11.4 AGRICULTURAL PESTS UNDER FUTURE CLIMATE CONDITIONS: DOWNSCALING OF REGIONAL CLIMATE SCENARIOS WITH A STOCHASTIC WEATHER GENERATOR

Christoph Spirig[1], Martin Hirschi[1], Mathias W. Rotach[1,5], Martin Dubrovsky[2], Pierluigi Calanca[3], Sibylle Stöckli[4], and Jörg Samietz[4]

1) Federal Office for Meteorology and Climatology MeteoSwiss, Zurich, Switzerland
2) Academy of Sciences, Prague, Czech Republic
3) Agroscope Reckenholz-Tänikon Research Station ART, Zurich, Switzerland
4) Agroscope Changins-Wädenswil Research Station ACW, Wädenswil, Switzerland
5) Present affiliation: University of Innsbruck, Institute for Meteorology and Geophysics, Innsbruck, Austria

1 INTRODUCTION

The projected climate change for temperate regions in Europe will lead to higher temperatures and less stable precipitation regimes with increased risk of drought and flooding, respectively. Beside these direct influences, agriculture is also largely affected by indirect effects of climate change, such as changes in pest and disease populations. Agricultural pests and diseases are expected to occur more frequently and possibly extend to previously unaffected regions, as a consequence of the projected temperature increase.

Already at present, crops are constantly threatened by pests such as nematodes and insects, as well as diseases caused by fungi, bacteria, viruses and other micro-organisms. Agricultural production therefore depends on effective pest control measures. Sustainable plant protection strategies largely rely on accurate pest and disease forecasting tools in order to avoid unnecessary treatments. Such prediction tools model the infestation depending on weather conditions. The development of pests and diseases is most successfully predicted if the microclimate of the immediate environment (habitat) of the causative organisms can be simulated (Samietz et al., 2007).

Assessing the risk of pest-related damages as a consequence of climate change therefore requires information on future weather that is downscaled to the pest relevant habitats and time scales. Pest models often need not only screen temperature and precipitation alone (i.e., the most generally projected climate variables), but might require input variables such as soil temperature, in-canopy net radiation or leaf wetness.

In this study we attempt to translate the coarse information of regional climate models on future temperature and precipitation changes to the type of weather input required by pest models with the use of a stochastic weather generator.

As a case study, we examine the influence of climate change in Switzerland on the future threat of codling moth (*Cydia pomonella*), the major insect pest in apple orchards worldwide (Dorn et al., 1999).

2 METHODS

2.1 Climate Scenarios

Climate scenarios provide potential future climatic states given an assumed development of greenhouse gas emissions in combination with plausible development of social and technological systems. The scenarios used in this study were generated in the frame of the EU-project PRUDENCE (Christensen and Christensen, 2007), and include simulations from 16 regional climate models with spatial resolutions of approx. 50 x 50 km. These simulations were seasonally and regionally aggregated to derive the expected change in mean temperature and precipitation for Northern and Southern Switzerland (Frei et al., 2007).

2.2 Weather Generator

Weather generators (WGs) represent an attractive method for downscaling the highly aggregated information from regional climate models to the high spatial and temporal resolution required by pest models. As part of statistical downscaling they rely on the availability of long observational data series as well as on dense climate information. WGs examine the statistical structure of the observed weather and simulate synthetic sequences of ‘weather data’ consistent with this structure (Calanca et al. 2009).

We applied a WGEN-like (Richardson, 1981) type of weather generator, the “Met&Roll flexible and improved” (M&Rfi) (Dubrovsky et al., 2000, 2004). M&Rfi was first calibrated to 20 years of observed weather at selected sites and then used to create daily values of precipitation, radiation and temperature (average and daily range) for 2050 by considering the expected mean changes of temperature and precipitation from the climate scenarios. Next, hourly values of these variables were generated with a nearest neighbor re-sampling approach, involving the following steps. 1) Selection of ten days from the observed weather series with most similar values of the WG-created daily variables (prec, temp, rad). 2) Random choice of one day among these nearest neighbors and adoption of this day’s hourly values 3) Scaling of these hourly rain and temperature data to match the daily values.

2.3 Pest Modeling

The hourly weather time series were then used for driving a model for predicting the development of codling moth, the most relevant insect pest in apple orchards worldwide. The larvae of codling moth (*Cydia pomonella)* directly feeds within the fruit, the market-relevant product. The flexible life cycle (1-5 generations per year) and the highly thermophilic behavior underline the sensitivity of this species to expected climate change. Several key life phases of this insect can be predicted by temperature sum models. For example, the onset of the moth’s first flight in spring depends on the stem temperatures of the apple trees, as the moth overwinters in pupae on the stems. Stem temperature can be related to the air temperature and radiation of a representative weather station as a function of the the solar angle and the state of the canopy (Samietz et al., 2007). The flight start can accurately be predicted by a stem temperature model, i.e. flight occurs after the sum of hourly temperatures reached a certain threshold. Temperature sum thresholds for several other key life stages of codling moth were derived from SOPRA (Samietz et al., 2007, 2008), a pest model describing the development of individual life stages based on time distributed delay functions. The hourly weather series from the WG were then used to determine the occurrence of different life stages based on these temperature sum thresholds, both for current and future climate.

3 RESULTS AND DISCUSSION

3.1 Validation of weather generator

After the calibration of the M&Rfi weather generator with 20 years of hourly weather data, 100 years of synthetic weather were created. Figure 1 shows a comparison of the statistics of observed and synthetic weather data (= direct validation). The good agreement proves the correct implementation and training of the weather generator, both for the seasonal and hourly time scale.

In a second step, the performance of the weather generator was evaluated by calculating the temperature sums relevant for the pest model from synthetic weather series. Figure 2 shows the dates for the onset of the first flight of codling moth both derived from observed and synthetic weather. Both the distribution and the average of dates agree well, demonstrating that the WG is able to correctly mimic the weather variables essential for this particular application (= indirect validation).

3.2 Pest predictions for future climate

The climate scenarios for the year 2050 predict a mean temperature increase of 1.8 and 2.8 °C for spring and summer, respectively in Southern Switzerland. Using the hourly weather for this scenario generated by M&Rfi, the development of codling moth is predicted to speed up significantly. Applying the temperature sum models described above, a clear shift towards earlier dates in the onset of codling moth’s first flight is predicted for future climate conditions (Figure 3). Such a trend of an earlier start of the flight could already be observed during the last 40 years, as documented by a data set monitoring codling moth flight activities since 1972 (Figure 4). Our analyses suggest that this trend is likely to continue in a similar fashion, leading to a flight start another 10-12 days earlier as compared to today’s average. Similar shifts towards earlier dates were obtained by applying temperature sum models for other life stages of codling moth. The faster development of codling moth throughout all stages of the life cycle increases the risk of additional generations occurring and their magnitude.

3.3 Implications

The predicted faster development of codling moth and the increased risk of additional generations require higher control efforts in apple growing. A precise timing of control measures will become even more important in future, as will be the development of new treatments and agents for avoiding the occurrence of resistances and negative side effects. As environmentally friendly control measures are particularly vulnerable to increased resistance effects, sustainable apple production may only be possible in part of today's apple orchards.

4 CONCLUSIONS AND OUTLOOK

M&Rfi was successfully applied to produce site specific hourly weather for future climate scenarios. These weather data could be used to predict the timing of several key life phases of codling moth for future climate conditions. The analyses suggest a faster development and a shift towards earlier dates for all life stages, continuing an already observed trend towards more favorable conditions for this insect during the last 40 years. As a consequence, efforts for pest control in apple orchards will increase and control measures will need to be adapted (new agents, combination of treatments) in order to allow sustainable apple growing in future.

The methods applied here will be extended to predictions of other pest and diseases. In particular, it is intended to apply the same approach for predictions of fireblight infection risk, which will require the inclusion of leaf wetness as an additional WG variable.

ACKNOWLEDGEMENTS

Funding for this work was provided by COST Action 734 (Impacts of Climate Change and Variability on European Agriculture – CLIVAGRI) and the National Centre of Competence in Research on Climate (NCCR Climate) of the Swiss National Science Foundation.

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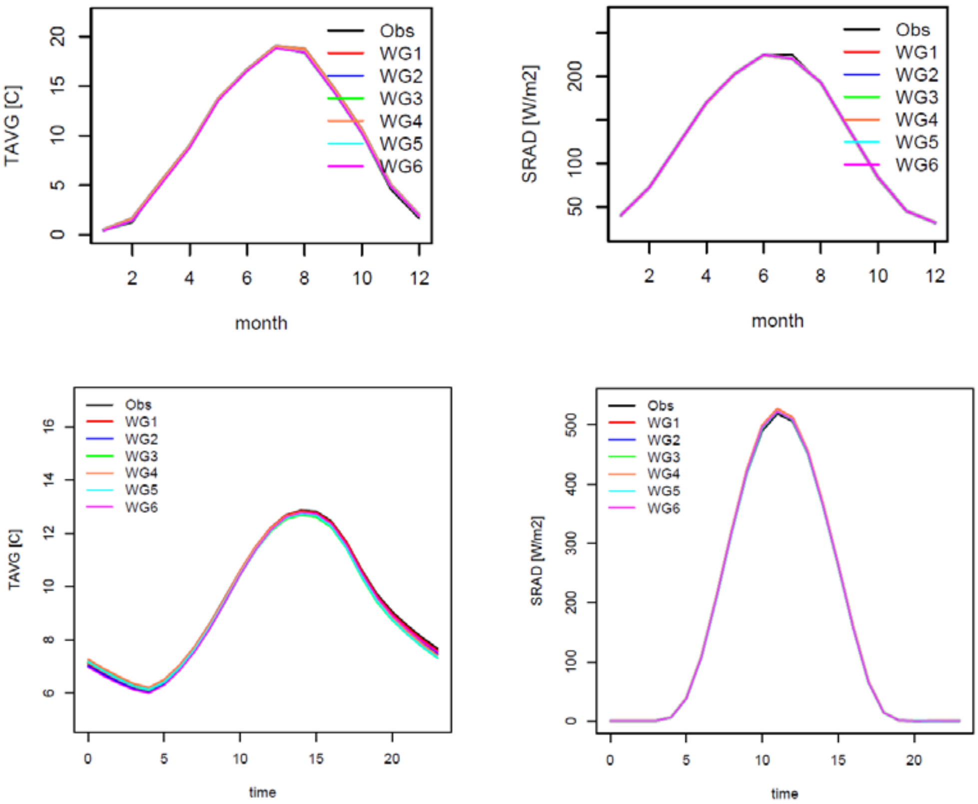

Figure 1: Direct validation of weather generator. Comparison of observed (black line) and synthetic weather (colored lines) statistics.

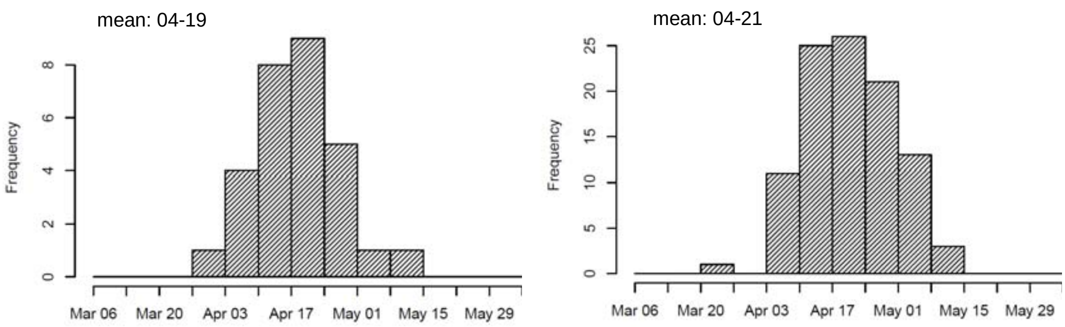

Figure 2: Indirect validation of weather generator. First flight of codling moth predicted with a stem temperature model using observed (left) and synthetic (right) weather data.

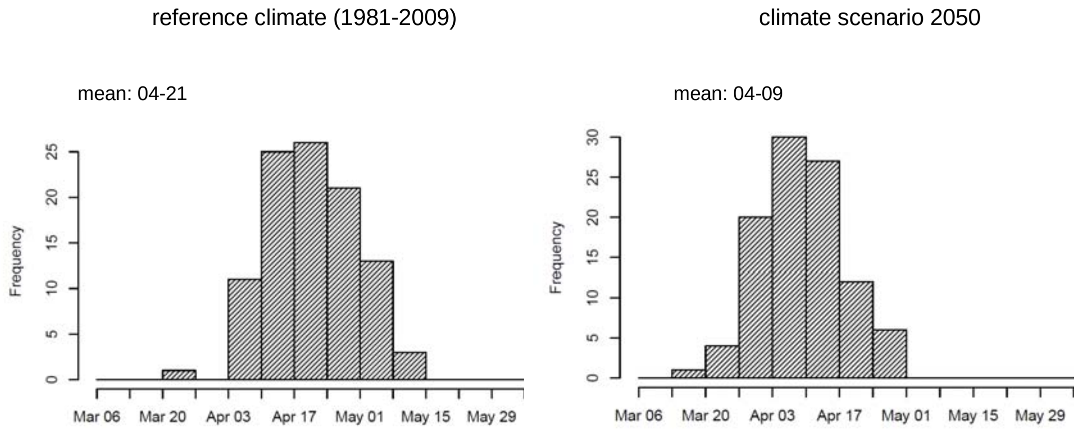

Figure 3: Dates of first flight of codling moth in current and future climate

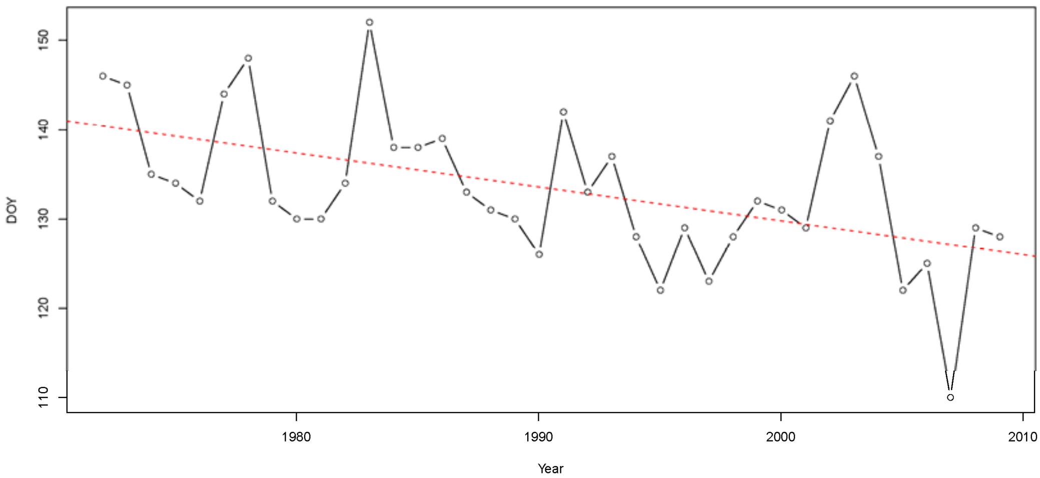

Figure 4: Dates of first flight of codling moth as observed since 1972.