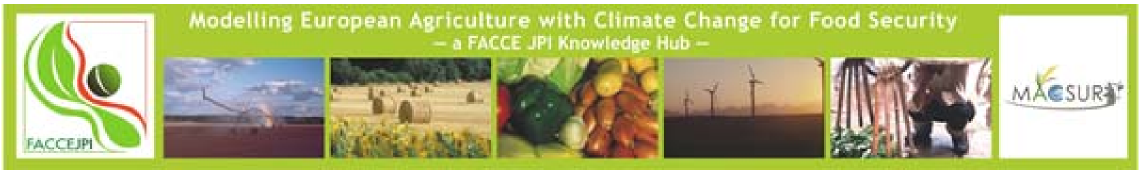

FACCE-MACSUR

Uncertainties in climate change prediction and modelling

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Abstract

As models become increasingly complex and integrated, uncertainty among model parameters, variables and processes become critical for evaluating model outcomes and predictions. A framework for understanding uncertainty in climate modelling has been developed by the IPCC and EEA which provides a framework for discussion of uncertainty in models in general. Here we report on a review of this framework along with the results of a survey of sources of uncertainty in livestock and grassland models. Along with the identification of key sources of uncertainty in livestock and grassland modelling, the survey highlighted the need for a development of a common typology for uncertainty. When collaborating across traditionally separate research fields, or when communicating with stakeholders, differences in understanding, interpretation or emphasis can cause confusion. Further work in MACSUR should focus on improving model intercomparison methods to better understand model uncertainties, and improve availability of high quality datasets which can reduce model uncertainties.

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Introduction

During the process of deriving projections for probable future developments of our climate system, not only did the underlying assumptions for the scenarios undergo conceptual as well as qualitative advancements. Also, the use and perception of the respective uncertainties have changed over the years. Here, the development of different metrics and the disentanglement of different sources for uncertainties helped to draw knowledge from this formerly disregarded and discredited information.

For climate projections, three main sources of uncertainties have been identified (SREX Report, IPCC 2012): the natural variability of climate, uncertainties in climate model parameters and structure, and projections of future emissions. The distinction between these sources have enabled the identification of the source of shortcomings and to improve the reliability of projections. Uncertainty was considered in two dimensions (IPCC, 2007): in relation to the evidence supporting the findings and in relation to the agreement between model results. The higher the chosen metric value is for both of these dimensions, the higher is the confidence level which can be assigned and consequently the lower the uncertainty.

Adopting this approach for the evaluation of uncertainties of climate change effects for grassland and livestock modelling, on the one hand allows consolidation of the knowledge on the reliability of current projections and on the other hand identifies current knowledge gaps which are responsible for the major uncertainties. Thus, not only is the assessment of uncertainties of climate change projections (as already achieved by the IPCC) of importance here, but the propagation of uncertainty from the definition of emission pathways through climate models to the outcome of livestock models. As for the whole impact community, this field is still wide open.

LiveM model uncertainties

Uncertainty in modelling agricultural responses to climate change arise from a range of interlinked sources. At the heart of all climate change modelling are the many climate change models which each has their own associated uncertainties (Gosling, 2013). These climate change models feed into various impacts models, which again have their own associated uncertainties (Gosling, 2013). Together with the uncertainties associated with emissions estimates and socio-economic assumptions (Gosling, 2013), it is clear that any predictions on responses to climate change are subject to a very high degree of uncertainty.

Previous meta-analysis of grassland models with respect to their ability to contribute to climate change and food security studies (Rivington and Koo, 2011) found that for the improvement of the main processes, most of the modellers specified targeted experimentation to give more specific calibration data as the most important issue. Another necessity for improvement was given as greater flexibility in the models to account for growth responses to management i.e. grazing or cutting. Although more specific information on strategies for refinements were gathered, it was not differentiated by the source of deficiencies and uncertainties.

In order to take into account modellers' expertise for the assessment of model uncertainties, a questionnaire was designed for the identification of critical sources of uncertainty in commonly used models for grassland (G) or livestock (L) modelling systems. For each critical source of uncertainty, modellers were asked to rank the level of uncertainty on a scale from 1 to 5 (1 for very low, 2 for low, 3 for medium, 4 for high and 5 for very high). Responses were received for 7 models (5 grassland and 2 livestock, details see table 1). All responses are summarized in the appendix (tables 2-5).

It is clear from the responses received, that all grassland models have some critical variables in common. Precipitation is highlighted as a critical physical variable in all models, though to varying degrees. Grassland management is naturally important for all grassland models, with the full range of possible options having an impact to some extent. The removal of biomass from the pasture, either by cutting or grazing animals, highly determines the reliability of the results as well as fertilization (when included in the model).

There were also clear differences between models, with many critical variables and processes only listed for one or two models, reflecting the great diversity in modelling systems. The PASIM and LPJmL models are both critically influenced by temperature, radiation and soil processes. The two Wadiscape models, on the other hand, include shrub and tree growth in the model and hence fire management and tree removal have a critical impact on the model outcomes.

When regarding the most prominent processes and their susceptibility to parameter uncertainty, the range of possibilities widen. Photosynthesis and growth processes are mentioned for nearly all grassland models. The parameterisation of water fluxes in the plants and the soil are regarded by some as major uncertainty source whereas the role of management such as grazing is classified from low to high importance.

The livestock models reported have some clear parallels to the grassland models, particularly in the critical physical variables. Livestock models are also greatly influenced by climatic variables such as precipitation and temperature, both directly in animal responses and indirectly in forage crop inputs. Remaining critical livestock variables relate to the quality and quantity of inputs (crop yield, crop type, feed intensity) and the quality and quantity of outputs (GHG emissions, milk yields). For the HolosFor livestock model, processes determining soil carbon development and greenhouse gas emissions are in the focus for model uncertainties.

When asking for validation related topics, most questionnaires have a rather sparse outcome. Also here, only some modellers gave uncertainty estimates on the data sources used. Only two grass models use flux measurements between biosphere and atmosphere as a specific data group. The other categories which are given are very non-specific and comprise either data (such as field experiments and remote sensing) or qualitative sources such as expert knowledge.

The final question aimed at the assessment of the modellers conception of the uncertainty of their input data. It was mostly answered by suggestions for how to circumvent input shortcomings. These go mostly in the direction of scenario analysis such as systematic variation of grazing intensities, stochastic rainfall, or synthetic terrain slopes. Others state that they have to rely on the data given by authorities.

Typology of uncertainties

Answers to the final question on the questionnaire raises an important point about the nature of uncertainty. There are two very different aspects of uncertainty discussed in the answers provided. Firstly, there is the uncertainty relating to the quality of the input data modellers use. As many modellers state, they are reliant on data provided by the authorities which may or may not be of the standard of accuracy or coverage desired for conclusive model outputs. Secondly, there are uncertainties associated with using different model parameters or model assumptions. The same model, run with equally plausible assumptions, will produce very different outcomes. This second aspect, uncertainty arising from the application of different versions of the same model, has not been well quantified in the impacts modelling literature (Gosling, 2013).

One reason why the same question generated such diverse answers is that we do not yet have a clear typology of uncertainties. Different communities may interpret questions of uncertainty in very different ways. Also, different types of uncertainty may be more or less important depending on the community (Overbeek and Bessembinder, 2013). Creating a common typology of uncertainty will become increasingly important as we attempt to work across traditional boundaries, through merging models, by communicating results to a wide range of end users and by combining impacts from diverse sectors into more comprehensive assessments. Some effort has been made to produce a common typology within a particular field (cropM are attempting to do so for the crop modelling community), and this exercise should be expanded. The ongoing activities on model intercomparison in the AgMIP community (on certain crops such as wheat, maize or rice as well as on economic modelling approaches) aim to improve knowledge on uncertainty by using different modelling approaches. The extension of this approach to the modelling intercomparison of livestock and grassland models is included in MACSUR WP2 and WP3 and incorporated into AgMIP. This combination allows for a broad contribution from the modelling community and ensures the development of common metrics inside the community.

Using common metrics within the modelling community, will also facilitate better communication of uncertainties to the relevant stakeholders. Policy makers are acutely aware of the difficulties in developing policies in the face of uncertainty (EEA, 2012). In some cases, stakeholders are looking for definitive answers before making a decision or looking for clear cut messages to deliver. Policy drivers, such as the IPCC and the EEA, have over the past 10 years put in a lot of effort in developing methods for describing uncertainties in

climate predictions (Fussel, 2013; EEA, 2012). It is now necessary to ensure that the typology of uncertainty used by the scientific modelling community accurately informs this policy typology of uncertainty.

Implications for modelling responses to climate change

In order to establish a procedure for evaluating uncertainties of grassland and livestock modelling responses to climate change, we firstly summarize the knowledge on uncertainties in climate modelling. Subsequently, we concentrate on the most relevant input variables for the grassland and livestock models and estimate their uncertainties.

From observations, the following conclusions were drawn (IPCC, 2007):

- It is a robust finding that global mean temperature is rising.
- There is a high uncertainty about the development of extreme events (droughts, storms, extreme temperatures, frequency and intensity of precipitation) due to insufficient data coverage.
- Feedbacks in the climate system with land-use and livestock related GHG emissions introduce high uncertainties.
- The attribution of the causes of observed temperature changes to natural or human causes remains uncertain at smaller than continental scales.
- The magnitude of CO2 emissions from land-use change and CH4 emissions from individual sources remain as key uncertainties.

Climate projections for the 21st century were evaluated and key statements were extracted (IPCC, 2007):

- It is a robust finding that global GHG emissions will continue to grow and global mean temperature will continue to rise.
- The increase of impacts is very likely due to increased frequencies and intensities of some extreme weather events (heat waves, tropical cyclones, floods and drought).
- A major source of uncertainties remain to be the feedbacks in the climate system which create uncertainty in the emissions trajectory required to achieve a particular stabilisation level. The strength of feedbacks differ considerably between models (e.g. cloud feedbacks, oceanic heat uptake and carbon cycle feedbacks).
- Impacts research is hampered by uncertainties surrounding regional projections of climate change, particularly precipitation. The confidence in projections is higher for some variables (e.g. temperature) than for others (e.g. precipitation), and it is higher for larger spatial scales and longer time averaging periods.

With respect to climate extremes, the corresponding uncertainties are summarized by IPCC (2012):

- High uncertainty in sign of change for coming two to three decades due to high natural climate variability and relatively small effect of climate change.
- High uncertainty in (e.g. precipitation-related) extremes by the end of the 21st century due to uncertainties in climate models rather than in future emissions.

- Uncertainty for other extremes (in particular temperature) mainly due to the emissions uncertainties.
- Inclusion of the assessment of the past performance of models in simulating extremes increases the assessed uncertainty.
- Low-probability, high-impact changes associated with the crossing of poorly understood climate thresholds cannot be excluded, given the transient and complex nature of the climate system.
- Feedbacks play an important role in either damping or enhancing extremes in several climate variables.

These summaries highlight the advanced evaluation of uncertainties in climate change modelling for the 21st century. This process is much less complete for other major input data and scenarios used in livestock and pasture modelling. The survey of land-use activities in space and time is rare on the European continent let alone on the global scale. Datasets on the distribution of pasture vary greatly (Köchy, 2013) and therefore are considered to be of low reliability because most other types of activity (such as cropland, forest or unsuitable land) are more easily identified. Estimates of the global pasture area differ considerably (3.3 billion ha by Klein Goldewijk et al. (2011), 4.7 billion ha by Erb et al. (2007) and 3.4 billion ha (permanent pasture in FAO, faostat)) highlighting the need for an improved and repeated detection of pasture areas. So far, a global dataset on pasture management (grazing, cutting, fertilizing, irrigation, etc.) is not existent, highlighting the need for improved data-sets for reducing or understanding modelling uncertainty.

Concerning the link between grassland and livestock modelling, descriptions for specific sites of feed baskets, energy content of grass and other feed, feeding efficiencies, conversion of feed biomass into meat and milk yields as well as emissions, energy requirements of animals for maintenance, lactation and growth are available. Attempts to derive generalized compilations of these data have been made (e.g. Wirsenius, 2000) but a thorough evaluation of uncertainties of these data, rates and information remains premature. Efforts to address this gap are underway within several large international collaborative projects (e.g. AnimalChange), with reports expected to be available within the next two years. With such information available, thorough evaluations of model uncertainties should be possible also within livestock and grassland modelling.

Recommendations for future

Firstly, in order to address the question of how to assess and reduce uncertainties in livestock and pasture modelling, it has to be distinguished between several areas:

- uncertainty in model approaches (approach taken by AgMIP Grass),
- uncertainty in climate projections (approach taken by CMIP and IPCC) and
- uncertainty in input data (approach taken by AnimalChange).

Thus, the most promising area of activity for the reduction of uncertainties in livestock modelling will be to learn from the experiences in AgMIP on model intercomparison (as is happening in WP2 and WP3) and to expand on the compilation and analysis of major input data that is happening in AnimalChange.

The second major issue concerns the handling of researchers and stakeholders of uncertainty. Within the scientific community, both model parameters and model results could be complemented by estimates of their uncertainties. These could be standard deviations, certain percentiles or even probability density functions which can be derived by deterministics models after evaluation by Bayesian parameter estimation, Monte Carlo simulations or other sensitivity analysis methods. These uncertainties should then be used as an additional input by subsequent models. When sharing model results with stakeholders, the communication of uncertainties is received rather rather differently depending on the audience and seems to be different depending on the topic. While in the climate-related community, stakeholders from authorities of various levels (community to EU) are familiar with using the information contained in uncertainty estimates, other groups are more reluctant or unfamiliar with the terminology or interpretation of uncertainty. Here, further efforts are worthwhile to introduce and promote the concept of uncertainty. Efforts in this field should be incorporated into the on-going stakeholder activities taking place within MACSUR.

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Appendix

Table 1: Details of models contributing to questionnaire

Name	PaSim
Description	Pasture Simulation Model
Developer	INRA
Inputs	weather, soil, grassland management
Output	Productivity, fluxes (C, N, water)
Published	https://www1.clermont.inra.fr/urep/modeles/pasim.htm
Name	LPJmL
Description	Global model for natural vegetation and crop development
Developer	PIK
Inputs	weather, soil, grassland management
Output	Productivity, fluxes (C, water)
Published	Sitch et al. 2003, Bondeau et al. 2007
Name	AnnuGrow
Description	Permanent grassland with annual species (semiarid regions)
Developer	Martin Köchy
Inputs	Rainfall, Soil texture etc.
Output	production of ag biomass, Water fluxes (infiltration, transpiration, percolation)
Published	http://code.google.com/p/annugrow/
Name	Wadiscape 3.x
Description	Permanent grassland with annual species (semiarid regions) and low shrubs
Developer	Martin Köchy
Inputs	Rainfall, Topography (slope)
Output	generation of a neutral (fractal) wadi landscape with specified slope angles, calculation of accumulated flow
Published	http://sci.martinkoechy.de/AdditionalMaterial/WadiscapeGeneratorDoku/main.html
Name	Wadiscape 6.x
Description	as above, but including native trees
Developer	Martin Köchy
Inputs	Rainfall, Topography (slope), Fire frequency
Output	wadi landscape, calculation of accumulated flow
Published	http://sci.martinkoechy.de/AdditionalMaterial/WadiscapeGeneratorDoku/main.html
Name	HolosNor

Description	Crop, dairy & beef, and pig production. Estimates GHG emissions including soil C change
Developer	Helge Bonesmo et al.
Inputs	consistent data set of soil, weather, and farm operational data for 30 Norwegian dairy farms (2008)
Output	GHG emissions including soil C change
Published	Bonesmo et al. 2012, 2013, 2013
Name	EcoDreams_Spain
Description	Bayesian regression-like models of milk performance on organic farms as a function of management and climate
Developer	Isabel Blanco Penedo, IRTA
Inputs	Temperature, Precipitation, Wind
Output	Milk performance
Published	Blanco Penedo et al. 2012

Table 2: Summary of answers to Question 1: Please note the most important physical variables for your model (up to 3) and estimate the sensitivity of your model to their uncertainties.

	PASIM	LPJmL	AnnuGrow	Wadiscape 3.x	Wadiscape 6.x	HolosNor	EcoDreams_Spain
	G	G	G	G	G	L	L
Precipitation	5	5	2	2	2	4	4
Air temperature	5					4	4
Solar radiation	5	4					
Soil texture etc.		4	4			4	
Topography (slope)				2	2		
Fire frequency					3		
Wind related							4
Milk yield						4	
Crops and forage DM yields						4	

Table 3: Summary of answers to Question 2: Please note the most important management options (up to 3) for your model and estimate the sensitivity of your model to their uncertainties.

	PASIM	LPJmL	AnnuGrow	Wadiscape 3.x	Wadiscape 6.x	HolosNor	EcoDreams_Spain
	G	G	G	G	G	L	L
Cutting	5	4					
Fertilization	5					5	
Grazing	5	4		4	4		
Fire management					2		
Tree removal					2		
Feed intensity						4	
Type of crop						4	
Housing type							2
Milk consistency							2
Genetics							2

Table 4: Summary of answers Question 3: Please note the most important processes (up to 3) for your model and estimate the sensitivity of your model to parameter uncertainties

	PASIM	LPJmL	AnnuGrow	Wadiscape 3.x	Wadiscape 6.x	HolosNor	EcoDreams_Spain
	G	G	G	G	G	L	L
Plant photosynthesis	5	5		3	3		
Evapotranspiration			3				
Water infiltration			4				
Soil respiration	5	4					
Soil water balance	5						

Soil C change						5	
Competition of plants			3				
Tree growth					3		
Grazing		4		2 to 4	2 to 4		
N2O production						5	
Methane production						4	

Table 5: Summary of answers Question 4: Please note the most important data sources or types for your model validation (up to 3) and estimate uncertainties of these.

	PASIM	LPJmL	AnnuGrow	Wadiscape 3.x	Wadiscape 6.x	HolosNor	EcoDreams_Spain
	G	G	G	G	G	L	L
Flux data	x	2					
Field experiments		2	2				
Remote sensing		3	4				
Expert knowledge				x	x		
Farm inspection							2
Monitoring data							1

Question 5: How do you estimate the uncertainties of your main drivers themselves?