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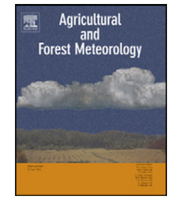

Assessing relevant climate data for agricultural applications

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ABSTRACT

Climate change is expected to substantially reduce agricultural yields, as reported in the by the Intergovernmental Panel on Climate Change (IPCC). In Sub-Saharan Africa and (to a lesser extent) in South Asia, limited data availability and institutional networking constrain agricultural research and development. Here we performed a review of relevant aspects in relation to coupling agriculture–climate predictions, and a three-step analysis of the importance of climate data for agricultural impact assessment. First, using meta-data from the scientific literature we examined trends in the use of climate and weather data in agricultural research, and we found that despite agricultural researchers' preference for field-scale weather data (50.4% of cases in the assembled literature), large-scale datasets coupled with weather generators can be useful in the agricultural context. Using well-known interpolation techniques, we then assessed the sensitivities of the weather station network to the lack of data and found high sensitivities to data loss only over mountainous areas in Nepal and Ethiopia (random removal of data impacted precipitation estimates by ±1300 mm/year and temperature estimates by ±3 °C). Finally, we numerically compared IPCC Fourth Assessment Report (4AR) climate models' representation of mean climates and interannual variability with different observational datasets. Climate models were found inadequate for field-scale agricultural studies in West Africa and South Asia, as their ability to represent mean climates and climate variability was limited: more than 50% of the country-model combinations showed <50% adjustment for annual mean rainfall (mean climates), and there were large rainfall biases in GCM outputs (1000–2500 mm/year), although this varied on a GCM basis (climate variability). Temperature biases were also large for certain areas (5–10 °C in the Himalayas and Sahel). All this is expected to improve with IPCC's Fifth Assessment Report; hence, appropriate usage of even these new climate models is still required. This improved usage entails bias reduction (weighting of climate models or bias-correcting the climate change signals), the implementation of methods to match the spatial scales, and the quantification of uncertainties to the maximum extent possible.

1. Introduction

Agriculture is expected to play an important role in the context of climate change, not only because it is considered amongst the most vulnerable sectors, but also because it is part of the solution (i.e. potential to mitigate greenhouse gases [GHGs] emissions) (FAO, 2009; IPCC, 2007). Agriculture will likely be severely affected over the next hundred years due to unprecedented rates of changes in the climate system (IPCC, 2007; Jarvis et al., 2010; Lobell et al., 2008; Thornton et al., 2011). Some of these impacts have already been observed (Battisti and Naylor, 2009; Schlenker and Lobell, 2010). To help cope with such impacts, a framework to assess the effects of climate change on agriculture and food security and to aid with adaptation was established in 2008, as described by Jarvis et al. (2011): The Consultative Group of International Agricultural Research (CGIAR) Research Program on Climate Change, Agriculture and Food Security (CCAFS).

For adaptation to be successful, agricultural and climate data are crucial, and these are scarce in their basic forms (data from research and weather stations, respectively) or not very well managed and/or maintained in certain parts of the world. Most importantly, climate databases and their derived products are sometimes inaccurate, or else lack the documentation necessary to facilitate their use within the agricultural research community. In some instances, this may be indicative of the gap between the agricultural and climate research communities (Pielke et al., 2007; Thornton et al., 2011). Even when the two do collaborate, agricultural researchers face critical constraints when accessing basic sources of climate data (i.e. weather stations) due to a number of factors, from access

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to data, to weather maintenance and data quality checks, to the weather itself (DeGaetano, 2006).

In the last 10 years, various datasets have been developed by different institutions, usually based on either a combination of weather station data, satellite data, and numerical weather prediction models in addition to interpolation methods, or on the sole application of climate models. The usage of these datasets for agricultural modelling purposes is rather limited for one or more of the following reasons: (1) their time step is long (monthly in the best case); (2) their temporal coverage is limited to an average of several years (Hijmans et al., 2005; New et al., 2002); (3) their spatial resolution is too coarse (Adler et al., 2003; Schneider et al., 2010); (4) their geographic coverage is not wide enough (Di Luzio et al., 2008); and (5) only certain variables (i.e. temperatures, rainfall) are reported whereas other agriculturally relevant measures (e.g., potential and/or reference evapotranspiration, relative humidity, solar radiation) are rarely reported (Di Luzio et al., 2008; Hijmans et al., 2005). Moreover, assessments of these data (particularly climate models) have been done only under a climate-science perspective (Gleckler et al., 2008; Pierce et al., 2009), for a limited number of variables (Jun et al., 2008; Reifen and Toumi, 2009), or for a reduced realm (Walsh et al., 2008).

In this paper, we sought to improve the general knowledge on the available climate data for agricultural research using a three-step thorough analysis on fundamental aspects related to agricultural modelling. First, we perform a meta-analysis on the usage of various data sources for agricultural applications; second, we assess the quality and distribution of weather station records by exploring both the ability of these data to fill geographic information gaps by means of interpolation, and the sensitivities of the different regions to data loss; and finally, we assess the accuracy of climate model outputs against different observational datasets using various metrics reported in previous literature (Gleckler et al., 2008; Pierce et al., 2009). We finally analyse the main implications of our findings on agricultural impact assessment.

2. Review of knowledge and data

2.1. Understanding of processes and crop modelling

Mechanisms to fix carbon in plants (i.e. photosynthesis) are affected by a number of factors (El-Sharkawy, 2005; Prasad et al., 2002), although responses strongly depend on the type of mechanism used by the plant to produce biomass (i.e. C_4, C_3, CAM) and on any other stresses to which the plant could be subjected simultaneously. In crop production, apart from appropriate plant growth it is the amount of biomass accumulated in fruits and seeds and the nutrients in them that matters most (Thuzar et al., 2010). Yields are a direct consequence of photosynthesis and biomass accumulation, and these are directly or indirectly affected by environmental conditions [see (Challinor et al., 2009b) for a review]. Well-watered crops grown under optimal temperature and solar radiation ranges develop to their full production potential (van Ittersum et al., 2003), but growth potential reduces if the crop is stressed during the growing season (Hew et al., 1969; Huntingford et al., 2005).

Therefore, modelling crop growth depends on (1) correct formulation of the simulation model, (2) our ability to understand the effects of environmental factors on growth, and (3) correct measurement of the relevant environmental factors for correct mapping of their interactions (Boote et al., 1996; El-Sharkawy, 2005). Hence, crop modelling largely benefits from accurate measurements of temperatures, rainfall, and solar radiation, as the main factors acting on photosynthesis (Challinor and Wheeler, 2008; Hoogenboom et al., 1994), but even these basic data are often unavailable, messy, or of limited quality. The more available data there exist, the better calibration and evaluation of crop models can be (Adam et al., 2011; Niu et al., 2009; Xiong et al., 2008).

Additionally, most crop models simulate growth of individual plants and then scale out the modelling results to the plot-scale, based on management decisions such as plant and row distances, and plot size (Aggarwal et al., 2006; Boote et al., 1996; Hoogenboom et al., 1994). On the other hand, available weather data (when not measured in the field) is only available at coarse spatial scales. Matching these two spatial scales is not an easy task [see (Challinor et al., 2009a; Jagtap and Jones, 2002; Trnka et al., 2004) for a review]. The challenge is thus to increase the knowledge of the interactions between atmospheric and crop-growth processes (Boote et al., 1996) whilst avoiding model over-parameterisation (Challinor et al., 2009b), improving the accuracy of inputs (Adam et al., 2011), and matching both spatial scales (Challinor et al., 2009a). All this requires closing the gap between crop and climate scientists.

2.2. Weather data

Measurements of weather for a given site are often unavailable because (1) there is no weather station; (2) weather stations are not well maintained so data are either only available for a short period or contain gaps, (3) collected data are not properly stored; (4) data do not pass basic quality checks; and/or (5) access to data is restricted by holding institutions (Fig. 1). This all further constrains agricultural impact assessment, highlighting the importance of making data public.

Apart from the constraints related to access and weather station locations, probably the most important issue regarding weather data is quality (Begert et al., 2008; DeGaetano, 2006) (Fig. 1), which also greatly affects the performance of impact models. Therefore, the climate and agricultural community has partly focused on developing methods for either temporal or spatial data gap filling, and on using such methods for developing global or regional datasets with public access (Hijmans et al., 2005; Jones and Thornton, 1999; Soltani et al., 2004).

However, uncertainties in global datasets derived from interpolation methods have been only barely (if at all) estimated (Buytaert et al., 2009; Challinor and Wheeler, 2008; Soria-Auza et al., 2010). Researchers using global datasets and any weather station source

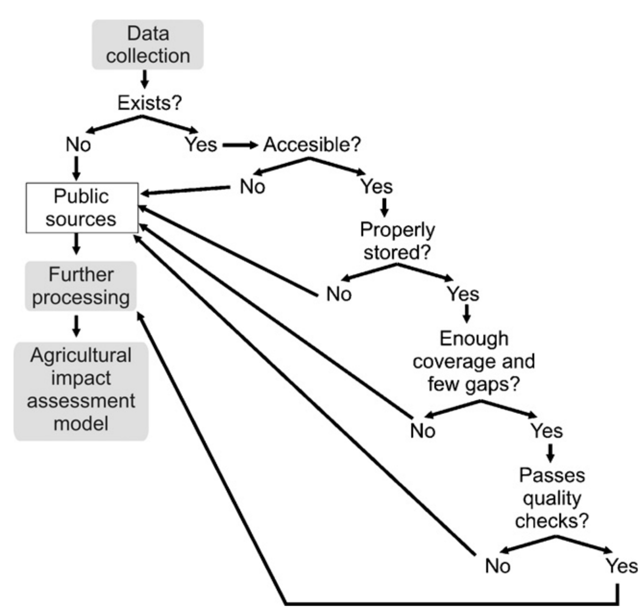

Fig. 1. Cascade of constraints to climate data, as normally observed in agricultural impact assessment.