Food Research International 68 (2015) 31–40

Contents lists available at ScienceDirect

Food Research International

journal homepage: www.elsevier.com/locate/foodres

Preparing suitable climate scenario data to assess impacts on local food safety

Cheng Liu *, Nynke Hofstra, Rik Leemans

Environmental Systems Analysis Group, Wageningen University, P.O. Box 47, 6700AA Wageningen, the Netherlands

ARTICLE INFO

Article history:
Received 25 April 2014
Received in revised form 7 August 2014
Accepted 14 August 2014
Available online 23 August 2014

Keywords:
Statistical downscaling
Delta method
Climate change
Scenario analysis
Daily temperature
Daily precipitation

ABSTRACT

Quantification of climate change impacts on food safety requires food safety assessment with different past and future climate scenario data to compare current and future conditions. This study presents a tool to prepare climate and climate change data for local food safety scenario analysis and illustrates how this tool can be used with impact models, such as bacterial and mycotoxin growth and pesticide models. As an example, coarse gridded data from two global climate models (GCMs), HadGEM2-ES and CCSM4, are selected and downscaled using the "Delta method" with quantile-quantile correction for Ukkel, Belgium. Observational daily temperature and precipitation data from 1981 to 2000 are used as a reference for this downscaling. Data are provided for four future representative concentration pathways (RCPs) for the periods 2031–2050 and 2081–2100. These RCPs are radiative forcing scenarios for which future climate conditions are projected. The climate projections for these RCPs show that both temperature and precipitation will increase towards the end of the century in Ukkel. The climate change data are then used with Ratkowsky's bacterial growth model to illustrate how projected climate data can be used for projecting bacterial growth in the future. In this example, the growth rate of *Lactobacillus plantarum* in Ukkel is projected to increase in the future and the number of days that the bacteria are able to grow is also projected to increase. This example shows that this downscaling method can be applied to assess future food safety. However, we only used two GCMs. To obtain a more realistic uncertainty range, using many different GCM output datasets and working directly with climate modellers is recommended. Our approach helps food safety researchers to perform their own climate change scenario analysis. The actual algorithm of the downscaling method and its detailed manual is available in the supplementary material.

1. Introduction

The likelihood of food contamination is strongly related to prevailing weather and climate (FAO, 2008; Lake et al., 2010; Liu, Hofstra, & Franz, 2013; Nelson, 2009). Temperature and precipitation patterns are, for example, closely related with not only the fate and transport of enteric bacteria but also with their growth and survival. A temperature increase and shifts in precipitation intensity and patterns change contamination processes (Liu et al., 2013). Additionally, climatic change affects toxigenic fungi colonization and diffusion, and enhances the production of mycotoxins (Miraglia, De Santis, & Brera, 2008). Moreover, increased temperature and changing precipitation more rapidly degrade pesticides and thus can increase the use and costs of pesticides on certain crops (Chen & McCarl, 2001). Pests from the southern areas may occur in the north due to temperature increase, although pesticide reformulation can be expected with new technology (Delcour et al., 2015–in this issue). Liu et al. (2013) clearly showed that considering climate change will be important in food safety research and management.

Identification and quantification of climate change impacts on food safety requires impact modelling with different climate scenarios (Jacxsens et al., 2010; Liu et al., 2013). Such a modelling exercise requires the best possible climate and climate change data to specify both current and future conditions. These data are provided by the Intergovernmental Panel on Climate Change (IPCC) for specific future scenarios, which are commonly used by ecologists, hydrologists and agronomists to assess impacts on ecosystems, floods and droughts and food security, respectively (Stocker, Dahe, & Plattner, 2013). Scenarios are plausible descriptions on how the future may unfold based on if–then propositions (Tirpak, 1990). Changes in temperature, precipitation and other climate variables are calculated with general circulation models (GCMs). GCMs simulate the horizontal and vertical flow of matter (e.g. water, clouds, aerosols and air) and energy in the atmosphere and the oceans. The whole system is driven by the sun's radiative energy and involves many complex interactions between, for example, ice, land, topography and greenhouse gases. The basic physics of this complex system are well understood (Sillmann, Kharin, Zhang, Zwiers, & Bronaugh, 2013; Stocker et al., 2013). The

---

* Corresponding author. Tel.: +31 317 485270; fax: +31 317 419000.
E-mail address: cheng.liu@wur.nl (C. Liu).

http://dx.doi.org/10.1016/j.foodres.2014.08.017
0963-9969/

main uncertainties in understanding the climate system stem from subtle feedbacks and other interactions, and stochastic or teleconnected processes, such as the proverbial flap of the Amazonian butterfly wing later causing a storm in the North Atlantic (Brayshaw, Hoskins, & Blackburn, 2009). Many different GCMs are developed to understand past, present and future climate change. All these different GCMs have slightly different objectives and focus, and together form a model ensemble, which captures some of the uncertainties (Kharin & Zwiers, 2002; Tebaldi & Knutti, 2007). Results from individual GCM and averages/ranges from ensembles describe future climate conditions that could be used in impact studies (Christensen & Lettenmaier, 2007).

Until the most recent IPCC assessment came out in 2013, the radiative forcing levels resulted from socio-economic scenarios (e.g. SRES, the Special Report on Emission Scenarios by Nakicenovic et al. (2000)). Recently, a new scenarios development procedure (Moss et al., 2010) was generated by the climate change research community. The procedure starts from radiative forcing levels. For this procedure, representative concentration pathways (RCPs) have been distilled from the scenario literature to cover the best possible range of future atmospheric greenhouse gas concentrations. Four typical pathways were selected. These lead to radiative forcing levels of 8.5 W/m^2 (business as usual), 6.0 W/m^2 (slowdown in emissions), 4.5 W/m^2 (mitigation) and 2.6 W/m^2 (strong mitigation) by the end of this century (van Vuuren et al., 2011). The "strong mitigation" RCP likely keeps climate change within the desired 2 °C target of the politically agreed Copenhagen Accords. Using RCPs as input data, GCMs calculate climate, atmospheric and carbon cycle projections to study the impacts (van Vuuren et al., 2011).

While climate change projections are calculated, various socio-economic scenarios can be developed that are consistent with the specified RCPs. This procedure is substantially faster than the earlier procedure, but the RCPs only provide a future climate that results from the specific change in radiative forcing. Their outputs have become a lookup table and are no longer based on consistent social-economic assumptions such as those in the SRES emission scenarios. Making consistent assumptions for additional policy scenarios or for local and regional scenario interpretations is straightforward for SRES (e.g. Metzger, Bunce, Leemans, & Viner, 2008), but extremely difficult for the RCPs (van Vuuren et al., 2011). To conform to the latest trends in climate research, we use the GCM results for the new RCPs for this paper.

Direct GCM outputs are inadequate for assessing local and regional food safety (Ramirez-Villegas & Challinor, 2012). The spatial GCM resolution (typically 200 × 200 km) is much coarser than the detailed resolution of food safety impact models. The GCM outputs are averages of large grid cells (40,000 km^2). This implies that these data are "smooth" compared to local data, probably underestimating temperature and precipitation extremes of actual field situations (Hofstra, New, & McSweeney, 2010). Additionally, the available temporal resolution of GCMs (typically daily averages) is also too crude for many food safety models (especially those that model pesticide use; Karpati et al., 2004). These two issues result in a spatial and temporal resolution mismatch between the GCM output and the input required by food safety models. The data thus need to be processed before they can be beneficially applied. This is generally done by combining climate data from local observations and GCM outputs.

This study describes an appropriate methodology for combining climate and climate change data for food safety assessments. A methodology to downscale the GCM data to a locality (e.g. a field) for food safety modelling is developed (Section 2). Subsequently, the downscaled data are presented and summarised (Section 3) and an example in which these data are used to estimate future bacterial growth illustrates how the data can be used (Section 4). Finally, data uncertainties and limitations are discussed to show the robustness and applicability of our approach (Section 5).

2. Methodology

This section discusses the selected data sources and models, and presents how spatial and temporal scales and resolutions of the data are selected and prepared for food safety modelling.

2.1. Observational data

We take Ukkel, Belgium as an example location, since many food safety studies are performed on fields near Ukkel (Wesemael & Moens, 2008). We could, however, select any other example site. Daily minimum and maximum temperature and precipitation data have been obtained from the Belgium Royal Meteorological Institute.

2.2. The CMIP5 data and model choice

GCM outputs from the fifth phase of the Coupled Model Intercomparison Project (CMIP5; (Taylor, Stouffer, & Meehl, 2012)) were used in this study. CMIP5 is a standard experimental climate change protocol for GCMs. All CMIP5 data can be downloaded from the Earth System Grid Federation Portal (http://pcmdi9.llnl.gov/esgf-web-fe/). CMIP5 includes the most recent global GCM outputs available. These are also used in the most recent assessment report (AR5) of IPCC (Stocker et al., 2013).

To represent the full range of outputs, the full multi-model ensemble (including 61different GCMs) for climate impact studies should ideally be used (Houtekamer & Derome, 1995; Tebaldi & Knutti, 2007). However, since we merely develop an approach to assess climate change impacts on food safety (and running impact models 61 times is time-consuming), we feel that using the full model's ensemble does not add information in this paper. On the other hand, using a single GCM projection as a representative of the possible change can lead to anecdotal future conditions and thus to misleading conclusions. When an uneven number of models are used, choosing the middle one as the "most likely" one is tempting. For these reasons, data from two renowned GCMs are used: the Hadley Centre Global Environmental Model 2-Earth System (HadGEM2-ES; Collins et al., 2008, 2011; Jones et al., 2011) and the Community Climate System Model version 4 (CCSM4; Gent et al., 2011). The reasons for using HadGEM2-ES and CCSM4 GCM output are that they model temperature and most precipitation indices, including extreme precipitation, most robustly (Flato et al., 2013; Sillmann et al., 2013). These indices are important climate variables for food safety modelling (Liu et al., 2013). The HadGEM2-ES model is used for the core climate simulations carried out by the Met Office Hadley Centre for the CMIP5 project and the HadGEM2 series is one of the most important and commonly used GCMs for future climate projections. The open access CCSM4 model is developed and used by a community of scientists and students from universities, national laboratories and other institutions. This model is available from CCSM's website (http://www.cesm.ucar.edu/models/ccsm4.0/).

2.3. Spatial resolution and scale

Gridded temperature and precipitation data from GCMs are used in this study. These gridded data should be interpreted as average values of an infinite number of points in the grid (Harvey et al., 1997). To get a feel for what the gridded data looks like, maximum temperature from both GCMs for the grid on top of Ukkel, Belgium is presented in Fig. 1. The modelled current gridded data (grey lines) from the CCSM4 model are, on average, 1 °C higher than from the HadGEM2-ES model. The size of the grid indicates the model's spatial resolution (HadGEM2-ES: 1.25° × 1.88°, CCSM4: 1.25° × 0.9°). The difference in modelled current maximum temperature is determined by these different resolutions. The HadGEM2-ES grid cell covers a part of the cooler North Sea, while the CCSM4 grid cell only covers land. This shows that