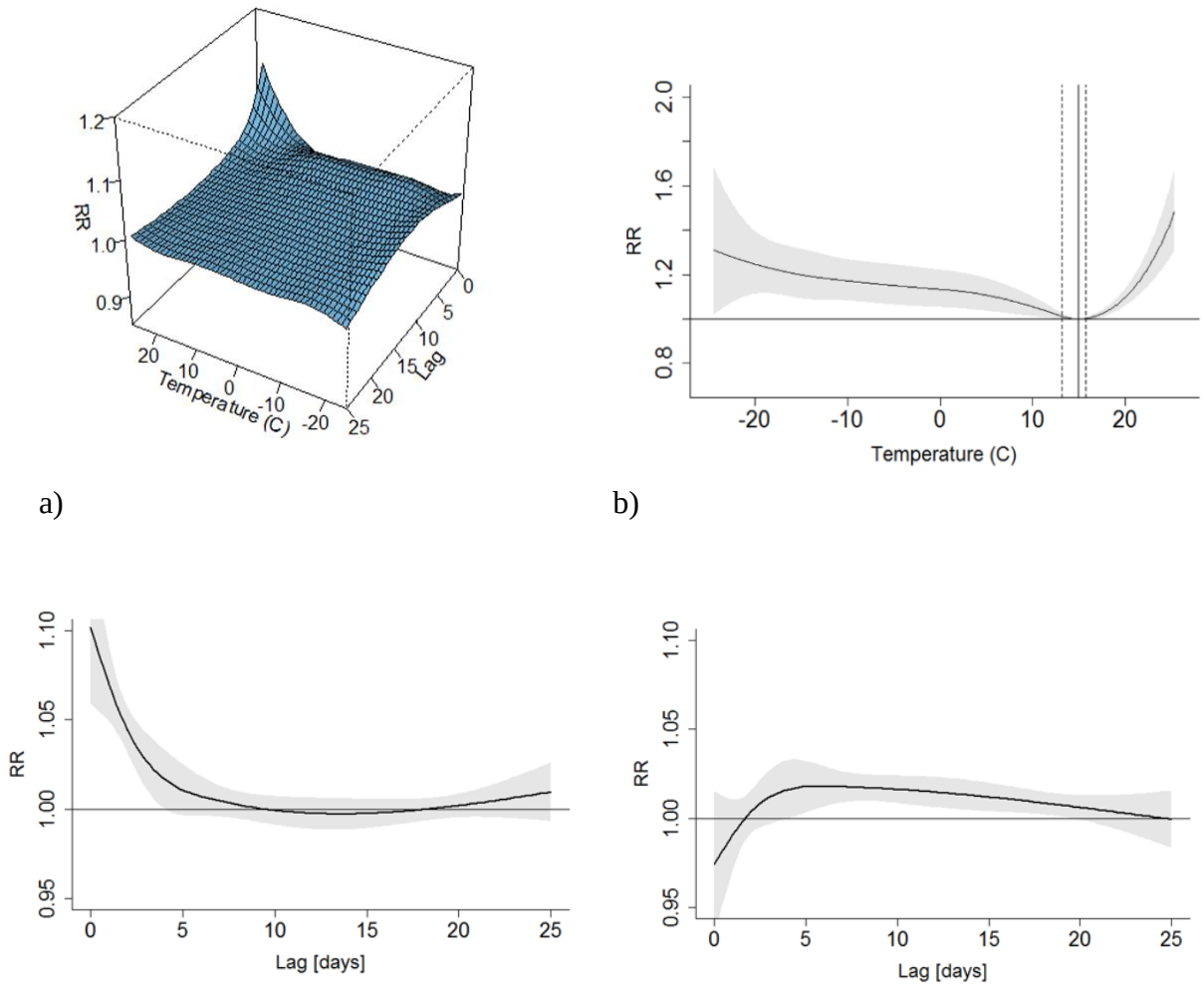

Figure 6. Example of DLNM with 25-day delayed temperature effect on relative risk of mortality (RR) in Helsinki−Uusimaa hospital district. a) 3D-visualizaton on RR as a function of daily mean temperatures and lag. b) Overall temperature−mortality relationship when impacts are aggregated over the 25-day period. c) Lagged temperature effects at Tavg = 24°C, representing heat stress and d) Tavg = −20°C, representing cold stress. (Adopted from Study II, Figure 4 and Figure 5.)

4.3. Impacts of weather and climate on suicides and suicide attempts

4.3.1. Deaths from suicide in Finland, 1971-2003

A key finding of this study was that from meteorological variables, solar radiation explained best the inter-annual variability in suicide rates in Finland, and men appeared to be more sensitive to lack of solar radiation than women (Figure 7). In simple regression, global solar radiation was statistically significantly correlated with suicide rate at the inter-annual level (negative correlation, R^2=0.23). Temperature or precipitation alone could not explain variations in suicide rates, but using them in multiple regression together with global radiation increased the explanatory power (R^2=0.32). In a multiple regression, temperature had also statistically significant positive partial correlation with female suicide rate.

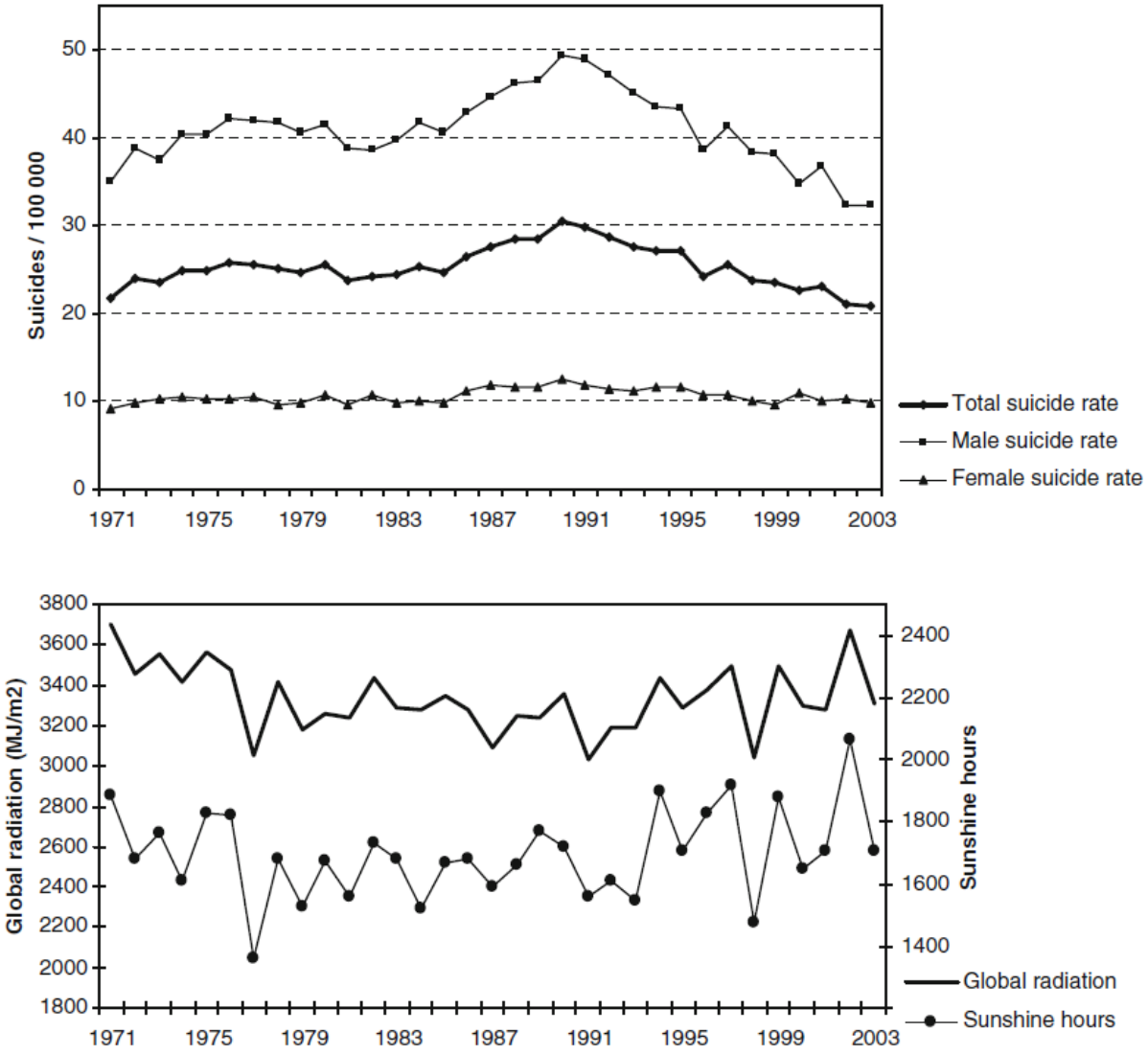

Figure 7. Annual suicide rates (upper panel) in Finland and annual global solar radiation and sunshine hours in Jokioinen weather station in 1971−2003. (Adopted from Study III, Figure 1).

In the regression analysis, at monthly and seasonal levels only a few statistically significant correlations between suicides rates and meteorological variables were found. In order to identify the time window in which lack of solar radiation had best correlation with suicide rates, the relationship was calculated in various cumulative time windows starting from November, which can be considered the beginning of the darkest period in Finland. The strongest negative correlation was found in a five month period from November to March, when (lack of) solar radiation explained 40% of variation in male suicide rate. For women the correlation was substantially smaller, only 14% of the variation of female suicide rate was explained by solar radiation in this 5-month time window.

4.3.2. Suicide attempts in Helsinki

Based on Poisson regression, the daily number of suicide attempts in Helsinki were correlated with atmospheric pressure but not with solar radiation, air temperature or precipitation. Small, but statistically significant, correlations between daily mean atmospheric pressure and the number of suicide attempts were opposite for women and men. For women the correlation was positive with rate ratio, RR=1.005/hPa ($p=0.026$) and for men the correlation was negative with RR=0.995/hPa ($p=0.016$). In the cases of violent methods of suicide attempt, the correlation was stronger for men with RR=0.983/hPa ($p<0.001$), but for women not significant. The Poisson regression was repeated by using a few-day average of the atmospheric pressure as an explanatory variable. For women the correlation was found to be statistically significant for two days and for men for one day before the suicide attempt.

Descriptive case studies on cluster days of suicides attempts indicated that low-pressure situations with cloudy weather with rain or snow typically prevailed on male cluster day, but in spring the cluster days were in high atmospheric pressure situations with sunny weather. Female cluster days were days with high pressure and cloudy weather. No day-of-the-week effect was found on cluster days.

Days free from suicides or suicide attempts can partly be explained by a harvesting effect, thus short-term displacement in suicides and their attempts due to earlier higher incidences. Those days were excluded from the case studies. For men “protective” weather conditions could be described as near average atmospheric pressure with varying meteorological variables otherwise. For women “protective” conditions appeared to be warmer than usual for the season and cloudy weather in context of low pressure situations. Monday is the most probable day without suicides or suicide attempts.

5. Discussion

5.1. All-cause mortality

The studies of this thesis increase the understanding of temperature-related mortality in Finland and provide relevant information for further development of Heat-Health Warning System and cold weather warnings. Heatwaves in Finland will become more intense and longer due to climate change (Kim, 2017). Temperature–mortality relationships produced in this study in the current climate can be used as a baseline for further studies on climate change impacts on mortality. Both studies indicate that heat-related mortality is substantial even in northern countries like Finland. Seemingly contradictory outcomes concerning the importance of cold-related mortality are due to different definitions for baseline mortality. In study I the increase in mortality was compared to seasonally varying expected mortality while in study II the increase in mortality was compared to minimum mortality, which was found at daily mean temperature of 14°C. The baseline mortality used in study I is applicable especially in research concentrating on impacts of extreme temperatures, while the baseline mortality used in study II is applicable in research on generic temperature–mortality relationships.

Study I, in which baseline mortality includes seasonal variation, indicates that increases in relative mortality are greater in hot than in cold extreme conditions, and people in Finland are less accustomed to high than low temperatures. This finding supports the globally demonstrated phenomenon that people adapt to their climatic conditions. The increase in relative mortality appears above the 95th percentile of the thermal distribution and is highest above the 99th percentile among elderly, 75 years and older. However, the dependence of mortality on extreme temperatures has weakened during the 43-year-long study period, even among the age group 75 years and older. Thus, the study shows that the sensitivity of the Finnish population to temperature extremes has decreased in recent decades. It was beyond the scope of the study to explain reasons behind the decreasing sensitivity. Potential explanations can be physiological or behavioural changes of people or infrastructural changes in society, such as improved public health and lengthening of life expectancy.

The calculation of PET values requires sub-daily meteorological data – temperature, humidity, wind speed and solar radiation – and spatial distribution of PET values is affected remarkably by topography and the built environment. The study I shows that temperature may give results that in many cases are good enough for studies related to impacts of weather and climate on mortality. Especially in climate change impact studies it may be adequate to use only

temperature scenarios without considering projections for all the input variables that are needed for calculations of PET. The use of gridded temperature data instead of station-wise meteorological data extends the possibilities to study weather impacts on mortality in sparsely-populated larger areas, which is the case in most parts of Finland.

Study II showed that modelling temperature–mortality relationships at the hospital-district level gave realistic, U-shaped relationships even in sparsely populated areas, in hospital districts with population less than 50 000. The shapes of hospital-district-specific first-stage relationship varied substantially but the best linear unbiased prediction (BLUP) reduced the variability in the relationships and statistically significant differences in the temperature–mortality relationships across hospital districts were not found. Thus, based on the meta-analysis the same mortality–temperature relationship can be applied in all parts of the country.

There are substantial regional differences in mortality and morbidity in Finland (THL, 2016; Figure 8). People in southern and western parts of the country are healthier and mortality lower than in eastern and northern parts of the country. The hypothesis for the study II was that there would be regional differences in temperature–mortality relationships and acclimatization of population in Finland, but this hypothesis could not be confirmed. However, the meta-regression on the relative temperature scale suggests that morbidity index and population in the hospital districts might explain some of the small regional heterogeneity of the temperature–mortality association. In future studies this could be further examined by using more relevant

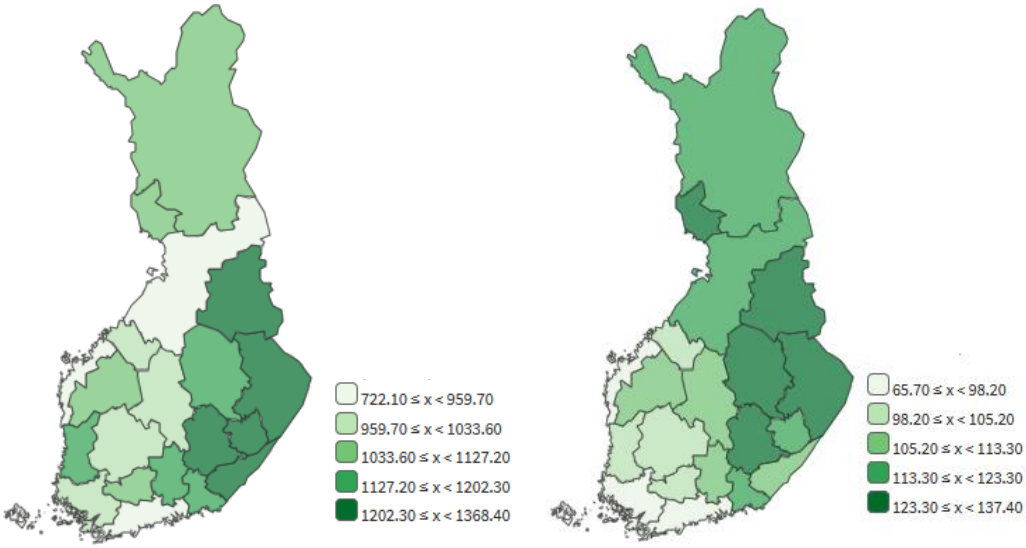

Figure 8. Mortality (1/100,000; left) and morbidity index (right) in hospital districts in 2014. (THL, Sotkanet)

health indicators such as incidences of weather-sensitive chronic diseases (e.g. cardiovascular and respiratory diseases) as additional explaining variables. Climatological factors – climatological mean temperature and range of daily mean temperature – did not explain considerably the small heterogeneity.

Seasonality in mortality is well-known, however, the reasons behind this seasonality are not self-evident. Based on the studies of this thesis I tend to support the conclusion of Ebi and Mills (2013) that higher mortality during winter is not related to temperature variation only but also to other seasonally varying meteorological and behavioural factors, and influenza epidemics. Furthermore people spend most of their time indoors. Based on a population study in Finland, people spent only 4% of their total time under cold exposure (Mäkinen et al., 2006). A climatologically interesting candidate to explain excess mortality during winter might be lack of solar radiation and vitamin D concentration, which typically varies seasonally. In a meta-analysis of Rush et al. (2013) vitamin D status was inversely associated with all-cause mortality. That meta-analysis included also the study of Virtanen et al. (2011) from Finland.

Sensitivity to temperature extremes has decreased over decades, but based on that result from the past times series we cannot conclude that this trend would continue also in the future. In climate change impact studies various scenarios for development in sensitivity and acclimatization should also be considered and applied together with different climate change scenarios. People spend most of their time indoors. Therefore the studies, in which the exposure to thermal stress is based only on outdoor thermal conditions, do not provide accurate information on the real exposure to heat or cold stress and further studies are needed to assess relationship between indoor and outdoor thermal conditions. Furthermore, urbanization is expected to continue in the future, and a big share of the population will be exposure to thermal stress, that is also modified by the urban heat island effect. Further holistic, multi-disciplinary research is needed to better explain and predict future temperature-related mortality.

5.2. Suicides and attempted suicides

In 1970s the Finnish health authorities became concerned about the increasing suicide trend and in 1986 a nationwide suicide-prevention program was launched, which lead to decreasing suicide trend after 1990 (Beskow et al. 1999, Hakko et al. 1998). The main finding of *study III* is that the variation in annual solar radiation explains part (about 20%) of the inter-annual variation in suicides. Furthermore, this finding also suggests that both increasing suicide trend

until 1990 and decreasing trend after that could partly be explained by long-term variation in solar radiation (see also Figure 7).

Lack of solar radiation was associated with higher suicide risk especially during a five month period from November to March. Thus, the darker the winter the higher the suicide mortality. This raises another concern related to climate change. In Finland the amount of solar radiation is expected to decrease in winter, in the high-emission RCP8.5 forcing scenario the projected change is −17% to +2% by middle of the century (Ruosteenoja et al., 2016). The decrease in solar radiation will be exacerbated by a shortening snow-cover period, which will reduce the amount of reflected shortwave radiation from the ground. The worst scenario is that the positive development in suicide prevention and decreasing suicide trend will come to a halt because of darker winters. Since e.g. seasonal affective disorders depend on solar radiation, future studies need to be extended more widely to the impacts on mental health. Furthermore, the impacts of various solar-radiation spectral ranges on mental health need to be better understood.

The outcome of this study may seem to contradict the earlier studies that associate quickly increasing solar radiation with higher suicide incidence in spring and early summer. However, season and length of the time windows explain these different outcomes. Correlations between deaths from suicide and meteorological variables indicated that the lack of solar radiation increased suicide risk especially in winter. It has been suggested that sunshine acts like an antidepressant that first increase the suicide risk and later improves the mood (Christodoulou et al., 2012). In future studies the impact of solar radiation could be studied by using more advanced modelling methods that would take into account both cumulative lack of solar radiation in winter as a factor that increases the number of people at suicide risk, and quickly increasing amount of solar radiation as trigger for committing suicide in spring. As suggested also by Vyssoki et al. (2014), sunshine may have a bimodal effect on suicidal behaviour: more sunshine may increase suicide risk in short exposure time scale but decrease suicide risks in longer exposure time scale.

Another interesting outcome of study III is that climatic conditions have impact on suicide risks for both genders, but men and women react differently. Men appeared to be more sensitive than women to variation in solar radiation. Furthermore, temperature was associated more with suicide risk of women than of men. A later study (Hiltunen et al., 2014) also concluded that daily temperatures and large increase in temperature in a few-day period, as can often happen in spring, may contribute to higher suicide risk. These gender differences might be related to

differences in circadian rhythms and thermoregulation between sexes, but requires further studies.

The main findings of *study IV*, on relationship between suicide attempts and weather, were that atmospheric pressure predicted the risk of suicides attempts, and the impact of atmospheric pressure was opposite on men and women. Low pressure conditions were associated with higher risk for suicide attempts of men, but with lower risk for suicide attempts of women. The other meteorological variables – solar radiation, temperature and precipitation – did not have statistically significant correlation with the suicide attempts in Helsinki. However, the robustness of these outcomes are limited due to short time series and small samples.

Understanding a causal pathway explaining this relationship needs further studies. If the atmospheric pressure as such has direct impacts on the suicide attempt risks, and when the impacts on men and women are opposite, the reason might even be hormonal and e.g. the levels of some sex-specific hormones have been found to respond to atmospheric pressure (El-Migdadi et al., 2000). On the other hand, atmospheric pressure might be an indicator describing the weather type. The descriptive meteorological case studies indicated that the impacts of weather types on para-suicides may also vary seasonally, but due to short datasets of suicide attempts a firm conclusion cannot be made.

These studies have increased the understanding on relationships between meteorological variables and deaths from suicide and suicide attempts, but only piecemeal, and further comprehensive, multidisciplinary research is needed to understand how individual, societal and environmental factors together impact on mental health and suicide risks. Associations between meteorological factors and deaths from suicides and suicide attempts appear seemingly contradictory. Partly these differences are related to differences in time spans used in the studies and a small sample size of suicide attempts is a limitation for the study. However, there may be also other factors explaining the differences, since for instance the differences in gender ratios between deaths from suicides and suicides attempts are not fully understood. The impacts of weather and climate on suicides and suicide attempts are small compared to the other risk factors, but they may contribute by increasing the probability or affect timing of self-harm. However, the applicability of these outcomes could also be studied in clinical work when assessing risk of suicidal patients.

6. Summary

Human beings are able to adapt to their climatic normal conditions, but despite this capability, weather extremes especially may pose a substantial health risk. Changing climate raises questions on how the weather-related health risks will change and to what extent people can adapt to continuously changing climate and extremes of the future climate. This thesis on weather dependence of all-cause mortality and suicides and suicide attempts in the present climate in Finland gives a basis for further studies on impacts of climate change on human health in Finland, and in general in northern-latitude countries.

Human thermoregulation aims to maintain the core temperature of the body as constant. Thermoregulation forms the basis of a human energy balance model that describes the heat exchange between body and environment. Ambient temperature, humidity, wind speed and radiation balance are essential meteorological factors in this energy exchange. Both heat and cold stress may pose severe risk to health and contribute to premature death. Elderly and people with pre-existing chronic diseases such as cardiovascular and respiratory diseases are most vulnerable to temperature extremes.

In this thesis different methods were used to study dependence of mortality on thermal conditions. The method to calculate relative mortality makes the long mortality time series stationary and, thus, comparable over the decades regardless of changes in population and life-expectancy. This method was applied to study changes in sensitivity of Finnish population to temperature extremes over a 43-year-long period. Hospital-district-specific temperature–mortality relationships were studied using complex, distributed lag non-linear models and differences in these relationships were assessed by meta-regression with selected climatic and sociodemographic covariates.

The studies of this thesis show that heat-related mortality is remarkable also in a northern country like Finland. The increase of the relative mortality in the hot extreme of the thermal distributions is more than in the cold extreme. On the other hand, based on the analysis of the 43-year-long time series, a statistically significant decrease in relative mortality in the upper percentiles of the thermal distribution was found indicating decreasing sensitivity to thermal stress in the Finnish population over the decades.

Regional differences in temperature–mortality relationships were not found at the statistically significant level on the absolute temperature scale, thus, the same pooled temperature–mortality

relationship can be applied in different parts of the country in e.g. climate change impact studies in future. On the other hand, the meta-analysis on a relative temperature scale indicated that morbidity indices and population in hospital districts could explain the small heterogeneity in the relationships – a characteristics that might be worthy of deeper studies. Further studies are also needed to assess temperature-related mortality in areas where urban heat island effect is clear.

Both station-wise PET (physiologically equivalent temperature) and spatially-averaged temperature over larger areas like hospital districts are feasible indicators in modelling the dependence of mortality on the thermal environment. The indicator can be selected depending on the scope of the study and availability of the data.

The study on deaths from suicide on the basis of a 33-year-long time series from Finland showed a significant association between suicide rates and global solar radiation especially during winter in the period from November to March, suggesting that a lack of solar radiation during the winter in higher-latitude regions increases the risk of suicide mortality. The study showed also that men are more sensitive to variation in solar radiation than women. On the other hand, women seemed to be more sensitive than men to variation in temperature, but the temperature dependence of suicides was not as strong as the dependence on solar radiation. The study of weather dependence of attempted suicides in Helsinki on the basis of two shorter periods showed another interesting difference between genders. The risk of suicide attempts of men increased with decreasing atmospheric pressure, while the risk of suicide attempts of women increased with increasing pressure.

Further studies on self-harm should be conducted by using more sophisticated modelling methods such as distributed lag non-linear models in order to understand better the impact of solar radiation. Based on studies of this thesis, lack of solar radiation in winter may increase the number of people at suicide risk, while – based on literature – quickly increasing amount of solar radiation in spring may act as a trigger for committing suicide.

The impacts of decreasing global solar radiation on suicide risks due to climate change need to be studied. Future winters in Finland will become milder with increasing cloudiness and precipitation and shorter snow-cover period. These together with decreasing solar radiation may lead to wider adverse mental health impacts in Finland through seasonally affective disorders, SAD.

The outcomes of this thesis can be used in communicating the impacts of weather and climate on both physical and mental health. They can also be applied in the health sector for instance to improve preparedness for heatwaves and cold spells, and planning long-term adaptation measures to climate change.

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