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D-C3.3 Report of scaling methods that have been compared in case studies

Uncertainties in Scaling-Up Crop Models for Large-Area Climate Change Impact Assessments

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Abstract/Executive summary

Problems related to food security and sustainable development are complex (Ericksenet al., 2009) and require consideration of biophysical, economic, political, and social factors, as well as their interactions, at the level of farms, regions, nations, and globally. While the solution to such societal problems may be largely political, there is a growing recognition of the need for science to provide sound information to decision-makers (Meinke et al., 2009). Achieving this, particularly in light of largely uncertain future climate and socio-economic changes, will necessitate integrated assessment approaches and appropriate integrated assessment modeling (IAM) tools to perform them. Recent (Ewertet al., 2009; van Ittersumet al., 2008) and ongoing (Rosenzweiget al., 2013) studies have tried to advance the integrated use of biophysical and economic models to represent better the complex interactions in agricultural systems that largely determine food supply and sustainable resource use. Nonetheless, the challenges for model integration across disciplines are substantial and range from methodological and technical details to an often still-weak conceptual basis on which to ground model integration (Ewertet al., 2009; Janssenet al., 2011). New generations of integrated assessment models based on well-understood, general relationships that are applicable to different agricultural systems across the world are still to be developed. Initial efforts are underway towards this advancement (Nelsonet al., 2014; Rosenzweiget al., 2013). Together with economic and climate models, crop models constitute an essential model group in IAM for large-area cropping systems climate change impact assessments. However, in addition to challenges associated with model integration, inadequate representation of many crops and crop management systems, as well as a lack of data for model initialization and calibration, limit the integration of crop models with climate and economic models (Ewertet al., 2014). A particular obstacle is the mismatch between the temporal and spatial scale of input/output variables required and delivered by the various models in the IAM model chain. Crop models are typically developed, tested, and calibrated for field-scale application (Booteet al., 2013; see also Part 1, Chapter 4 in this volume) and short time-series limited to one or few seasons. Although crop models are increasingly used for larger areas and longer time-periods (Bondeauet al., 2007; Deryng et al., 2011; Elliottet al., 2014) rigorous evaluation of such applications is pending. Among the different sources of uncertainty related to climate and soil data, model parameters, and structure, the uncertainty from methods used to scale-up crop models has received little attention, though recent evaluations indicate that upscaling of crop models for climate change impact assessment and the resulting errors and uncertainties deserve attention in order to advance crop modeling for climate change assessment (Ewertet al., 2014; R¨ otteret al., 2011). This reality is now reflected in the scientific agendas of new international research projects and programs such as the Agricultural Model Intercomparison and Improvement Project (AgMIP; Rosenzweiget al., 2013) and MACSUR (MACSUR, 2014). In this chapter, progress in evaluation of scaling methods with their related uncertainties is reviewed. Specific emphasis is on examining the results of systematic studies recently established in AgMIP and MACSUR. Main features of the respective simulation studies are presented together with preliminary results. Insights from these studies are summarized and conclusions for further work are drawn.

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References

Adam, M., Van Bussel, L. G. J., Leffelaar, P. A., Van Keulen, H., and Ewert, F. (2011). Effects of modelling detail on simulated potential crop yields under a wide range of climatic conditions, Ecol. Model.,222, 131–143.

Angulo, C., R¨otter, R., Trnka, M., Pirttioja, N., Gaiser, T., Hlavinka, P., and Ewert, F. (2013). Characteristic “fingerprints” of crop model responses to weather input data at different spatial resolutions, Eur. J. Agron.,49, 104–114.

Asseng, S., Ewert, F., Rosenzweig, C., Jones, J. W., Hatfield, J. L., Ruane,A. C., Boote, K. J., Thorburn, P. J., R¨otter, R. P., Cammarano, D., Brisson, N., Basso, B., Martre, P., Aggarwal, P. K., Angulo, C., Bertuzzi, P., Biernath, C., Challinor, A. J., Doltra, J., Gayler, S., Goldberg, R., Grant, R., Heng, L., Hooker, J., Hunt, L. A., Ingwersen, J., Izaurralde, R. C., Kersebaum, K. C., M¨uller, C., Naresh Kumar, S., Nendel, C., O'Leary, G., Olesen, J. E., Osborne, T. M., Palosuo, T., Priesack, E., Ripoche, D., Semenov, M.A., Shcherbak, I., Steduto, P., St¨ockle, C., Stratonovitch, P., Streck, T., Supit, I., Tao, F., Travasso, M., Waha, K., Wallach, D., White, J. W., Williams, J. R., and Wolf, J. (2013). Uncertainty in simulating wheat yields under climate change,Nat. Clim. Change,3, 827–832.

Bierkens, M. F. P., Finke, P. A., and de Willigen, P. (2000).Upscaling and downscaling methods for environmental research, Kluwer, Dordrecht. Bl¨oschl, G. and Sivapalan, M. (1995). Scale issues in hydrological modelling: a review,Hydrol. Proc., 9, 251–290.

Bondeau,A., Smith, P. C., Zaehle, S., Schaphoff, S., Lucht, W., Cramer, W., Gerten, D., Lotze Campen, H., M¨uller, C., and Reichstein, M. (2007). Modelling the role of agriculture for the 20th century global terrestrial carbon balance,Global Change Biol.,13, 679–706.

Boote, K. J., Jones, J. W., White, J. W., Asseng, S., and Lizaso, J. I. (2013). Putting mechanisms into crop production models,Plant Cell Environ.,36, 1658–1672.

Deryng, D., Sacks, W., Barford, C., and Ramankutty, N. (2011). Simulating the effects of climate and agricultural management practices on global crop yield,Global Biogeochem. Cycle, 25, GB2006.

Elliott, J., Deryng, D., M¨uller, C., Frieler, K., Konzmann, M., Gerten, D., Glotter, M., Fl¨orke, M., Wada,Y., Best, N., Eisner, S., Fekete, B. M., Folberth, C., Foster, I., Gosling, S. N., Haddeland, I., Khabarov, N., Ludwig, F., Masaki, Y., Olin, S., Rosenzweig, C., Ruane, A. C., Satoh, Y., Schmid, E., Stacke, T., Tang, Q., and Wisser, D. (2014). Constraints and potentials of future irrigation water availability on agricultural production under climate change,Proc. Natl. Acad. Sci.,111, 3239–3244.

Ericksen, P. J., Ingram, J. S., and Liverman, D. M. (2009). Food security and global environmental change: emerging challenges,Environ. Sci. Policy,12, 373–377.

Ewert, F. (2004).Modelling changes in global regionalized food production systems under changing climate and consequences for food security and environment — development of an approach for improved crop modelling within IMAGE, Wageningen University & Netherlands Environmental Assessment Agency (MNP), National Institute for Public Health and Environment (RIVM).

Ewert, F., R¨otter, R. P., Bindi, M., Webber, H., Trnka, M., Kersebaum, K. C., Olesen, J., van Ittersum, M. K., Janssen, S., Rivington, M., Semenov, M. A., Wallach, D., Porter, J. R., Stewart, D., Verhagen, J., Gaiser, T., Palosuo, T., Tao, F., Nendel, C., Roggero, P. P., Bartoˇsov´a, L., and Asseng, S. (2014). Crop modelling for integrated assessment of climate change risk to food production,Environ. Model. Software, submitted.

Ewert, F., van Ittersum, M. K., Bezlepkina, I., Therond, O.,Andersen, E., Belhouchette, H., Bockstaller, C., Brouwer, F., Heckelei, T., Janssen, S., Knapen, R., Kuiper, M., Louhichi, K., Olsson, J. A., Turpin, N., Wery, J., Wien, J. E., and Wolf, J. (2009). A methodology for enhanced flexibility of integrated assessment in agriculture,Environ. Sci. Policy,12, 546–561.

Ewert, F., van Ittersum, M. K., Heckelei, T., Therond, O., Bezlepkina, I., and Andersen, E. (2011). Scale changes and model linking methods for integrated assessment of agri-environmental systems, Agric. Ecosyst. Environ.,142, 6–17. Hansen, J. W. and Jones, J. W. (2000). Scaling-up crop models for climate variability applications, Agric. Syst.,65, 43–72.

Hoffmann, H., Zhao, G., van Bussel, L., Enders, A., Xenia, S., Carmen, S., Jagadees,Y., Fulu, T., Julie, C., Edmar, T., Balasz, G., Luca, D., Zhigan, Z., Nendel, C., Kiese, R., Raynal, H., Eckersten, H., Haas, E., Wang, E., Kuhnert, M., Trombi, G., Bindi, M., Lewan, E., Bach, M., Kersebaum, K. C., R¨otter, R., Roggero, P. P., Wallach, D., Krauss, G., Siebert, S., Gaiser, T., and Ewert, F. (2014). Effects of climate input data aggregation on modeling regional crop yields,Clim, Res., in press.

IT.NRW (2014). Statistik. Available at: http://www.it.nrw.de/statistik/index.html. Accessed on 19 September 2014.

Janssen, S., Athanasiadis, I. N., Bezlepkina, I., Knapen, R., Li, H., Dom´ınguez, I. P., Rizzoli, A. E., and van Ittersum, M. K. (2011). Linking models for assessing agricultural land use change, Computer Electron. Agric.,76, 148–160.

MACSUR (2014). Available at: http://www.macsur.eu/. Accessed on 21 September 2014.

Meinke, H., Howden, S. M., Struik, P. C., Nelson, R., Rodriguez, D., and Chapman, S. C. (2009). Adaptation science for agriculture and natural resource management — urgency and theoretical basis,Curr. Opin. Environ. Sustain.,1, 69–76.

Metzger, M. J., Bunce, R. G. H., Jongman, R. H. G., Sayre, R., Trabucco, A., and Zomer, R. (2013). A high-resolution bioclimate map of the world: A unifying framework for global biodiversity research and monitoring,Global Ecol. Biogeog.,22, 630–638.

Nelson, G. C., Valin, H., Sands, R. D., Havl´ık, P., Ahammad, H., Deryng, D., Elliott, J., Fujimori, S., Hasegawa, T., Heyhoe, E., Kyle, P., Von Lampe, M., Lotze-Campen, H., Mason d'Croz, D., van Meijl, H., van der Mensbrugghe, D., M¨uller, C., Popp, A., Robertson, R., Robinson, S., Schmid, E., Schmitz, C., Tabeau, A., and Willenbockel, D. (2014). Climate change effects on agriculture: Economic responses to biophysical shocks,Proc. Natl. Acad. Sci.,111, 3274–3279.

Nonhebel, S. (1994). The effects of use of average instead of daily weather data in crop growth simulation models,Agric. Syst.,44, 377–396.

Palosuo, T., Kersebaum, K. C., Angulo, C., Hlavinka, P., Moriondo, M., Olesen, J. E., Patil, R. H., Ruget, F., Rumbaur, C., Takac, J., Trnka, M., Bindi, M., Caldag, B., Ewert, F., Ferrise, R., Mirschel, W., Saylan, L., Siska, B., and R¨otter, R. (2011). Simulation of winter wheat yield and its variability in different climates of Europe: A comparison of eight crop growth models,Eur. J. Agron.,35, 103–114.

Rosenzweig, C., Jones, J. W., Hatfield, J. L., Ruane, A. C., Boote, K. J., Thorburn, P., Antle, J. M., Nelson, G. C., Porter, C., Janssen, S., Asseng, S., Basso, B., Ewert, F., Wallach, D., Baigorria, G., and Winter, J. M. (2013). The Agricultural Model Intercomparison and Improvement Project (AgMIP): Protocols and pilot studies,Agric. Forest Meteorol.,170, 166–182.

R¨otter, R. P., Carter, T. R., Olesen, J. E., and Porter, J. R. (2011). Crop-climate models need an overhaul, Nat. Clim. Change,1, 175–177.

R¨otter, R. P., Palosuo, T., Kersebaum, K. C., Angulo, C., Bindi, M., Ewert, F., Ferrise, R., Hlavinka, P., Moriondo, M., and Nendel, C. (2012). Simulation of spring barley yield in different climatic zones of Northern and Central Europe: a comparison of nine crop models,Field Crop Res., 133, 23–36.

Teixeira, E. I., Brown, H. E., Sharp, J. M., Meenken, E. D., and Ewert, F. (2014). Evaluating methods to simulate crop rotations for regional climate change assessments — a case study on the Canterbury plains of New Zealand,Environ. Model. Software, in press.

van Bussel, L. G. J., Ewert, F., Zhao, G., Hoffmann, H., Wallach, D., Klein, C., Biernath, C., Heinlein, F., Tao, F., R ¨otter, R., Cammarano, D., Asseng, S., Elliott, J., Glotter, M., Nendel, C., Basso, B., Baigorria, G. A., Romero, C. C., Kersebaum, K. C., Nendel, C., Specka, X., Gaiser, T., and Siebert, S. (2014). Spatial sampling of weather data for regional crop yield simulations,Global Ecol. Biogeog., in press.

van Bussel, L. G. J., M¨uller, C., van Keulen, H., Ewert, F., and Leffelaar, P. A. (2011). The effect of temporal aggregation of weather input data on crop growth models' results,Agric. Forest Meteorol.,151, 607–619.

van Delden, H., van Vliet, J., Rutledge, D. T., and Kirkby, M. J. (2011). Comparison of scale and scaling issues in integrated land-use models for policy support,Agric. Ecosyst. Environ., 142, 18–28.
van Ittersum, M. K., Ewert, F., Heckelei, T., Wery, J., Alkan Olsson, J., Andersen, E., Bezlepkina, I., Brouwer, F., Donatelli, M., Flichman, G., Olsson, L., Rizzoli, A. E., van der Wal, T., Wien, J. E., and Wolf, J. (2008). Integrated assessment of agricultural systems - A component-based framework for the European Union (SEAMLESS),Agric. Syst.,96, 150–165.
van Oijen, M., Thomson, A., and Ewert, F. (2009).Spatial upscaling of process-based vegetation models: An overview of common methods and a case-study for the U.K., StatGIS GeoInformatics for Environmental Surveillance., Milos Island, Greece, 17–19 June 2009., p. 6.
Webber, H., Gaiser, T., and Ewert, F. (2014). What role can crop models play in supporting climate change adaptation decisions to enhance food security in Sub-Saharan Africa?,Agric. Syst.,127, 161–177.
Zhao, G., Hoffmann, H., van Bussel, L., Enders, A., Xenia, S., Carmen, S., Jagadees,Y., Fulu, T., Julie, C., Edmar, T., Balasz, G., Luca, D., Zhigan, Z., Nendel, C., Kiese, R., Raynal, H., Eckersten, H., Haas, E., Wang, E., Kuhnert, M., Trombi, G., Bindi, M., Lewan, E., Bach, M., Kersebaum, K. C., R¨otter, R., Roggero, P. P., Wallach, D., Krauss, G., Siebert, S., Gaiser, T., and Ewert, F. (2014). Impact of weather data spatial resolution on simulation of cropping systems: a comparison of models, production systems and crops,Clim. Res., in press.
Zhao, G., Siebert, S., Rezaei, E. E., Yan, C., and Ewert, F. (2015). Demand for multi-scale weather data for regional crop modelling,Agric. Forest Meteorol., 156–171.