



Uncertainties in global climate and water models challenge future estimates of crop water use and sustainability

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The assessment of crop water sustainability under future climate scenarios is crucial for coping with predicted water scarcity and for devising strategies to ensure global food security. In this context, the evaluation of crop water indicators generally relies on global scale projections of climatic and hydrologic variables which often provide divergent estimates of precipitation, potential evapotranspiration, and renewable freshwater rates, thus affecting the final evaluation of crop water needs and associated risks. In this work, by performing a multi-model analysis (considering four climate models and six water models from the Inter-Sectoral Impact Model Intercomparison Project ISIMIP2b), we (i) evaluate and map crop water needs and sustainability under current and future climate scenarios, (ii) quantify the uncertainty associated with the climate and impact model selection, particularly focusing on how such uncertainties propagate both in time (from 2000 to 2090) and in space (ranging from global scale to the smallest grid cell unit), and (iii) assess the major sources of uncertainty (global climate or water models). Our results reveal a trend of increasing water unsustainability under future scenarios, despite significant uncertainties across models. Hotspots of unsustainable water use are identified in the Mideastern United States, Central Europe, and parts of South America, where blue water demands are projected to increase by over 150% by the end of the century relative to the year 2000. At the global scale, variations in green and blue water footprints from the average across all models are between $\pm 10\%$ and $\pm 30\%$, respectively. Such uncertainties are highly amplified as the spatial scale of analysis is increased. For example, country-scale variations in green and blue water footprints of $\pm 25\%$ and $\pm 100\%$ relative to the multi-model average are observed in the United States. Disagreement across global water models dominates global uncertainty for blue crop water use and sustainability calculations, while variability across climate models contributes more prominently to green water footprint uncertainty under severe climate change scenarios. This study emphasizes the critical role of uncertainty quantification in understanding the variability of crop water requirements, offering key insights for managing agricultural water resources under changing climates.