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Calibration and bias correction of climate projections for crop modelling: An idealised case study over Europe

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ABSTRACT

Producing projections of future crop yields requires careful thought about the appropriate use of atmosphere-ocean global climate model (AOGCM) simulations. Here we describe and demonstrate multiple methods for 'calibrating' climate projections using an ensemble of AOGCM simulations in a 'perfect sibling' framework. Crucially, this type of analysis assesses the ability of each calibration methodology to produce reliable estimates of future climate, which is not possible just using historical observations. This type of approach could be more widely adopted for assessing calibration methodologies for crop modelling. The calibration methods assessed include the commonly used 'delta' (change factor) and 'nudging' (bias correction) approaches. We focus on daily maximum temperature in summer over Europe for this idealised case study, but the methods can be generalised to other variables and other regions. The calibration methods, which are relatively easy to implement given appropriate observations, produce more robust projections of future daily maximum temperatures and heat stress than using raw model output. The choice over which calibration method to use will likely depend on the situation, but change factor approaches tend to perform best in our examples. Finally, we demonstrate that the uncertainty due to the choice of calibration methodology is a significant contributor to the total uncertainty in future climate projections for impact studies. We conclude that utilising a variety of calibration methods on output from a wide range of AOGCMs is essential to produce climate data that will ensure robust and reliable crop yield projections.

1. Introduction

There is a growing need to produce crop yield projections for the next few decades to enable effective adaptation to climate variability and change. It is known from case studies of the recent past that crop yields are seen to reduce in particularly hot seasons (e.g. Battisti and Naylor, 2009), and producing estimates of the number and extent of such seasons in the future may aid crop breeding or motivate a change in the crops grown in a particular location.

Climate information for assessments of future crop yields tends to come from atmosphere-ocean global climate models (AOGCMs). These models attempt to represent the full Earth system, and simulate the future with assumed scenarios for anthropogenic emissions, producing projections of future climate (e.g. Meehl et al., 2007). However, there are a number of issues to address in using output from AOGCMs to drive crop models. Firstly, the size of the AOGCM grid cell is normally far larger than required for crop models, meaning that some form of spatial downscaling is required (e.g. Baron et al., 2005). Secondly, the reliability and realism of the daily output from AOGCMs needs to be assessed. The next set of simulations for the Coupled Model Intercomparison Project (CMIP5), which will be examined by the Intergovernmental Panel on Climate Change (IPCC), will make more daily output available at higher spatial resolution than previous assessments, allowing a more comprehensive assessment. Thirdly, no AOGCM is a perfect representation of the true climate and so some 'calibration' of the raw climate model output would appear to be appropriate, where calibration refers to any attempt to make the AOGCM output more realistic. A wide variety of approaches have been adopted to produce calibrated data for crop yield projections (see Section 2). Weather generators are one such tool; they are often designed specifically with crop modelling applications in mind (e.g. Hansen and Ines, 2005; Semenov et al., 2010; Ines et al., 2011). Although we will not consider weather generators directly in this study, the findings have implications for their design.

As an example of these issues, Fig. 1 shows the mean daily maximum temperature (T_{max}) during summer (June–July–August) for the period 1970–1999 from the E-OBS v5.0 0.5° observations

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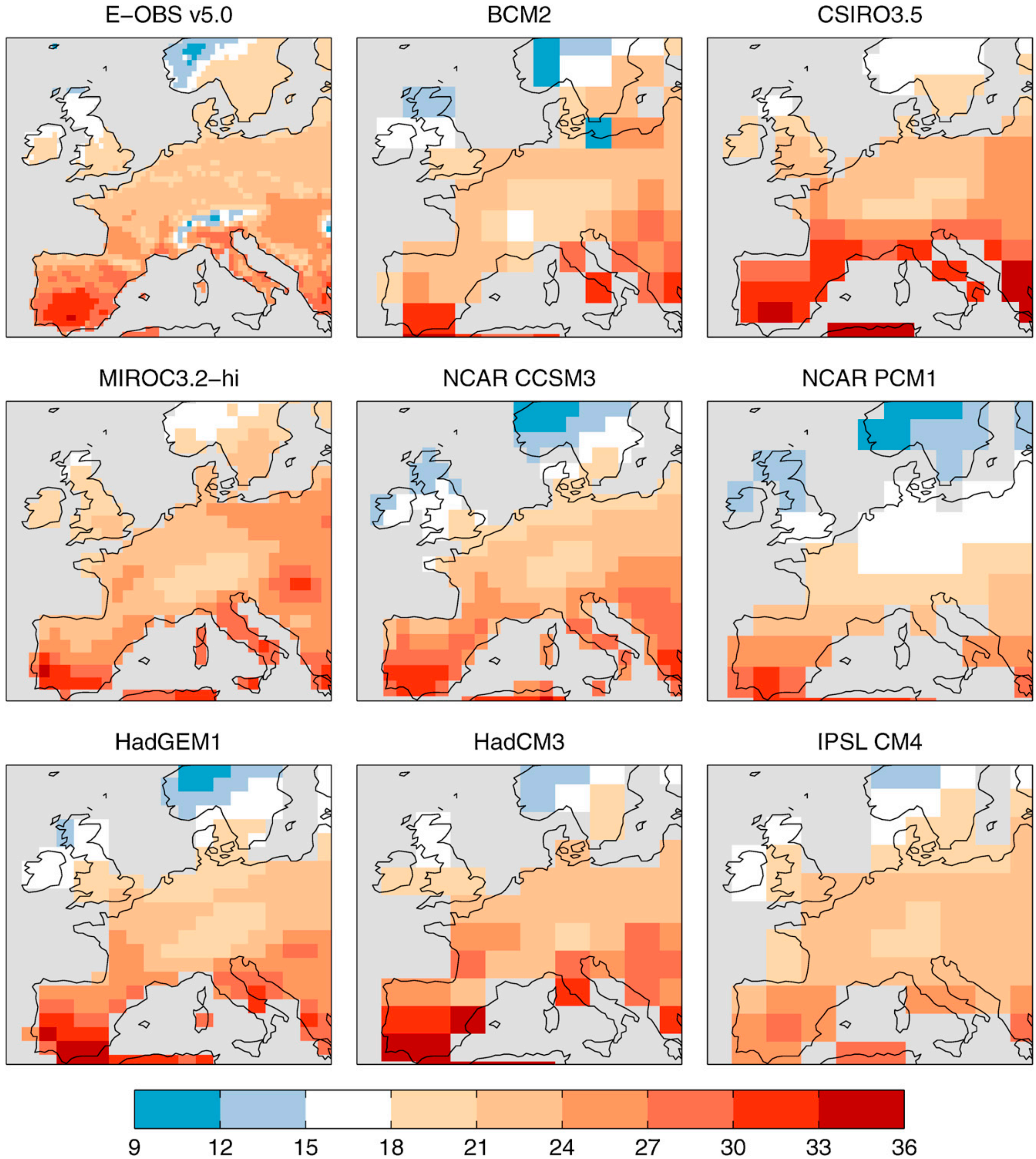

Fig. 1. Mean summer (JJA) T_{max} for the reference period 1970–1999 from observations (E-OBS v5.0 0.5°, Haylock et al., 2008) and a range of AOGCMs in the CMIP3 database as labelled. For the AOGCMs, only grid cells with a land portion of larger than 40% are shown. The units are °C.

(top left; Haylock et al., 2008) and a range of AOGCMs over Europe. The AOGCMs have different spatial resolutions, but all have larger grid cells than the observational data available. It is immediately obvious that many features visible in the observations are not seen in the AOGCMs, e.g. the cooler temperatures over the Alps. Additionally, the AOGCMs show a wide range of temperatures for the same location, differing by more than 6 °C in some places, and all exhibit a bias from observations which varies spatially. A crucial point to appreciate is that even if all the AOGCMs produce the same future temperature *change* as a response to radiative forcings such as greenhouse gases, the *absolute* value of the temperatures will be very different. As most crops are known to be sensitive to absolute thresholds in temperature (e.g. Vara Prasad et al., 2000; Schlenker and Roberts, 2009), these biases are problematic, and require correcting. Additionally, the various AOGCMs produce different estimates for the future rate and magnitude of warming to increasing anthropogenic forcing.

As more daily data from both AOGCMs and observations (e.g. Caesar et al., 2006; Xie et al., 2007; Haylock et al., 2008) becomes