Modelling adaptation of ancient agricultural societies to climate change, the core of an interdisciplinary approach Virtual meeting, 26-27 January 2021 (only afternoon sessions CET time)

Keywords: Society-climate relationship, paleoclimates, agrosystems, interdisciplinarity, multi-agent modelling

Ancient societies have long been perceived as particularly vulnerable to climate change, which has sometimes been considered as one of the causes of the decline or collapse of ancient civilizations. The recent emergence of the concept of resilience in the field of socio-environmental research now calls for a reassessment of societies' adaptive capacities. This new orientation requires going beyond the deterministic reasoning of direct cause and effect between climate change and societal change. It requires the integration of more complexity into an approach that must be enriched by socio-economic and agro-system components. Climate fluctuations directly impact on agricultural yields, which in themselves impact on societies' dynamics. Beyond certain thresholds, food safety can be weakened, forcing people to move or adapt their crops and agrarian systems.

At the interface between the environmental geosciences and the humanities, it requires us to strengthen the dialogue between historians-archaeologists, paleo-climatologists and agricultural specialists. Modelling is at the core of this dialogue. On the one hand, modelling society-environment interaction needs the inputs from these disciplines to characterize past agriculture, way of life and trade and to ask interdisciplinary questions, and on the other hand, the outputs of the model will challenge the scientists to reconsider the interpretation of their data at the light of the processes included in the model. This overarching model also can be assembled from models commonly used in these disciplines: climate models, agrosystem models, agents-based decision models, etc…

Therefore, the aim of this workshop will be to bring together modelers working in these different disciplinary fields to share their experiences and methodologies in order to strengthen the methodological integration around the question of the history of relations between societies and climate. The discussion can be built around specific questions:

How do you optimize the interdisciplinarity needed by your own research in this domain? Can modelling be of strong assistance to achieve that?

1- **What are the innovative perspectives of society-environment modelling?**

2- **Can we study the past as a future with a set of different scenarios? Can the past be a scenario for the future?**

3- **The concerned disciplines require and provide data of different natures. Some of them are qualitative. How to use them together with quantitative data and models?**

4- **How to design the modelling approach to answer questions related to resilience?**

PROGRAM:

The time for each communication is 30 minutes (1/4 hour of presentation - 1/4 hour for questions)

Tuesday 26th: Towards the Past, archaeological approaches

14:00 – 14:15	Introduction (J. Guiot)
14:15 – 14:45	Working from Regional Climates towards Local Consequences: Diachronic Settlement Patterns as Model Material in the Chicama Valley, Peru (D. Contreras et al.)
14:45 – 15:15	Modelling agrarian surplus production, carrying capacity and demography of the Dutch limes: lessons learned (Ph. Verhagen et al.)
15:15 – 15:45	The Indus Village model: Modelling population, agriculture, and climate change in the Indus Civilization (A. Angourakis et al.)
15:45 – 16:00	Pause
16:00 – 16:30	ModelAnSet: a modelling agenda to explore the role of socio-environmental interactions on Ancient settlement dynamics (F. Bertoncello, M.-J. Ouriachi et al.)
16:30 – 17:00	ROMCLIM: simulating the viability and profitability of Roman farms and villas in response to climate change (N. Bernigaud et al.)
17:00 – 18:00	Discussion

Wednesday 27th: Applications in other domains and new concepts

14:00 – 14:30	Future avenues (introduction): Moving modelling forward (S. Van der Leeuw)
14:30 – 15:00	Adaptation of Fishers to Climate Change: The POSEIDON Model (R. Axtell)
15:00 – 15:30	*Quanti* and *Quali* hand in hand (J. Rouchier)
15:30 – 16:00	A balanced methodology between eco-anthropological and agro-environmental variables in spatialized Neolithic modelling: the MASSE approach (M. Saqalli)
16:00 – 16:30	LPJmL-Med: an agroecosystem model for simulating the productivity of crops in the Mediterranean basin during the Holocene (A. Bondeau et al.)
16:30 – 16:45	Pause
16:45 – 17:45	Discussion

17:45 – 18:00 Conclusions (J. Guiot)

ABSTRACTS:

Day 1.

Working from Regional Climates towards Local Consequences: Diachronic Settlement Patterns as Model Material in the Chicama Valley, Peru

Contreras Daniel (Univ. Florida), Vining Benjamin (Univ. Arkansas) and Hillman Aubrey (SUNY Albany)

The scarcity of long-term climatic records of high temporal and spatial resolution poses a significant challenge to reconstructing socio-climatic dynamics at the scales associated with human experience. In order for archaeology to realize its potential to contribute to scientific and policy arenas, particularly in the global South where data are less abundant, this challenge must be addressed. In this talk we explore this problem through a case study from the Chicama Valley on Peru's North Coast, where we use spatially explicit models to integrate diverse climate and archaeological data. Climate data include spatially and temporally uneven instrumental data, global modeled climate data for the 20th-21st century, and recent remote sensing measures of localized El Niño-Southern Oscillation (ENSO) effects on vegetation, to which we are working on adding both regional and local paleoclimate records. Archaeological data include four decades of published settlement survey identifying at least site locations and periods of occupation, and in some cases sizes and functions. Downscaling the climate data allows us to reconstruct local hydroclimates, addressing problems of explanatory scale, but raising new questions about human-environment interactions. These include not only the practical question of how best to relate archaeological settlement data to downscaled climate data, but also the epistemological question of how to identify vulnerability and/or resilience in archaeological settlement data. In this talk we focus on both methodological challenges of data integration and the utility of modelling as a tool for identifying potential impacts of human-scale climate variability on past settlement patterns.

Modelling agrarian surplus production, carrying capacity and demography of the Dutch limes: lessons learned

Verhagen Philip, Joyce Jamie and Groenhuijzen Mark R.

VU Univ. Amsterdam

The Roman frontier zone in the Netherlands was long considered insufficiently productive to supply the army with substantial quantities of foodstuffs. However, mounting evidence for local production and consumption of grain and livestock has changed this perspective, raising the question as to what extent local agrarian production could actually supply the Roman troops and civilians living in the area. The ‘Finding the limits of the limes’ project has tried to answer this question using agent-based models of agrarian production in the area. The results from these models, which take into account crop cultivation, animal husbandry and wood collection, were confronted with environmental and demographic data to arrive at estimates of surplus production capacity in the area. It was concluded that limited surplus production was possible in the area, the main constraint being workforce rather than available land.

In this paper, I will present the setup of the model, the choices that were made in the light of highly diverse datasets and modelling assumptions, the scenarios explored and the interpretation of the modelling results. In particular the implications for the debate on the economic, environmental and demographic impact of the Roman occupation and consequent desertion of the area will be considered.

The Indus Village model: Modelling population, agriculture, and climate change in the Indus Civilization

Angourakis Andreas (1), *Bates Jennifer* (2), *Baudouin Jean-Philippe* (2,3), *Giesche Alena* (3), *Walker Joanna R.* (1), *Ustunkaya M. Cemre* (1), *Wright Nathan* (1,4), *Singh Ravindra N.* (5), *Petrie Cameron A.* (1)

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The urban phase of the Indus Civilisation (c. 2600/2500-1900 BC) presents a compelling case of contrasting trajectories of different components of a socio-ecological system, where the decline of urban lifeways coexists with the resilience of rural contexts. Seemly robust cities, whose occupation endured centuries, appear to have been ultimately unsustainable when facing a prolonged period of aridification. Villages, however, occupied a central place in the Indus settlement system before, during, and after the urban period, suggesting that rural lifeways remained flexible and capable of adaptive transformation. Indus archaeology offers a myriad of lines of evidence on this subject, which is unfortunately seldom unified in a single model.
We present an agent-based modelling (ABM) approach to illuminate the trajectory of the Indus Civilisation, the Indus Village model. This model aims to simulate rural settlements through the interaction of a population of farming households with its local environment. It consists of a set of modular components (submodels) designed to be sufficiently explicit, but still generic, representations of weather and land systems, food economy, demography and settlement at a local-to-regional scale. We expect to use it as a 'virtual laboratory' to explore different scenarios of adaptation to environmental conditions, specifically assessing the level of resilience of different cropping strategies (e.g., mono- versus multi-cropping). The core hypothesis to test is that strategies emphasising diversity strengthen resilience in front of climate change, but generally decrease the surplus needed for sustaining the urban (i.e., non-food-producer) population.
The Indus Village model represents an ongoing group effort to integrate contextual knowledge, datasets, assumptions, and narratives into a single coherent framework. Although ambitious in its scope and complexity, the model is intended to be rigorous, controllable, and intelligible at all stages of development. Additionally, by keeping its design modular and public, we aim to guarantee its usefulness to future models and generations of modellers. This work is part of TwoRains (2015-2020, ERC H2020-grant number 648609), a multi-disciplinary project focused on understanding human adaptations to variable rainfall systems and climate change in Indus Civilisation sites in Haryana, NW India. All files related to the Indus Village model and its submodels are stored under version control in a public repository (https://github.com/Andros-Spica/indus-village-model).

ModelAnSet: a modelling agenda to explore the role of socio-environmental interactions on Ancient settlement dynamics

Bertoncello Frédérique (1), *Ouriachi Marie-Jeanne* (2), *Da Costa Pereira Célia* (3), *Tettamanzi Andrea* (3), *Ajroud Rami* (3), *Lefebvre Jérémy* (3)

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The ModelAnSet Agent-Based Model was designed to explore the respective role of environmental and social factors in the evolution of the settlement pattern and dynamics during the Roman period in South-Eastern France. Considering that agricultural holdings (i.e. mainly villas and farms for the Roman period) are the basic elements of the rural settlement system, the model aims at simulating the impact of the climatic and macro-economic conditions on the behavior of Gallo-Roman landowners in relation to their agricultural holdings. According to the profit they derive from their farms and/or villas, which depends both on natural and socio-economic factors, the landowners can decide to maintain without change, improve, enlarge or abandon their holdings or to create a new one. Through the repeated landowners decision-making, the ABM simulates a changing macro-level settlement pattern, in terms of number, type and location of the settlements. In this talk, we will present the general setup of the model and how it can articulate with the ROMCLIM model developed within the RDMed project.

ROMCLIM: simulating the viability and profitability of Roman farms and villas in response to climate change

Bernigaud Nicolas (1), *Bondeau Alberte* (2), *Guiot Joël* (1), *Bertoncello Frédérique* (3), *Ouriachi Marie-Jeanne* (3), *Leveau Philippe* (4), *Bernard Loup* (5), *Isoardi Delphine* (6)

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The ROMCLIM agent-based model developed under NETLOGO simulates the impact of climatic variations on the profitability of different types of farms during the Roman period. One of the objectives of this model is to test the impact of the climate changes from the Iron Age to the Late Antiquity on the ancient economy through agriculture. It incorporates an emulation function of the LPJmL agroecosystem model, which allows to produce fast calculations of the potential yields of wheat, vine and olive between the 6th B.C. and the 7th century A.D., according to a reconstruction of climate variations. The model simulates the impact of yield changes on subsistence and commercial agriculture. Different types of villas and farms (grain farms, wine and olive farms) have been programmed as agents according to a set of parameters (exploited area, number of operators, production and transport costs, etc...) to which values derived from the latin agronomic treaties (Caton, Varron, Columelle, etc.) and historical works have been assigned. In this model, farms and villas disappear when they are no longer profitable or when wheat crops are insufficient to feed farmers. The first results show a positive impact of the Roman Climate Optimum (period?) on the profitability of farms. In particular, they show that climate change has largely changed crop geography and land use, as the cultivated species respond in a different way to temperature and precipitation changes.

Day 2.

Future avenues (introduction): Moving modelling forward

Van der Leeuw Sander (Arizona State Univ.)

Momentous new developments in computing, in particular High Performance Computing, our modelling of socio-environmental dynamics is challenged in a number of different ways. Not only improving the integration between our modelable understanding of societal dynamics and environmental dynamics (difficult enough) but also moving from the traditional "sampling and projection" approach of the social sciences to full use of HPC: modelling capacity by directly on millions of cases, in great detail (say 5000 characteristics per person), so that one can begin to understand the societal dynamics of change. Other major challenges involve bringing together the various modelling communities worldwide, setting standards for quality evaluation and publication, modularizing models so that different modules can be plugged in in order to test various modelling approaches, etc. The Open Modelling Forum is working in this direction, and I will brief you on some of its discussions.

Adaptation of Fishers to Climate Change: The POSEIDON Model

Axtell Robert (George Mason Univ.)

I will report on a new agent-based modelling platform for fisheries, POSEIDON, a joint project of several universities and an NGO. To date it has been used in various environments, from coastal ground fish to oceanic pelagic fish. It is capable of modelling a large number of individual fishing vessels and features a general behavioral model that can be particularized to specific environments. I will describe how it can be used to study the effect of climate change on fisheries and suggest how it might be modified for former societies.

***Quanti* and *Quali* hand in hand**

Rouchier Juliette (Univ. Paris-Dauphine, LAMSADE-CNRS)

We will talk quickly about the research process as an oscillation between qualitative and quantitative research (in general) and how this manifests itself in ABM. First comes the definition of categories, and then it is possible to apply quantitative analysis to already existing ontology. The model in that sense needs a qualitative analysis and the relevant objects and relevant interactions defining the problem must be defined. However, in ABM it is not possible to do without some quantification, as there is always some arbitrage to realize in decision processes. In which case we need to translate choices in numerical values that can be compared. It is a bit dangerous because numbers have their own lives and properties, and dealing with numbers around 0, 1, 2 can have extremely different effect from using 0, 10, 20 - just because numbers have properties. (examples will be given on the importance of this problem of quantification. This question must be known to practitioners who often ignore that (especially in recent years).

LPJmL-Med: an agroecosystem model for simulating the productivity of crops in the Mediterranean basin during the Holocene

Bondeau Alberte (1), *Fader Marinela* (), *Guiot Joël* (2), *Bernigaud Nicolas* (2), *Bouby Laurent* (3)

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The use of an ABM model like ROMCLIM (Bernigaud talk) for analyzing the responses of different farming systems to climate change requires a modelling tool able to simulate the climate impacts on the productivity of crops. ROMCLIM works with an emulator of the LPJmL-Med model, which is an agroecosystem model simulating the growth and productivity of the most important Mediterranean crops (e.g. wheat, olive, wine grapes, etc). We first give a description of the LPJmL-Med model: which physiological and biogeochemical processes are represented? Which farming practices can be accounted for? Which specific parameters must be adapted for simulating prehistorical and antique agriculture? Which inputs are needed? Which outputs are produced? We then briefly show how climate reconstruction for the Holocene can by derived from pollen paleo data by inversing a vegetation model. Following, using such reconstructed Holocene climate data, we show an application of the LPJmL-Med model in the Roman Gaul for the period 2500 BP – 1300 BP. The analysis of the spatio-temporal productivity dynamics reflects well the increase of the agricultural potential during the Roman Climate Optimum. The sensitivity of LPJmL-Med to the past climate variations allows the emulator setup and its use in the ROMCLIM model.

A balanced methodology between eco-anthropological and agro-environmental variables in spatialized Neolithic modelling: the MASSE approach.

Saqalli Mehdi (Univ. Toulouse, GEODE-CNRS)

Socio-ecological modelling is a demarche easily biased mainly due to the differential data and information availability and the differential expertises regarding the various concerned disciplines within modelling teams, especially regarding past socio-ecological systems where field based data on social components are rarely available. The MASSE sequential approach (Modelling Multi-Agent Spatialized Socio-Ecosystems) follows several principles that reduces such biases and allows some corresponding results. All these principles are practiced tacitly or separately in various spatialized agent-based modelling approaches and we simply present and highlight them here. (i) The DEEP-Rank&Weight demarche tend to first establish a conceptual model of the variables that matter, using only relative hierarchy reducing the quali-quantitative unjustified ponderation bias, but also an estimation of the required relative data precision, variability and uncertainty regarding socio-anthropological hypotheses and environmental data. As a result, work force, as the most often rarest resource, induces socio-anthropological rules, such as the family structure, hierarchy and geniture, to matter the most for evaluating the productivity of farming systems (including livestock & hunting /gathering/fishing practices) in concerned socio-ecosystems. (ii) The "EGI PER PRECIUM" data classification allows to outcast the best data, most often the structure and localized ones (non-exhaustive localized and equivalent to model output data) for the testing procedure implying to better use open-access data such as ESA, IGN, WorldClim, EPD and Baseflor data. (iii) The MASSTABA architecture (Modules Agent Socio-Spatialisés éTagés et Agencés en Briques Articulées) is a classical modelling procedure for expanding the sociobiome genericity by partitioning thematically defined modules. We processed climate, hydrological, pedological and ecological modules independently. Finally, regarding socio-anthropological choices, archaeology may provide clues and hypotheses but should follow a *Primum non nocere* principle before considering its implementation.

As a result, we present the construction of the Plant Functioning Types assessed for the ecological module in Languedoc Roussillon as part of the MISTRALS PALEOMEX program

and the LBK (Linear Band Keramik) household hypothesis, showing here the result of the mobilization of these three concomitant demarches altogether.