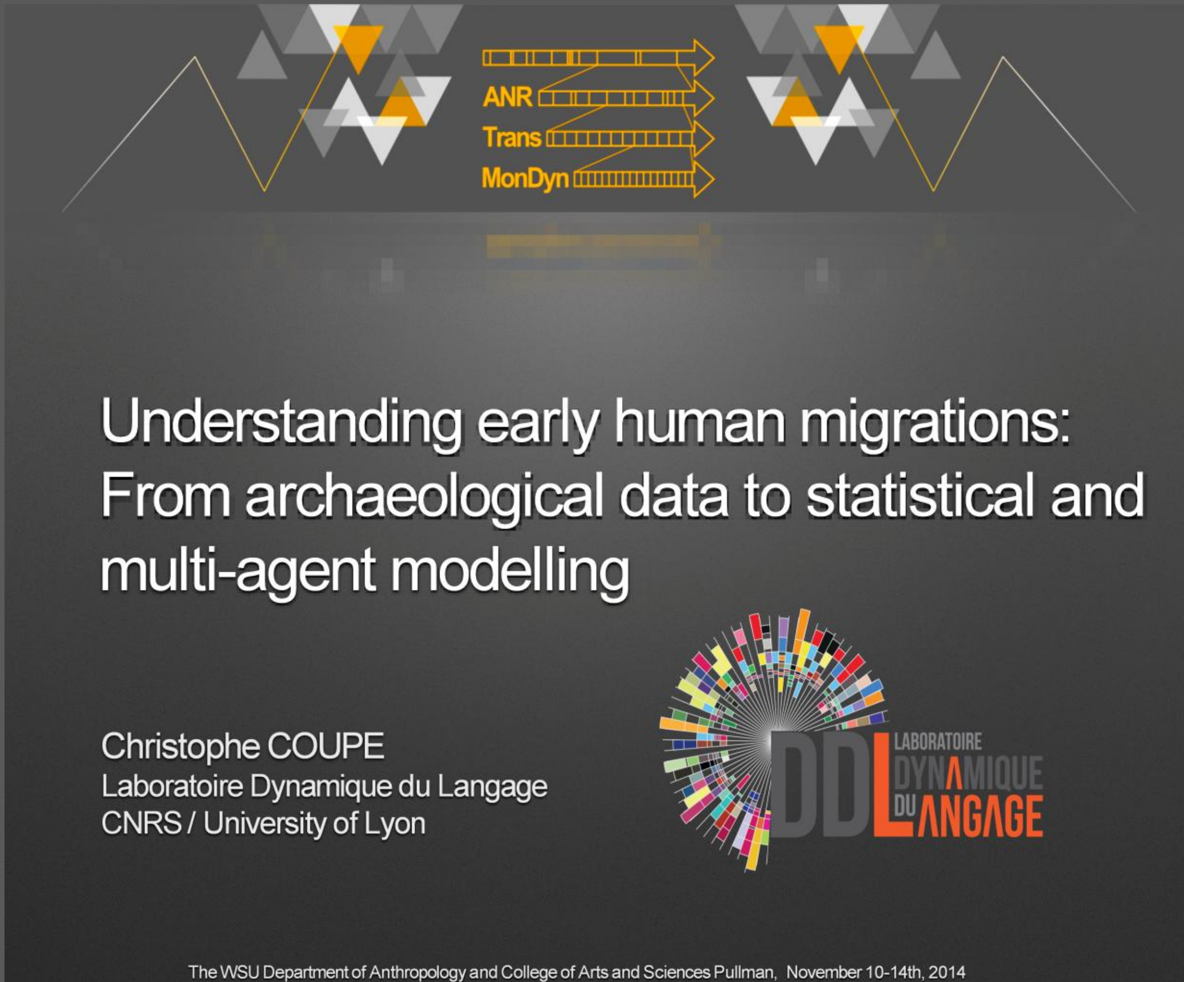
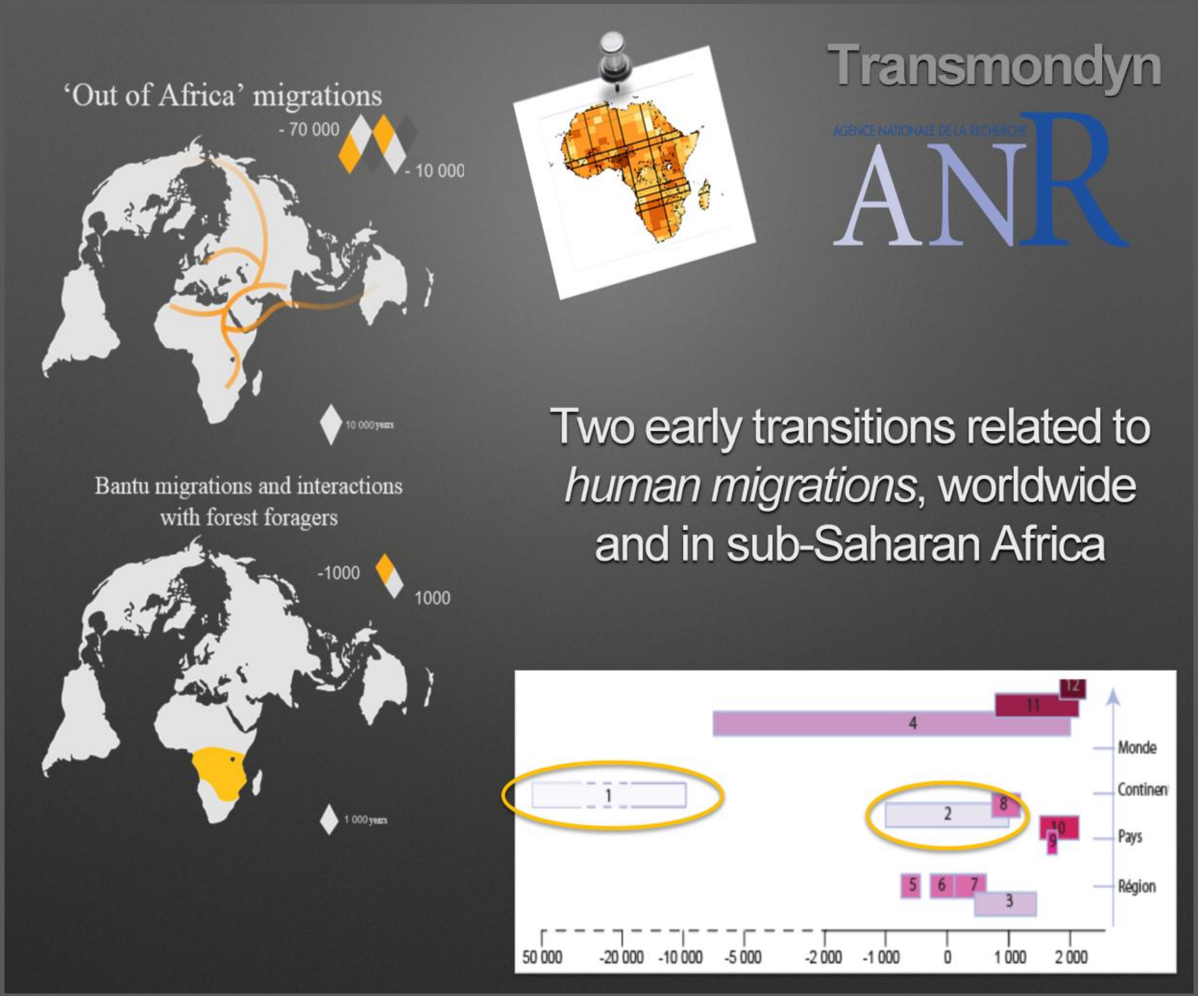


In this talk, we give details about two transitions of the « ANR Transmondyn ».

We highlight how integrating the methods and insights of several disciplines (archaeology, linguistics, computer modeling, statistics) can be helpful to better understand early human migrations.

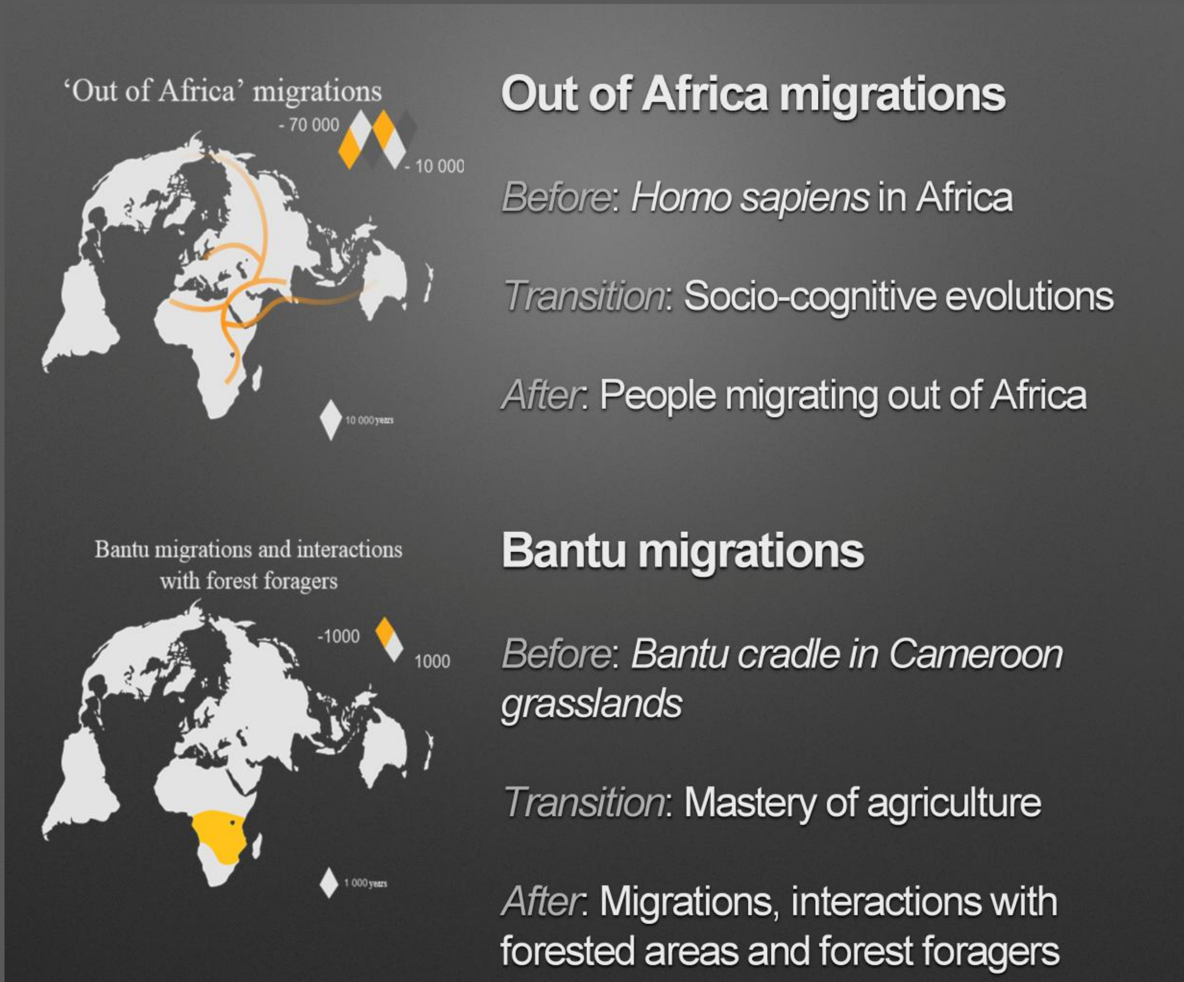


The first two transitions are related to two major human migrations:

- The first migration out of the African continent by our direct ancestors *Homo sapiens* around 70,000 years ago

- The expansion of Bantu farmers in sub-Saharan Africa from 1,000 BCE, which led them to enter into contact with forest foragers living in the equatorial forest.

We are interested in the spatial and dynamic patterns of these migrations, as well as in their causal mechanisms. Given the great time depth and the related lack of knowledge about the populations involved, we do not focus on social aspects dealt with in other transitions, such as social structures of power or hierarchies.



We can decompose the two transitions under study into 3 phases: the transition itself, a (more or less) stable state before it, and a state after it.

For ‘Out of Africa’ migrations, socio-cognitive evolutions can be related to the emergence of our species: new cognitive skills and their behavioral consequences could explain that our species was able to quickly conquer a wide range of environments, and reach locations previously unvisited by human beings.

For Bantu migrations, the development of agriculture and the social changes it carried (demographic growth, need for cultivable lands, property of resources) led farmers to expand from their initial cradle in today’s Cameroon.

Work is conducted among the Transmondyn team, with closer collaboration with the following members: Jean-Marie Hombert, Florent Le Néchet, Hélène Matthian and Lena Sanders

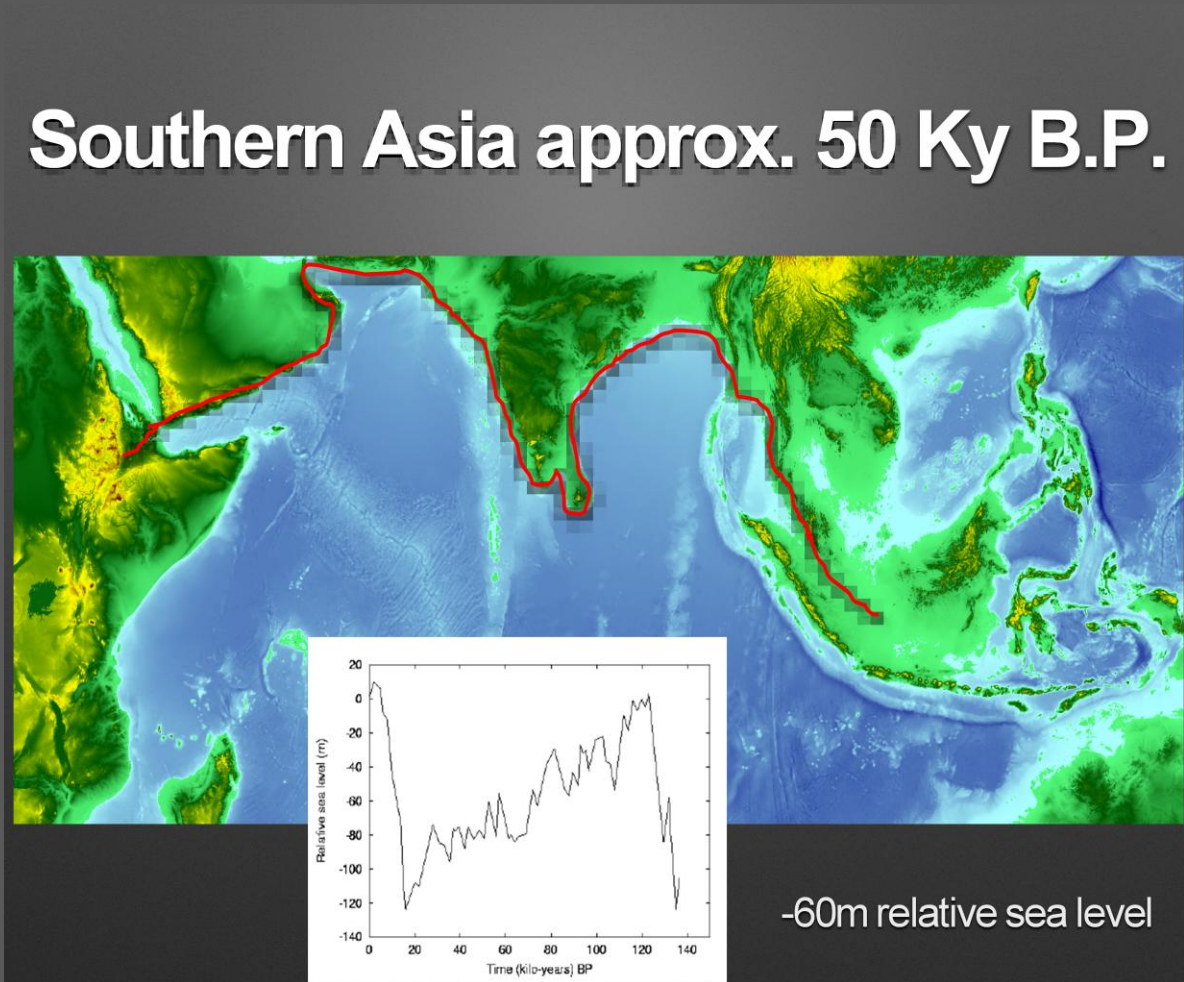
Issue

Only sparse archaeological traces of ancient human migrations and activities (behaviors, interactions etc.)

For both transitions, inquiries into what happened precisely and why it happened are constrained by the lack of data: no written document, sparse archaeological evidence. This explains why indirect approaches have their place in the investigation.

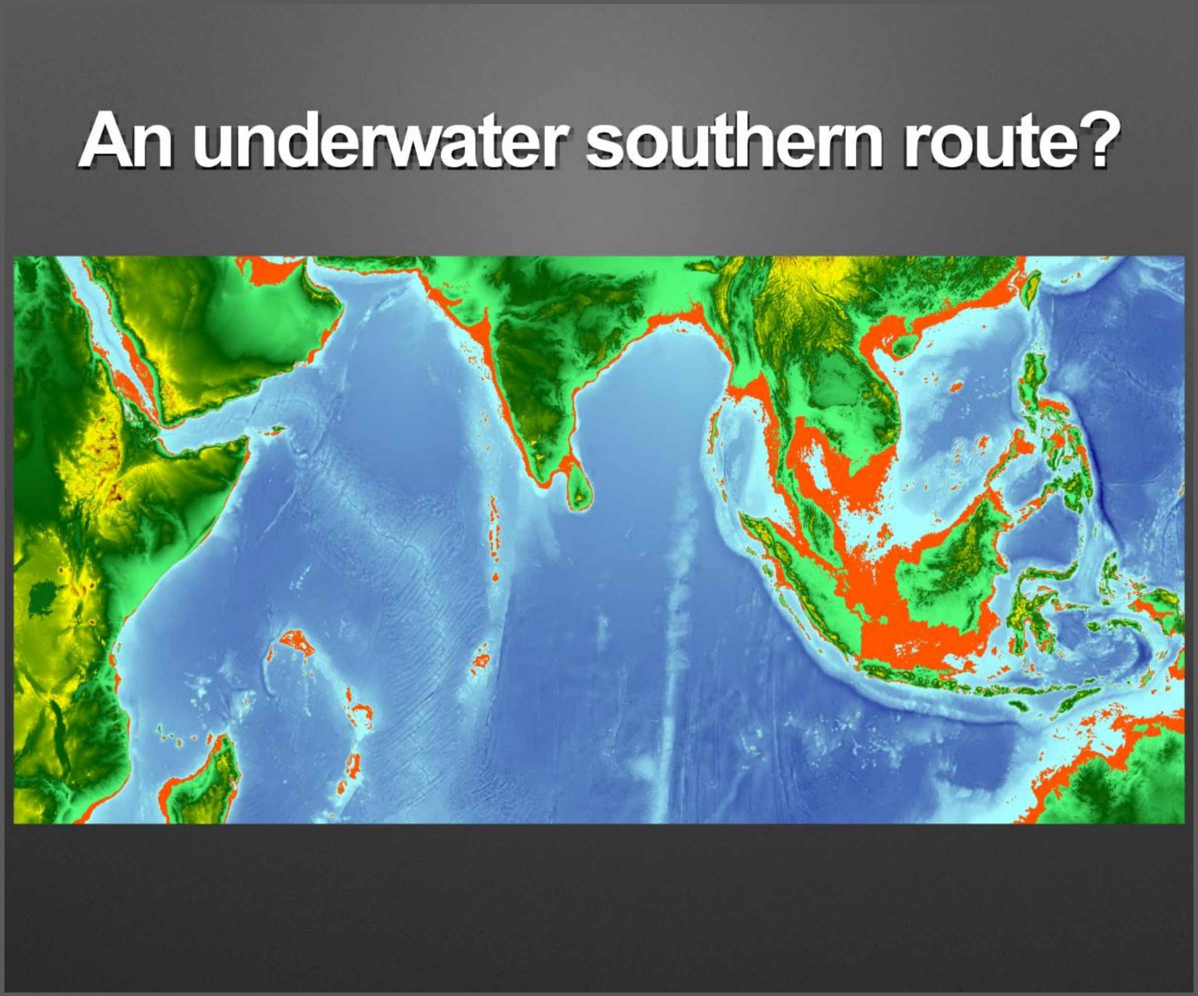
A telling example is the Southern dispersal route likely taken by *Homo sapiens* around 70,000 years ago.

This migratory path runs from eastern Africa to Australia and New Guinea along the southern coasts of the Asian continent.

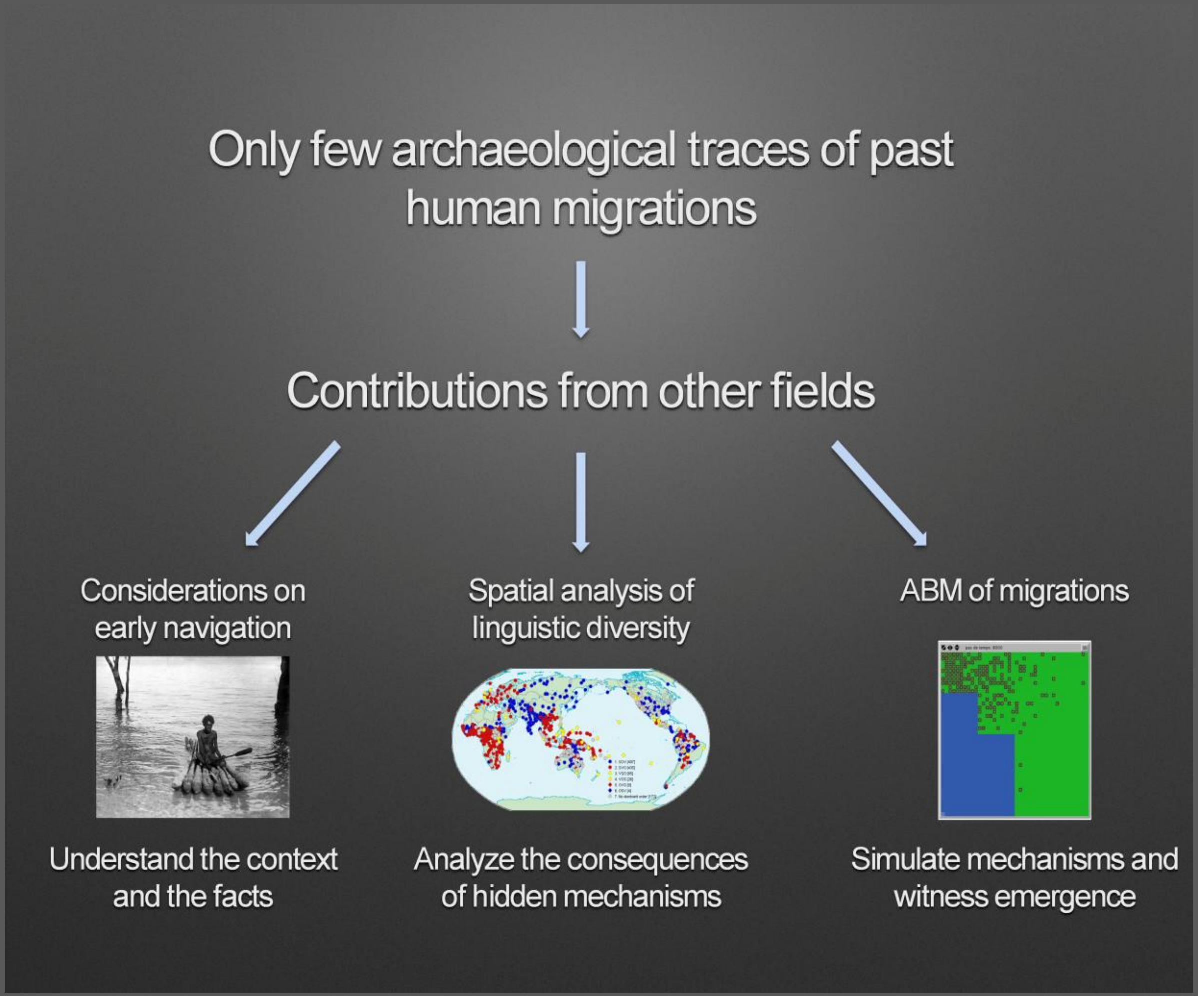


The evolution of sea levels during the last glaciation has to be taken into account: during colder periods of time, water from the ocean turns into massive ice packs at the poles, and the sea level decreases. Around 50,000 years ago, it was approximately 60 meters lower than today. As a consequence, migratory paths that were then close to the sea are now underwater. It is therefore very hard to find any material evidence of them.

The Southern dispersal route is thus attested indirectly by modern human presence in Australia around 50,000 years ago, as well as by genetic distributions in today's populations.



With modern cartographic tools, it is easy to highlight the differences between the current situation and the situation 50,000 years ago.



As previously said, indirect approaches have to be considered to compensate for the lack of material evidence.

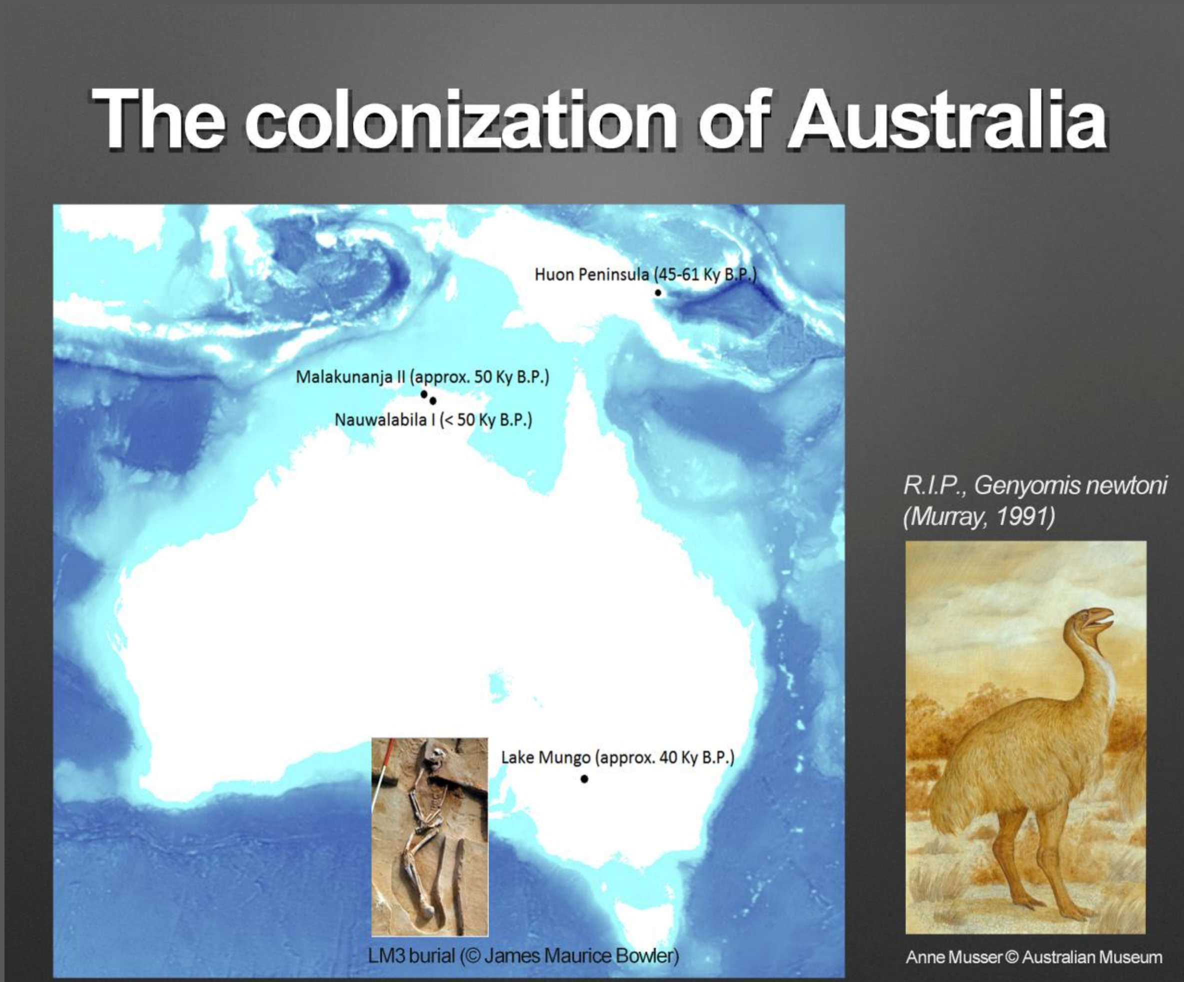
In this presentation, we successively review three lines of research. Each domain sheds light on specific epistemological aspects:

- Understand the precise context and facts
- Analyze the consequences of hidden mechanisms, i.e. observe what they produced without necessarily deciphering them
- Simulate mechanisms and witness emerging phenomena to better understand causal mechanisms at play

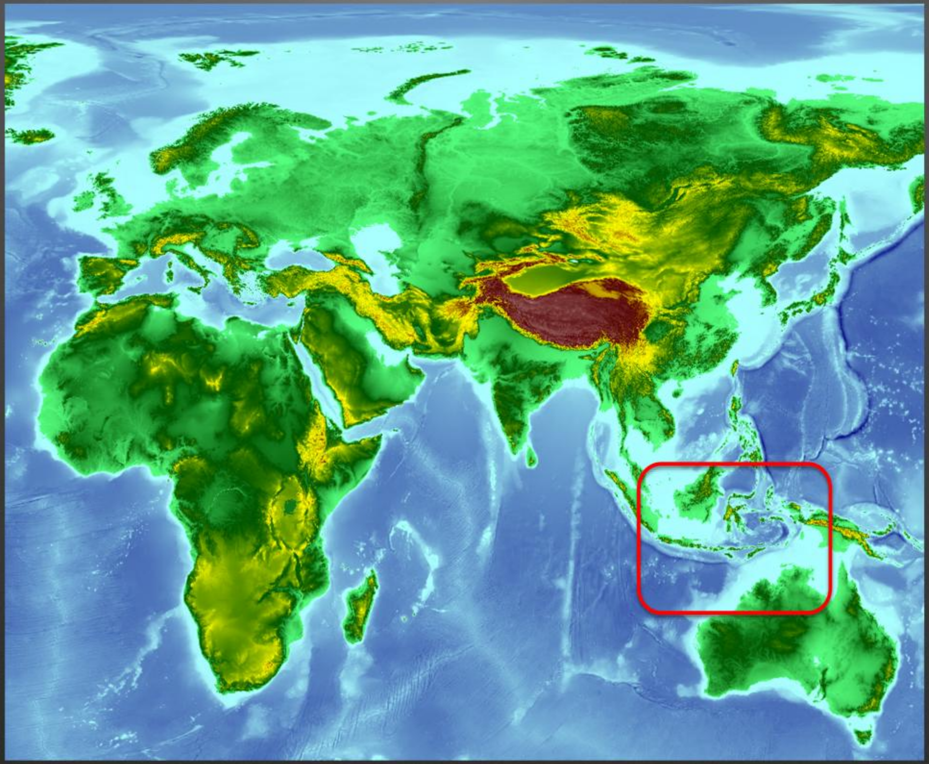
1. Considerations on early navigation

Worora youth on a mangrove tree raft (or 'kaloa'), George Water, Western Australia, 1916 (*Herbert Basedow)*

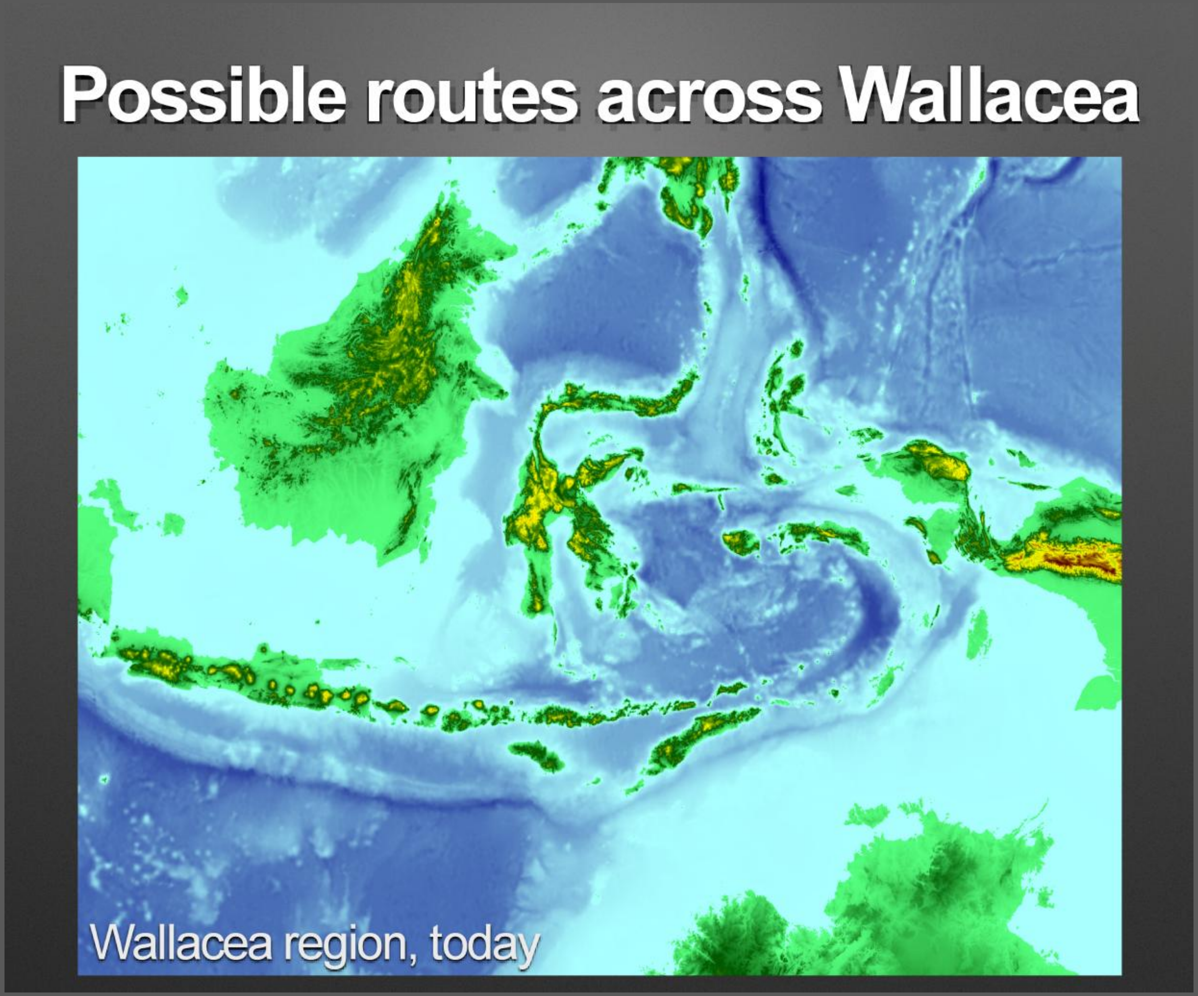
We first focus on the precise characterization of facts, taking early navigation as an example.



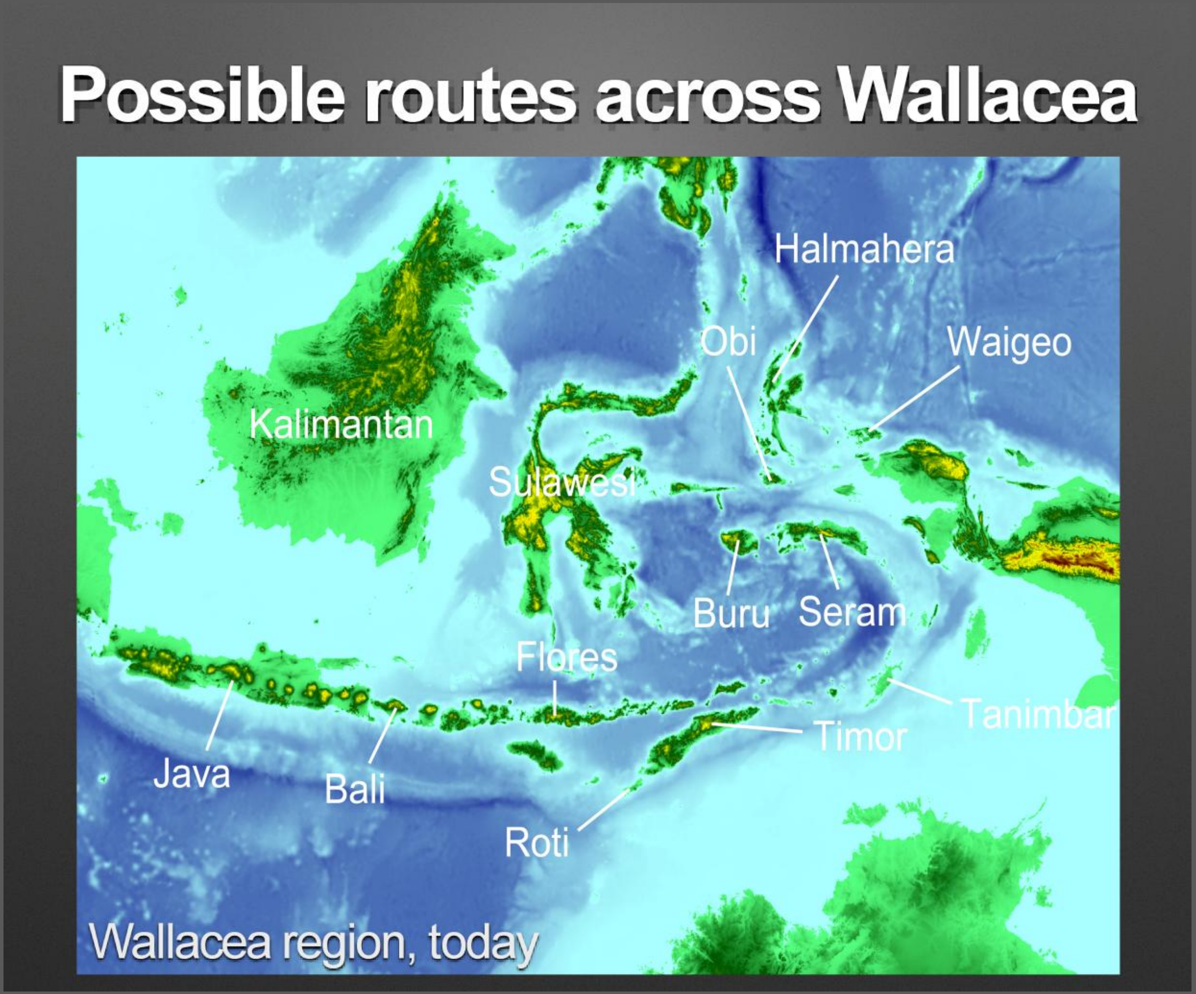
Several archaeological sites demonstrate that Australia was inhabited by modern humans from around 50,000 years ago. No other human beings had reached this land before. Other cues, such as the sudden disappearance of large animals, further prove human colonization.



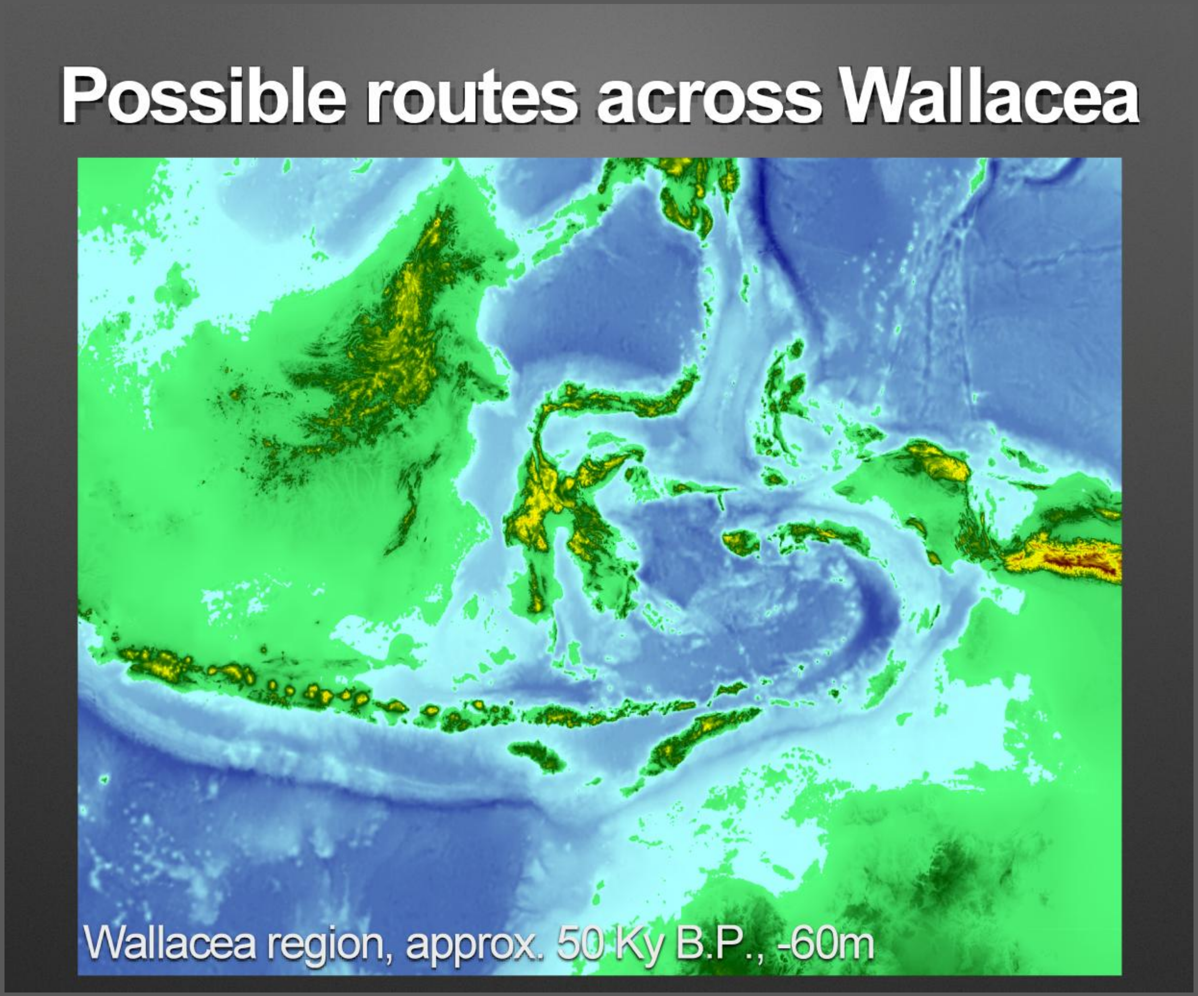
To reach Australia from Africa, humans had to cross a region between peninsular south-east Asia and Australia/New Guinea, where Indonesia can be found today.



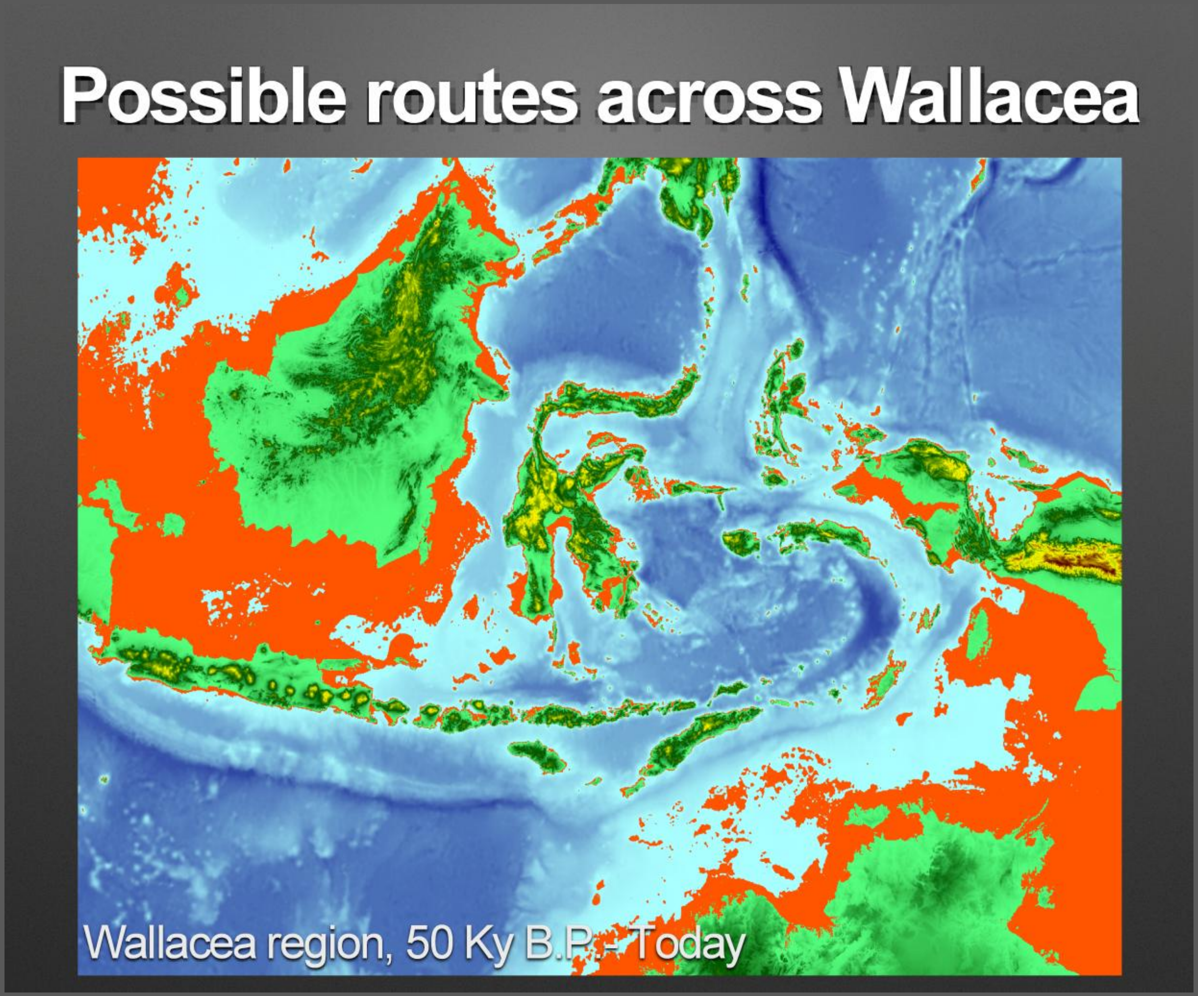
This is how the region, also known as the Wallacea region, looks today.



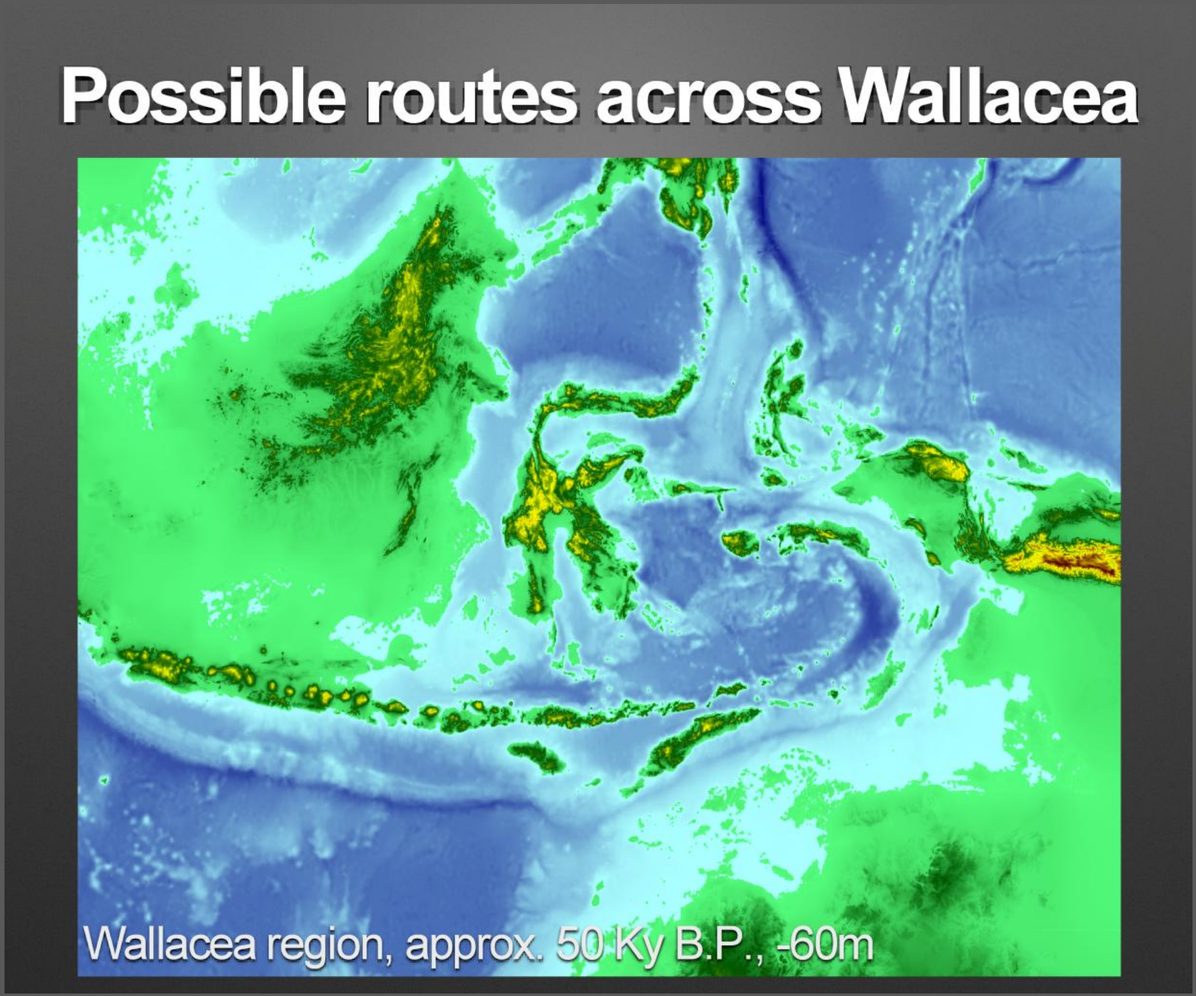
It can easily be noticed that it is impossible today to reach Australia or New Guinea on foot coming from southeast Asia. From Timor to Australia for example, several hundreds kilometers have to be crossed in open water.



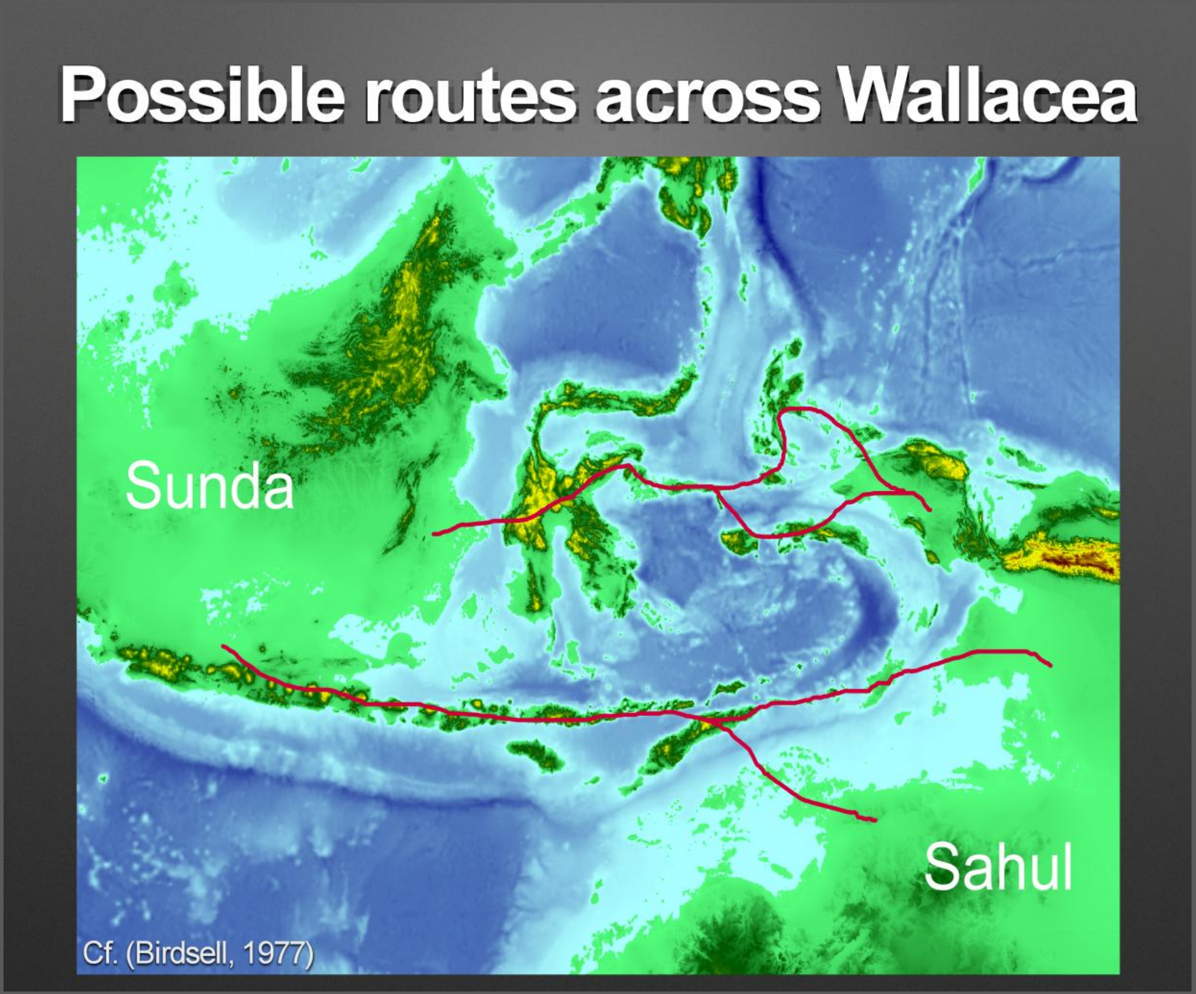
Taking into account the lower sea level 50,000 years ago, one can produce an approximate map of the Wallacea region at that time. Given the depth of the ocean floor in that region, large masses of land emerge. Many islands become connected together, as well as Australia with New Guinea.



Once again, the difference between today’s geography and the past situation can be highlighted.

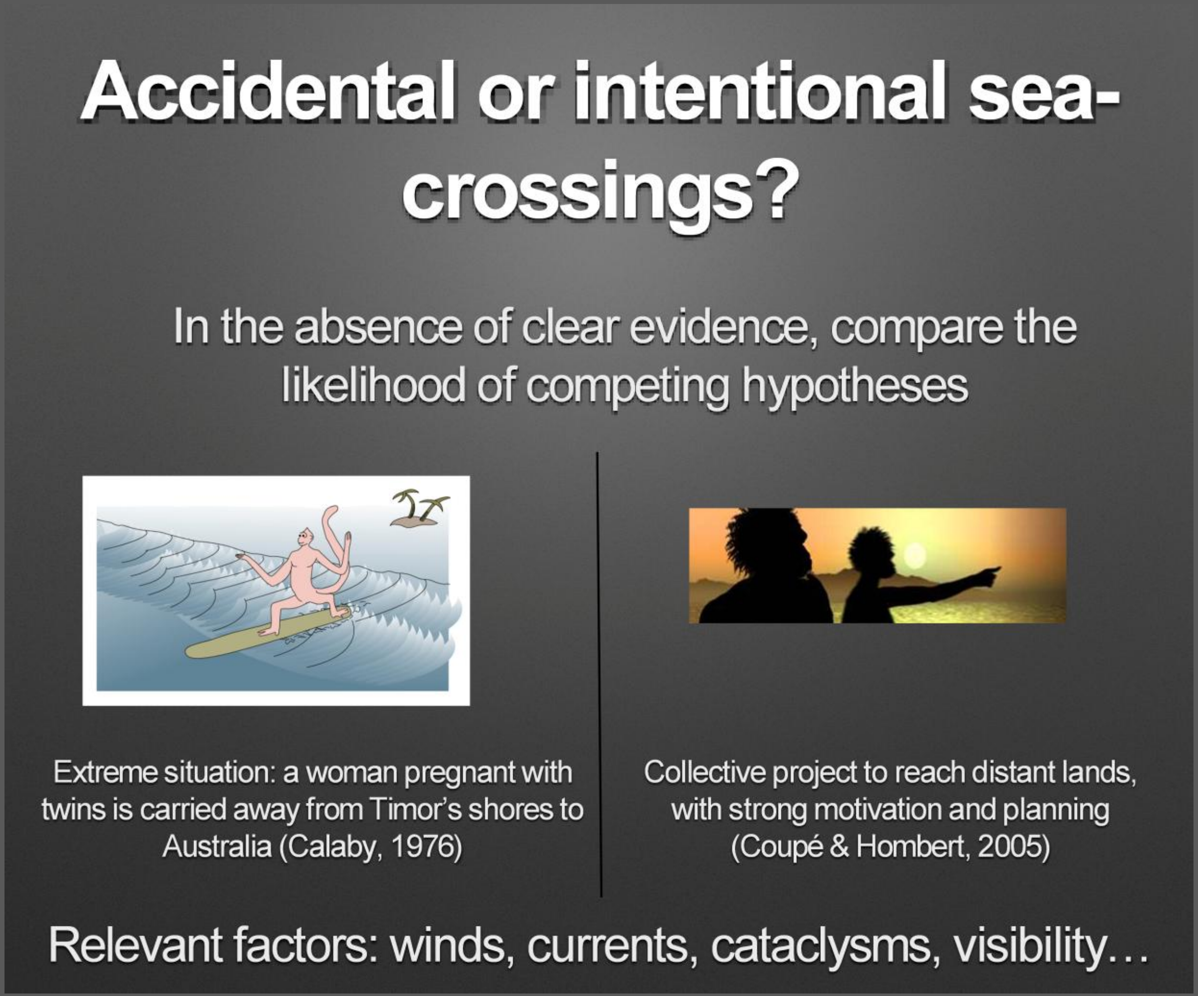


Just as England could be reached from continental Europe on foot during the colder part of the last glacial period, one could have hypothesized that Australia could have been reached on foot during past colder episodes. However, paleo-geographic reconstructions stress that it was not the case. Our ancestors therefore had to cross the ocean to reach Australia, even if no remains of raft have ever been found.



An ‘archaeology of the invisible’ can however be performed, and various routes between so-called Sunda (a large piece of land on the west) and Sahul (Australia and New Guinea joint together) can be considered and compared in terms of various features: number of kilometers to be crossed on the water, width of target islands etc.)

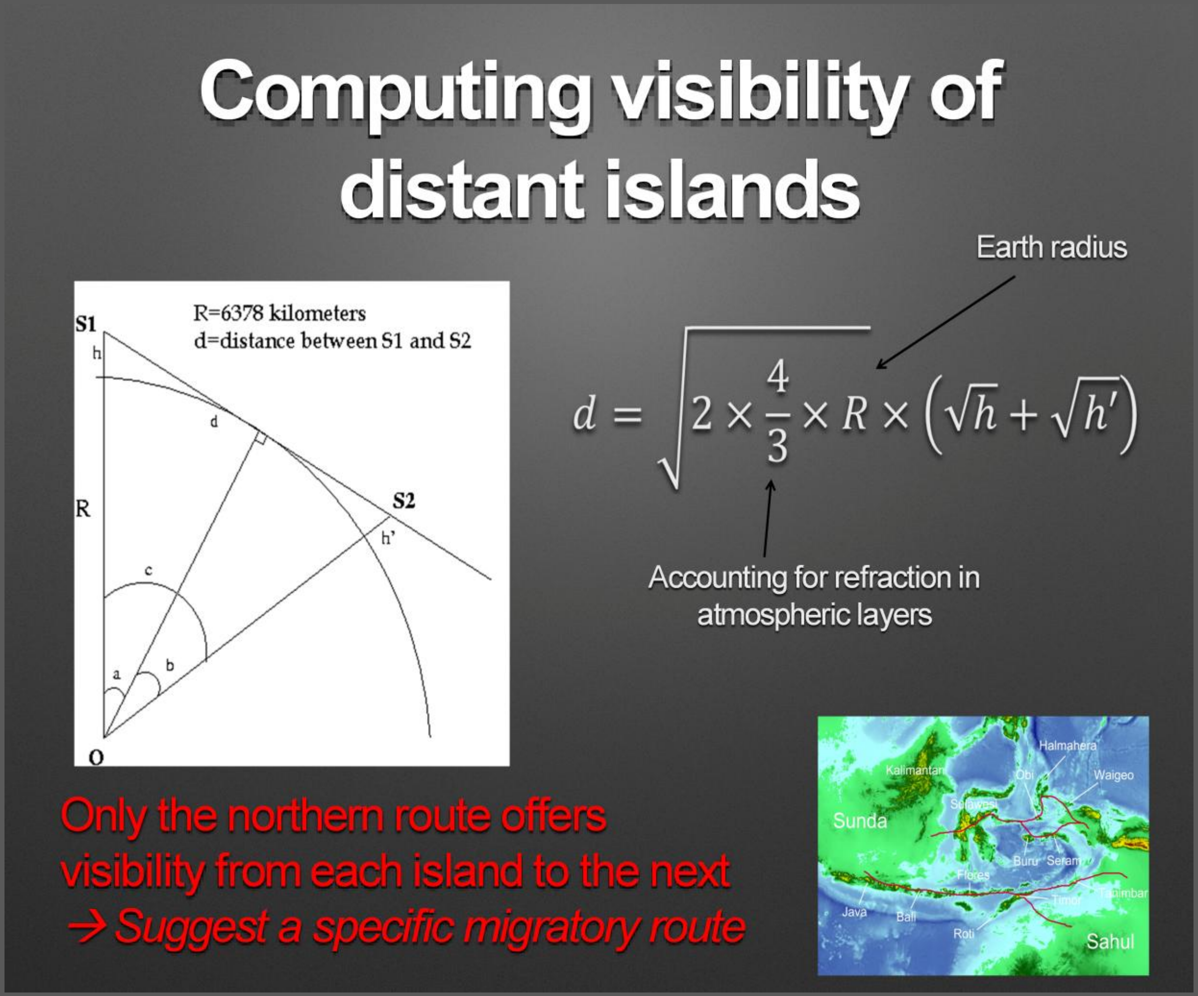
It can be shown that in the best case, *Homo sapiens* had to cross at least 100 kilometers on the sea, following a northern route reaching New Guinea.



More globally, different hypotheses regarding the nature of the sea-crossings which took place in the region are competing: were these journeys accidental or intentional? A range of scenarios can be put forward, which fall between two extreme cases:

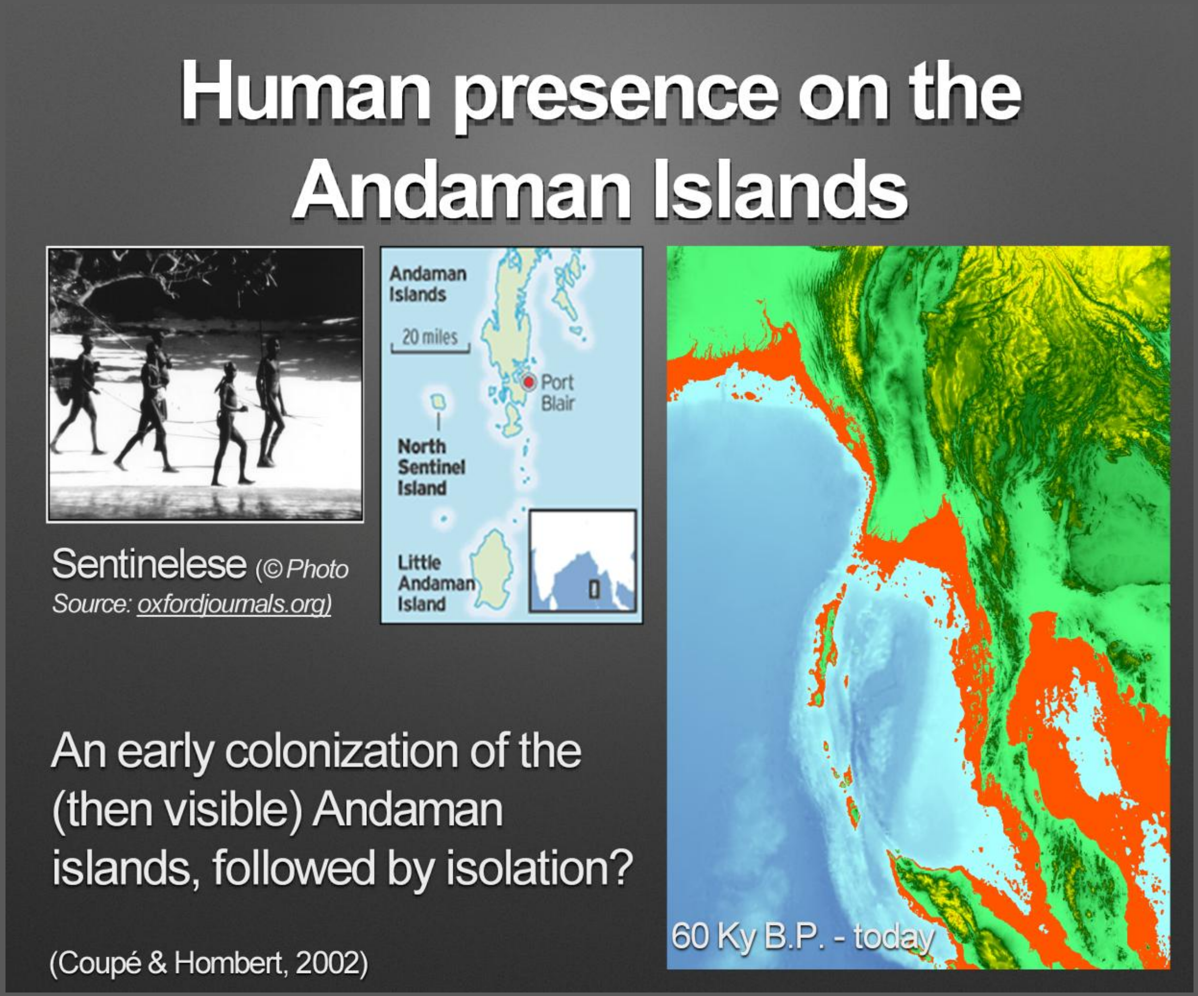
- A ‘purely accidental’ scenario, involving a few people being carried away by winds and currents while navigating close to one of today’s Indonesian islands (or Timor), successfully reaching Australia despite lack of resources and preparation, and further colonizing this new land. This seems highly unlikely, especially with respect to the initial number of individuals needed to successfully colonizing a new territory.
- A ‘fully intentional’ scenario, with human communities carefully planning their journey(s), planning food and water supply, leaving in groups etc. The motivations behind such projects can only be guessed.

To favor one scenario over the others on more solid grounds, factors like winds, currents or visibility have to be considered. Other facts should also be factored in, such as the Toba massive eruption on Sumatra island and its consequences 70,000 years ago, which could have forced people to move away from harsh living conditions.



We have stressed the potential role of the visibility of distant islands. It can be estimated with rather simple mathematical formulae. Computing visibility along the different possible routes leads to the conclusion that visibility from each island to the next as possible for one of the northern routes leading to today's New Guinea, but not for the southern routes ending in Australia. If one gives more credit to an intentional scenario of colonization, with decisions taken to reach islands that were visible from the starting points, a specific northern route then appears more likely.

The hypothesis of intentional sea-crossings toward visible destinations can gain support from the study of another colonization event: the reaching of the Andaman islands, located west of the Burmese shores.

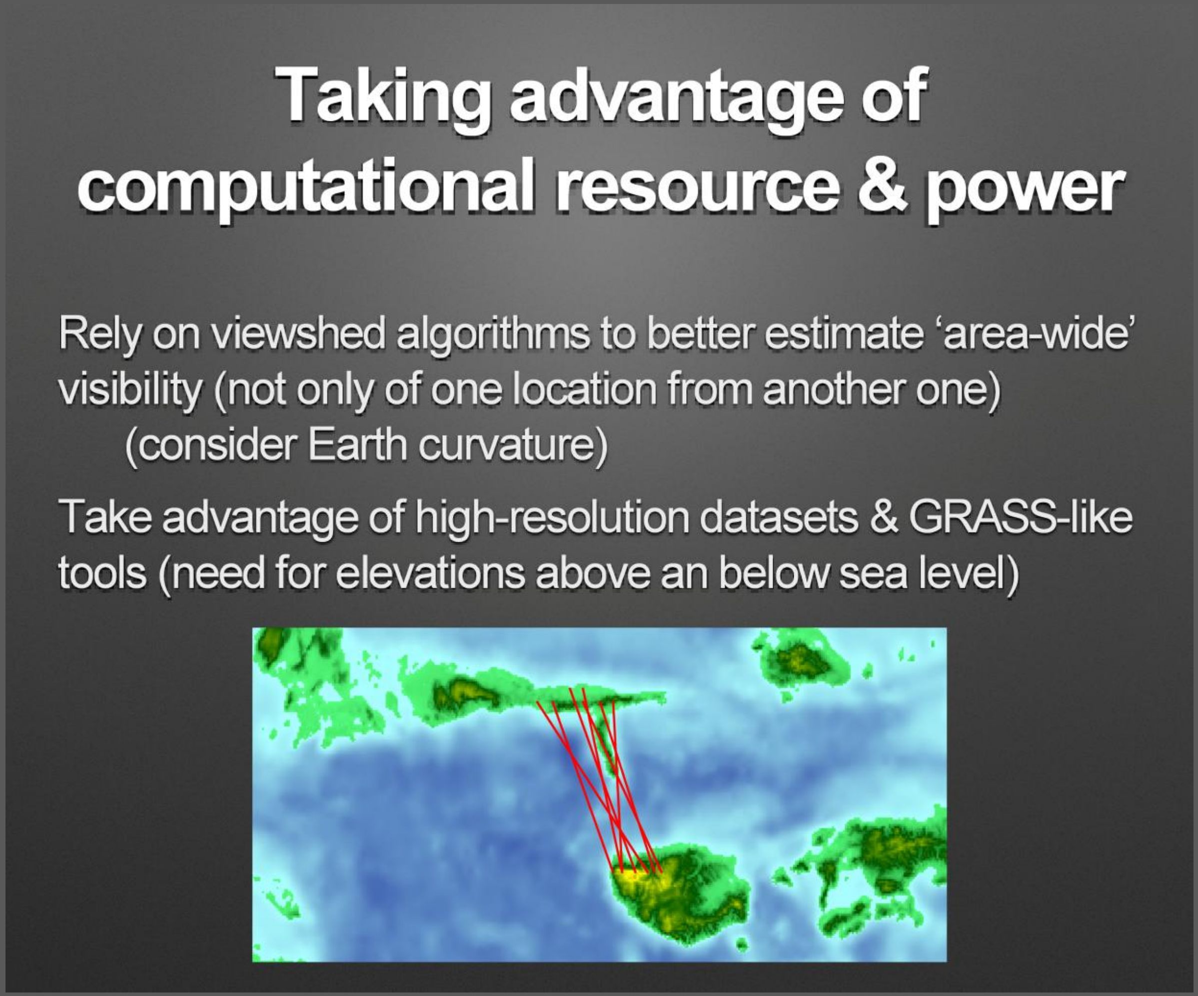


The Andaman Islands are located along the Southern dispersal route which could have led early *Homo sapiens* from Africa to Australia. Paleo-geographic reconstructions suggest that these islands were visible from the continent 60,000 years ago, while they are not visible today.

Some of the Andaman Islands are inhabited today by human communities which have strongly refused any contact with the outside world, and whose genes suggest a very ancient presence on the island and a relationship with early *Homo sapiens* migrations out of Africa.

It is tempting to interpret the presence and features of these populations as the result of an ancient colonization of the Andaman islands, by people already skilled in navigation – around 60 km had to be crossed on the sea – and who could then see the islands from the continent. Later rise of the sea level would have ‘hidden’ the islands, and isolated their inhabitants for a very long time.

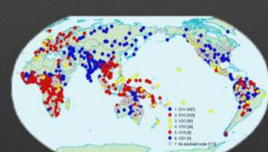
Such a scenario, implying a long-term development of navigation along the coast of southern Asia, supports the idea of further skillful and intentional sea-crossings in the Wallacea region.



To further assess hypotheses on ancient sea-crossings, one can today take advantage of available computational tools and data.

High-resolution topographic datasets and viewshed algorithms could especially provide more solid appreciation of visibility between islands.

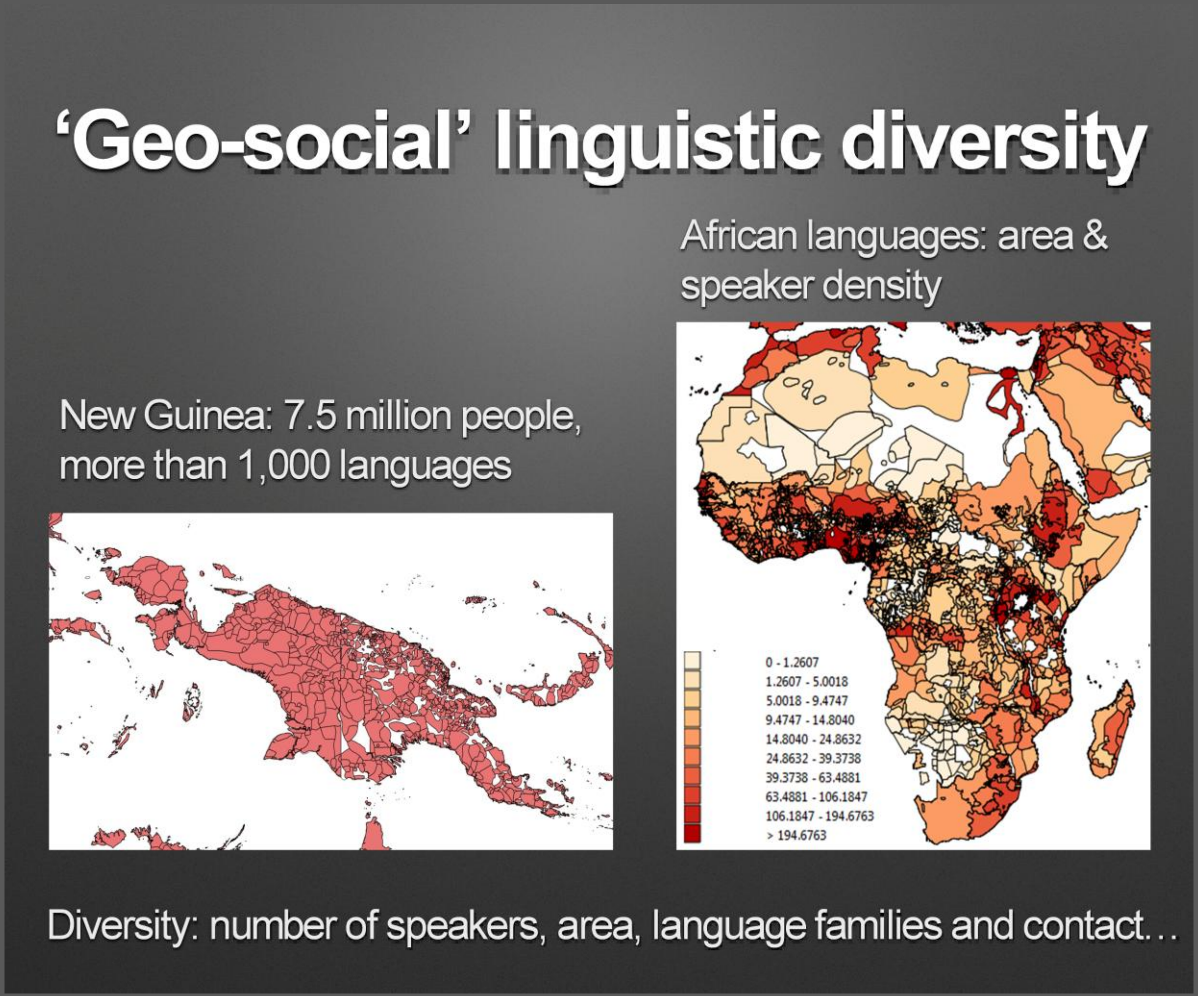
2. Spatial analysis of linguistic diversity



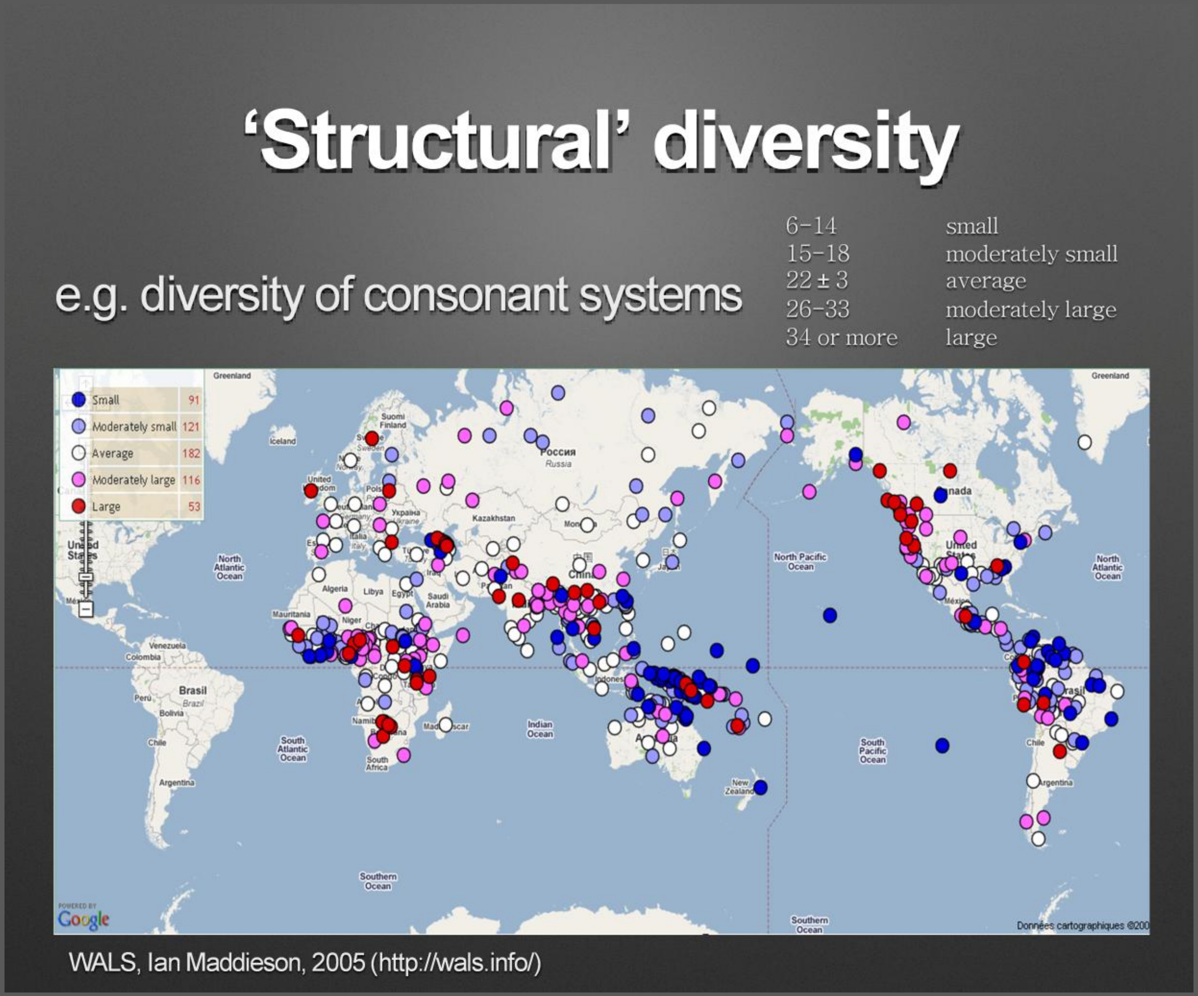
We now illustrate how a migratory event may be partly revealed by distributional patterns resulting from it taking place in a more or less distant past.

Genetic distributions are among the clearest signals of a past demographic events, but other non-biological features can also tell us about our ancestors' lives, such as present-day languages.

For the sake of clarity, we first introduce the extent of the concept of linguistic diversity.



Linguistic diversity first relates to geographic and social aspects: how many persons speak French or Swahili? What is the size of the area where Japanese is spoken? How many other languages are spoken in the area of the Thai language? Etc.



Linguistic diversity also refers to the variety of linguistic structures found in the languages of the world. These structures are found at the level of sounds, syllables, words or sentences.

Since we can observe regularities in the distribution of languages and of their features, we may be able to understand the different mechanisms that underlie these regularities. It is interesting to notice for example that hotspots of biodiversity match well with linguistic hotspots on the planet, and to wonder about similar mechanisms of diversification. Regarding our transitions, current linguistic diversity may relate to distant events.

Does phonetic diversity relate to ‘Out of Africa’ migrations?

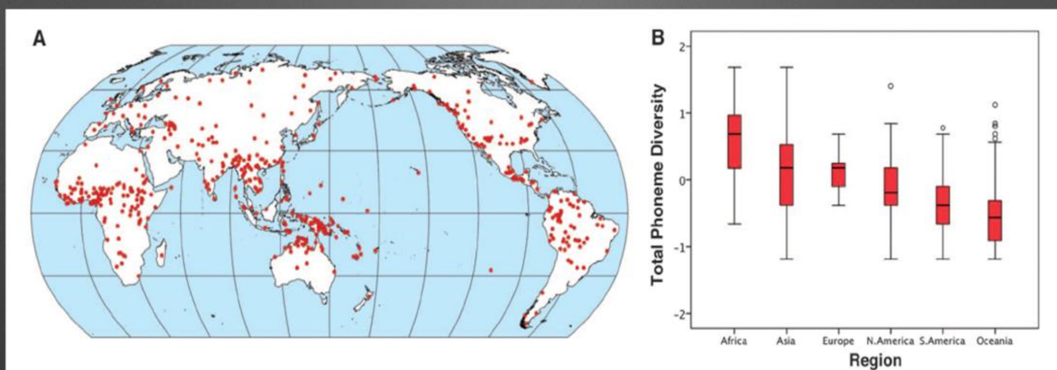
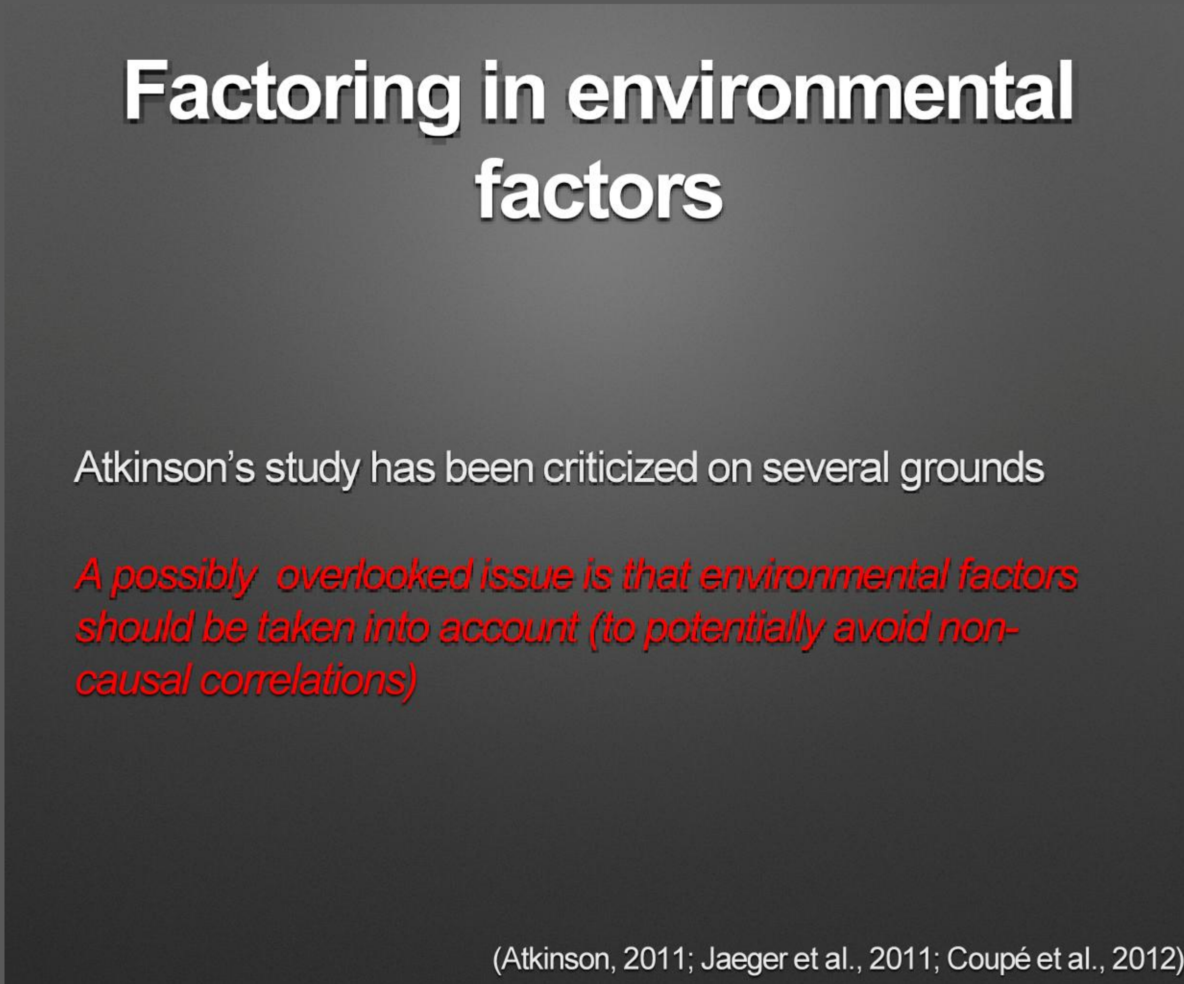


Fig. 1. Language locations and regional variation in phonemic diversity. (**A**) Map showing the location of the 504 sampled languages for which phoneme data was compiled from the WALS database. (**B**) Box plots of overall phonemic diversity by region reveal substantial regional variation ($\chi^2 = 188.7$, df = 5, $P < 0.001$), with the highest diversity in Africa and the lowest diversity in Oceania and South America. The same regional pattern also applies at the language family level (fig. S2).

31% of the variance of phonetic diversity predicted by a regression model with speaker population size and distance from central/southern Africa

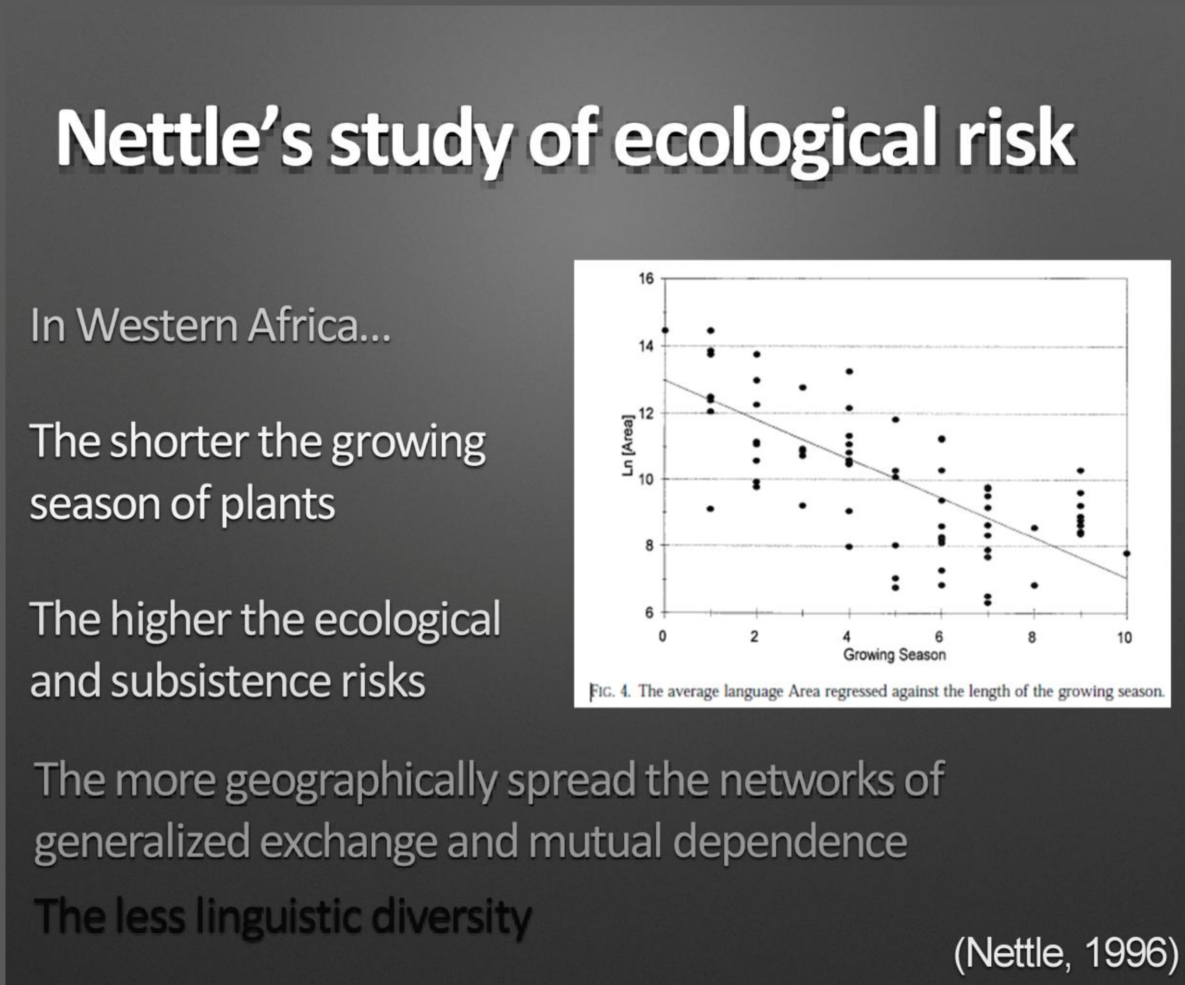
(Atkinson, 2011)

Atkinson suggested that the distribution of phonetic diversity, which is at its highest in Africa and its lowest in South America and Oceania when measured by the number of phonemes a language has, is a signature of the Out of Africa migrations. Considering 2560 potential origin locations for today’s populations in regression models, he found that phoneme inventory size was best predicted by speaker population size and distance from the origin location when this location was in central or southern Africa.

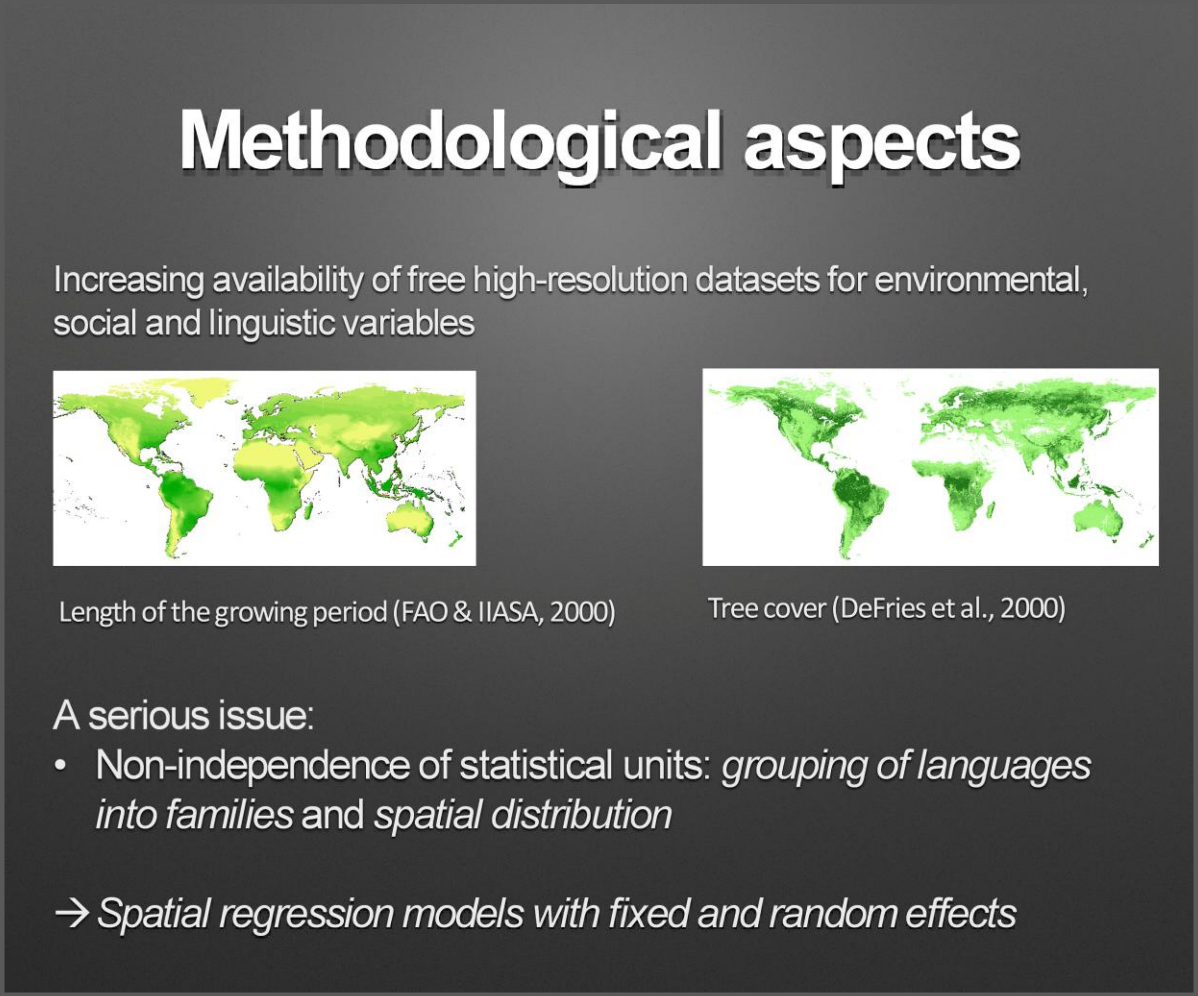


His approach has however been criticized, among others on statistical grounds: considering so many regression models indeed leads to a hugely inflated "Type I error", i.e. the best origin location identified by Atkinson may be purely accidental. His notion of phonemic 'founder effect' has also been contested.

We additionally suggest that such approaches should be more cautious of the possible influence of environmental factors. Left outside of such models, what could be interpreted as a causal relationship could indeed be only a side effect of an implicit mechanism, such as the one we describe in the next slide.

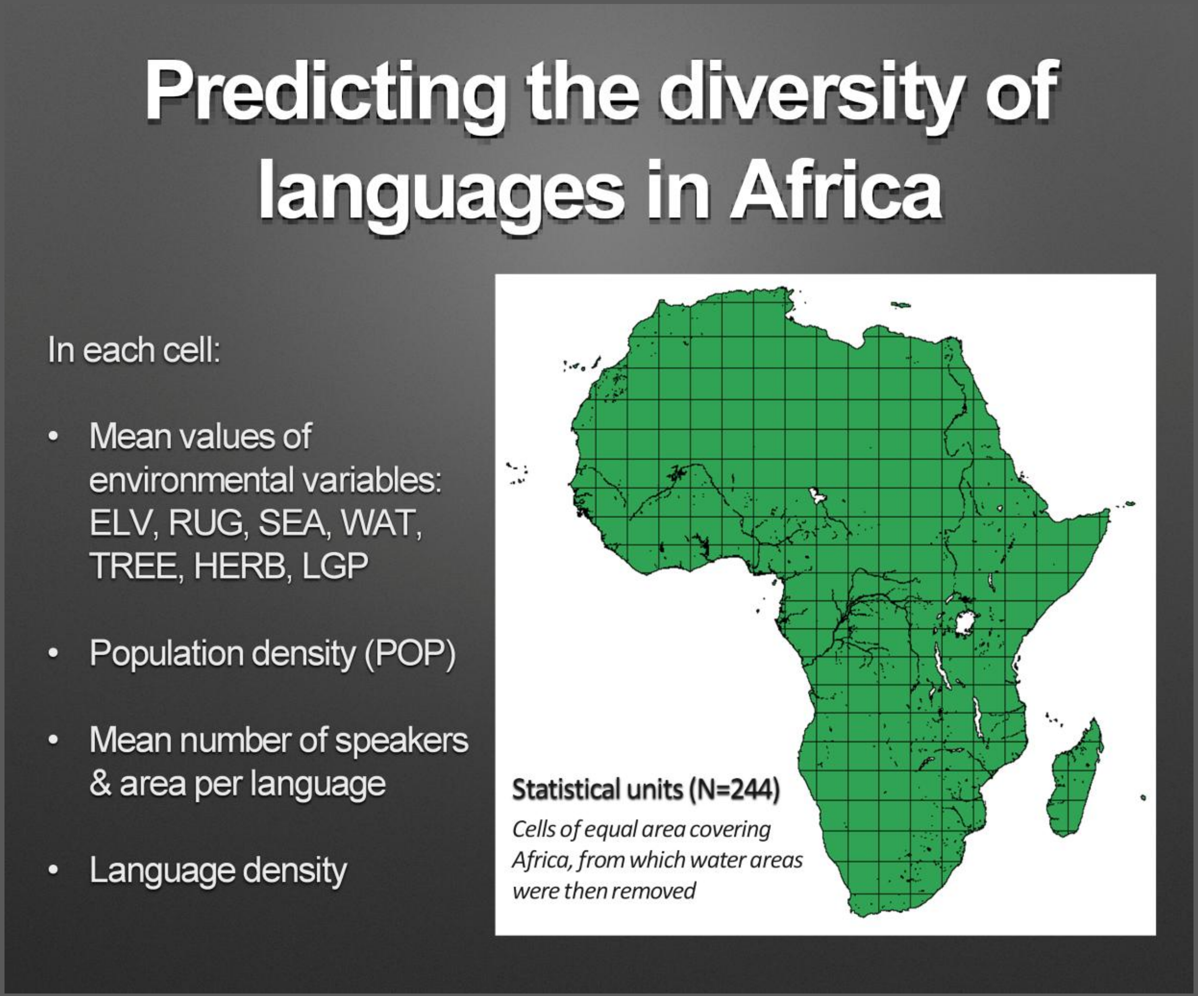


Daniel Nettle has stressed how an ecological factor such as ecological risk – the risk for a farmer or a pastoralist to suffer from ecological events such as drought or flooding – could explain geographic patterns of "geo-social" linguistic diversity. This is a clear example of the influence of an environmental factor, which as others should be tested in models aiming at explaining geographic distributions. More explicitly, the pattern of phonemic diversity found by Atkinson could be explained by an environmental factor (such as elevation, humidity, forest coverage etc.) rather by an ancient migratory event.



Developing statistical models with a spatial component is difficult, and various methodological challenges arise. At the same time, the advent of the “big data” era encourages us to apply such quantitative tools.

A particularly serious issue is to take into account into the models both non-independence of languages both in terms of linguistic families, and in terms of spatial proximity. The multicollinearity of the independant variables of the models is another problem to tackle.



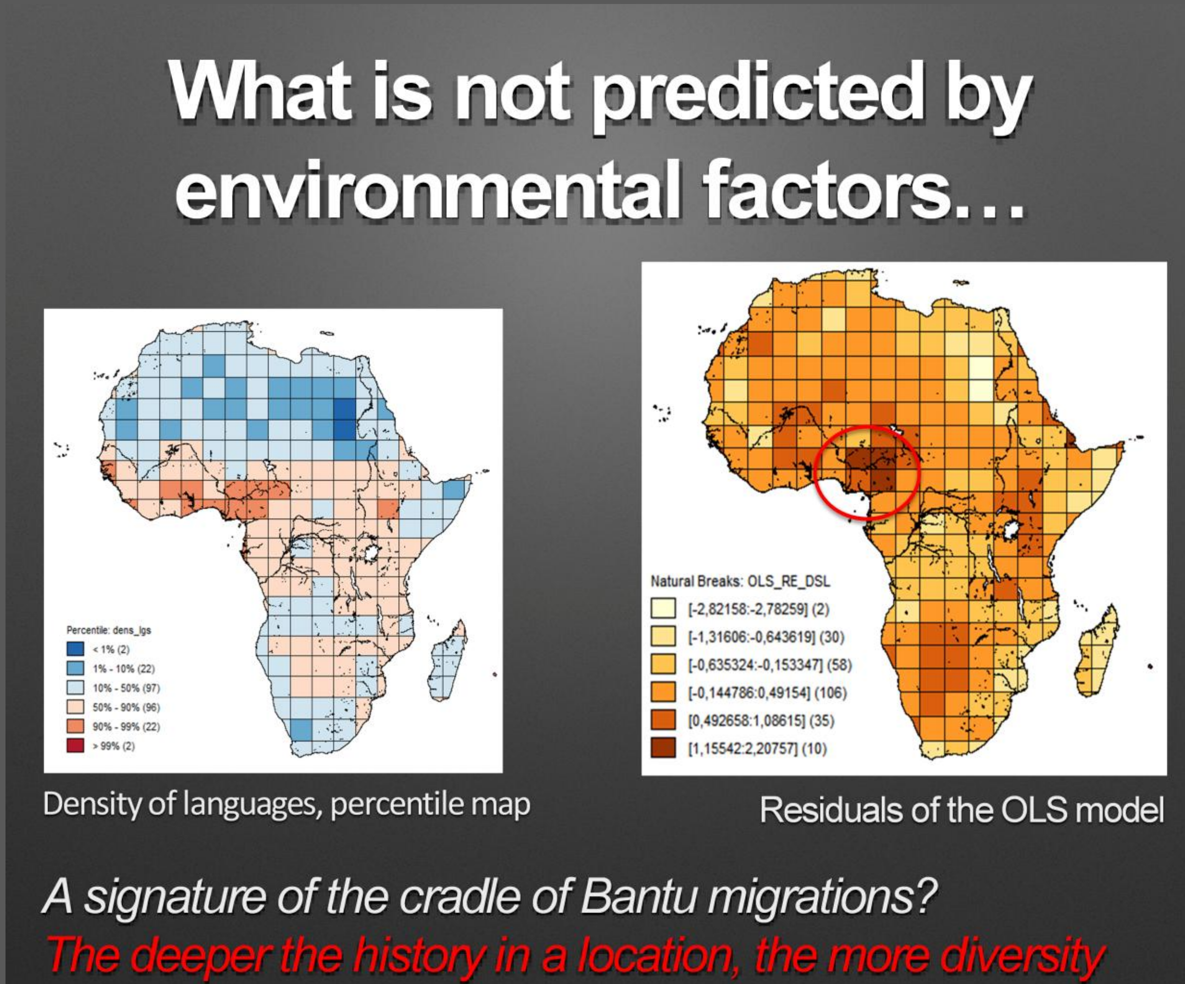
We investigated to which extent the "geo-social" linguistic diversity of Africa could be statistically predicted by environmental variables. We divided the continent into regularly distributed geographic units (i.e. the statistical units of the model), and for each of them computed the average elevation, land rugosity, distance from the sea, distance from fresh water, tree coverage, herbaceous coverage and duration of growth period for plants. We also computed the average population density. We tried to predict sociolinguistic variables such as the mean number of speakers of a language found to be spoken in the unit, its average area and the total number of languages spoken in the unit.

Example of regression model: predicting the density of languages

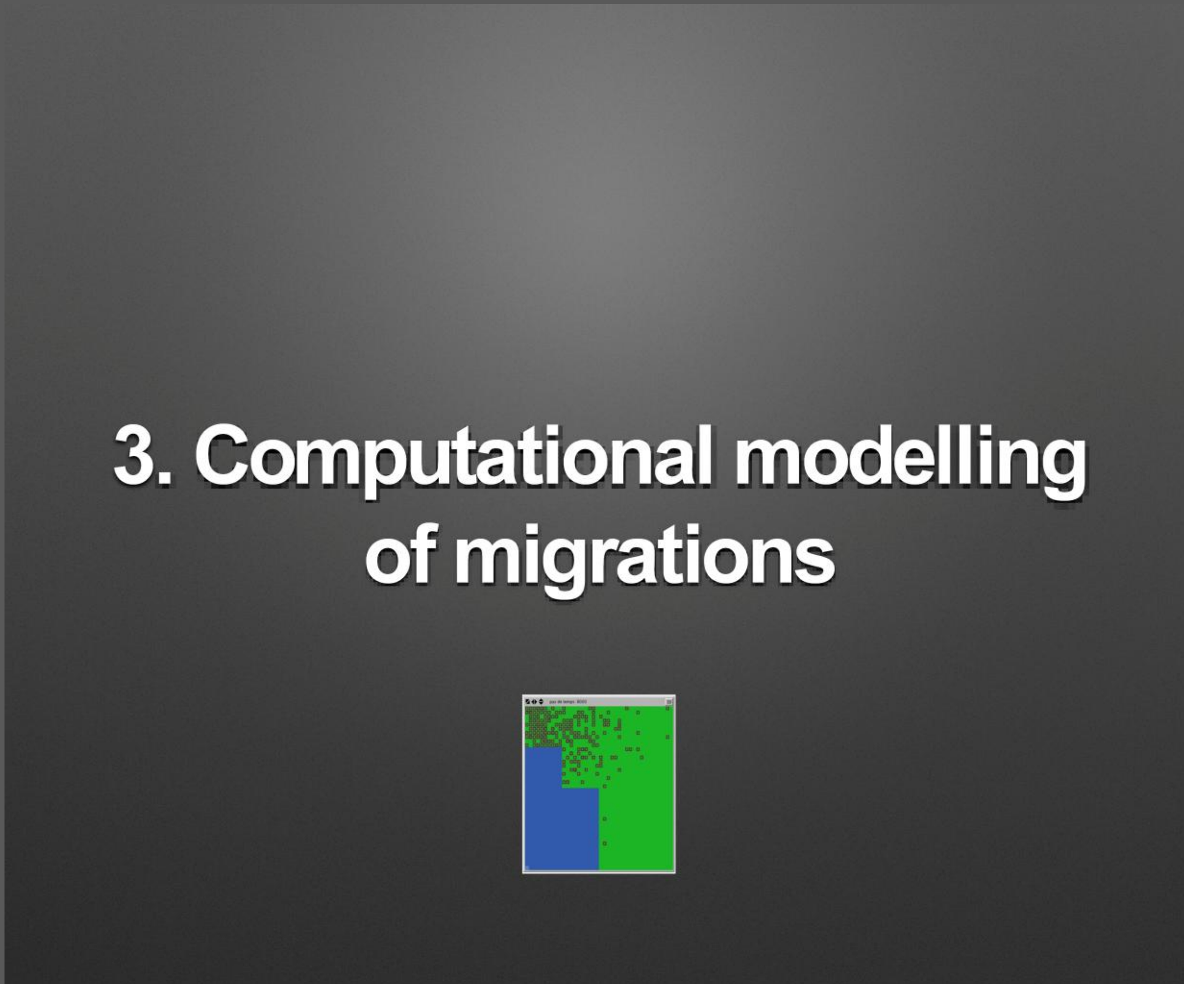
	OLS	Spatial error model
ELV	-0.27	-0.30
RUG	0.15	0.19
WAT	0.29	0.045
SEA	0.076	-0.19
LGP	0.15	0.046
HERB	0.46	0.29
TREE	0.34	0.27
POP	0.25	0.11
λ		0.80
Adjusted R^2	**0.59**	
Log likelihood	-229.9	-187.3
Akaike info criterion	477.9	392.7
Schwarz criterion	509.2	424.0

→ The density of languages in a cell is well predicted by environmental and social variables

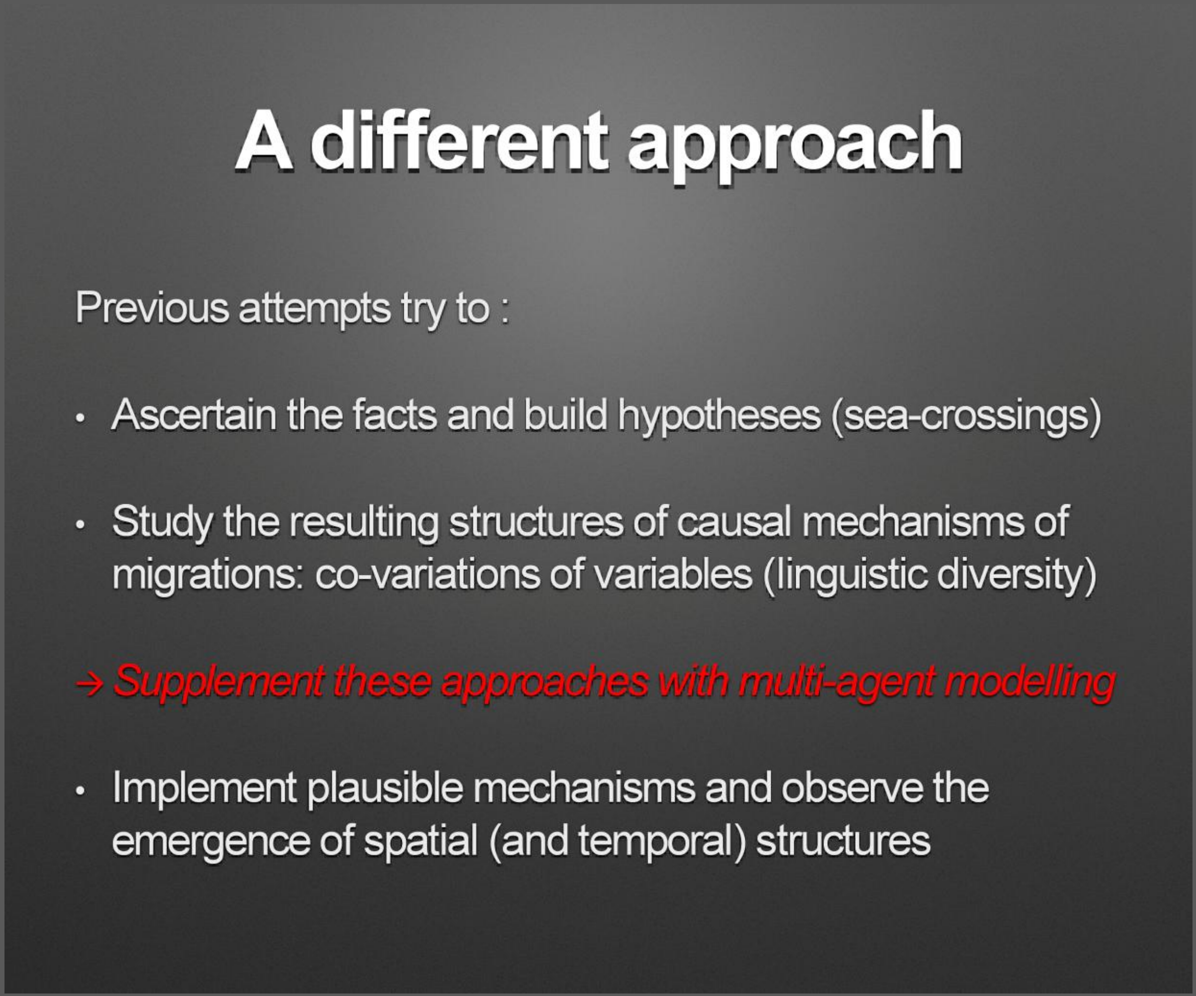
We found that some of the sociolinguistic parameters could be well predicted by the independent variables, in particular by models taking the spatial relationships of the statistical units into account. The variance of the density of languages in geographic units could be well explained by a linear combination of several of the environmental predictors.



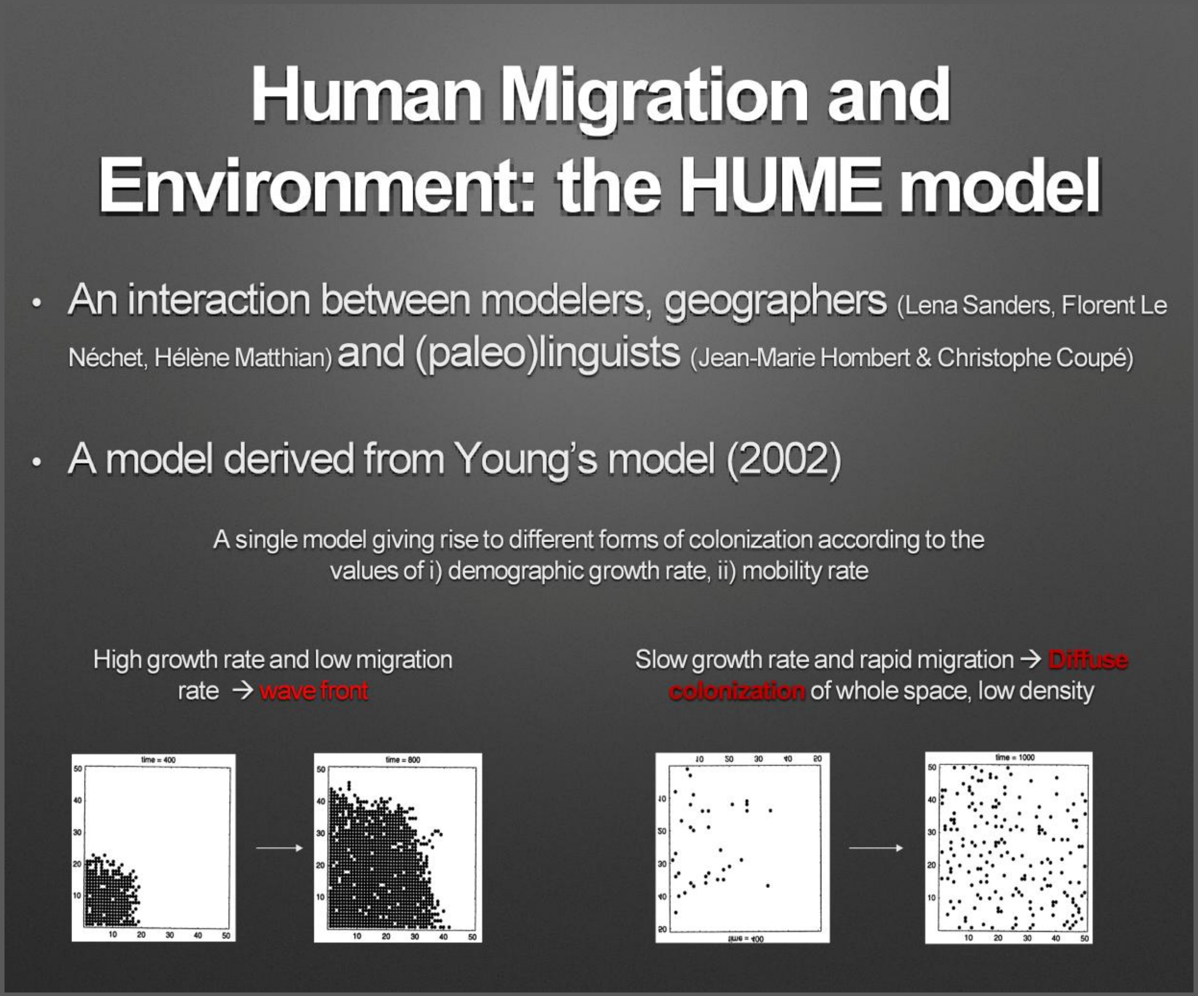
We also paid attention to the residuals of the non-spatial models. This amounted to identifying the locations in Africa where linguistic diversity was higher or lower than what was predicted by the relationship established at the continental level with environmental factors. The highest positive divergence was found to be located at the putative origin of Bantu languages. Given that, for languages as for genes, regions with the deepest history of human presence show the highest diversity, it therefore seemed that signals of ancient Bantu migrations could be found in today's distribution of languages, given a precise statistical treatment.



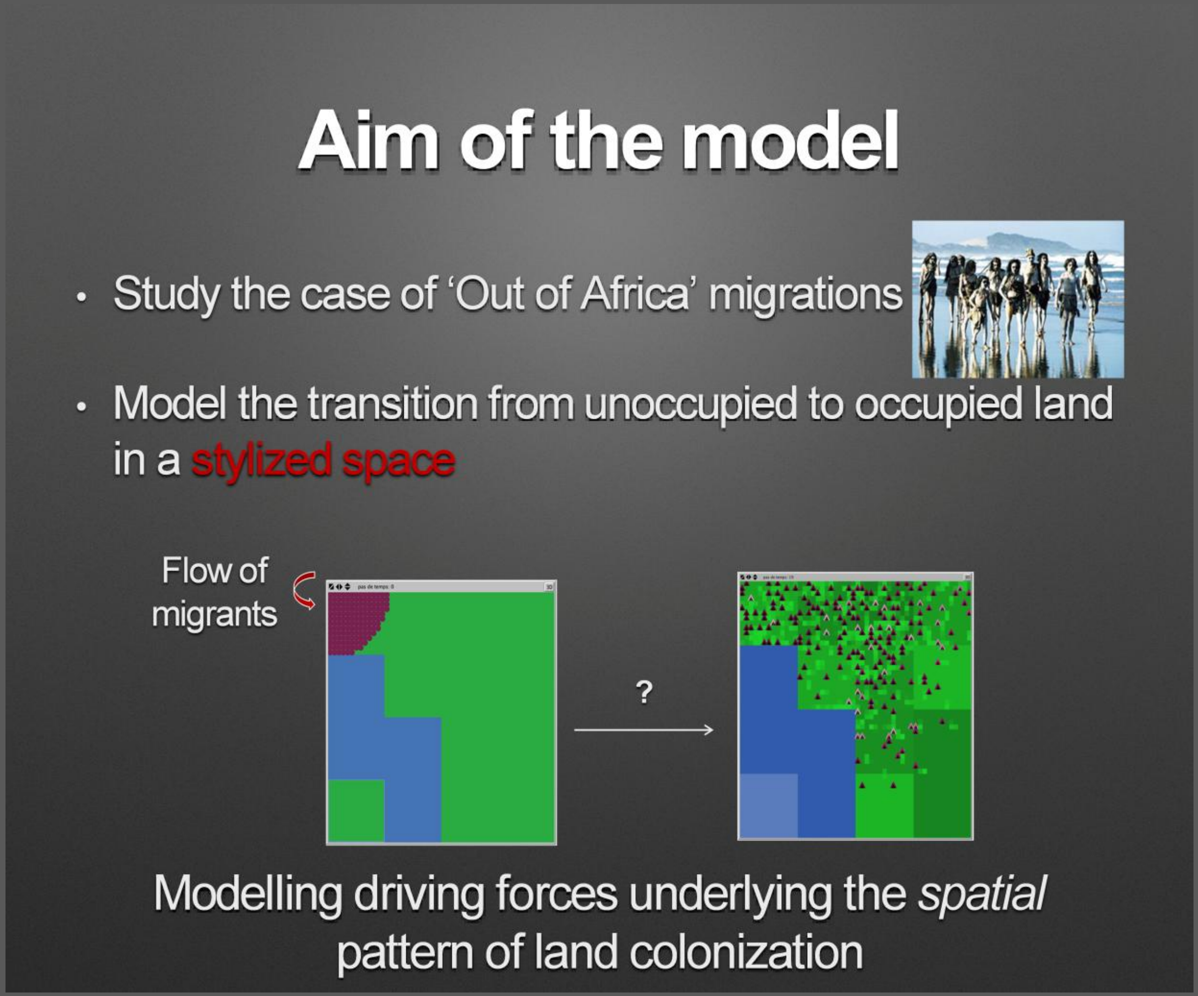
Finally, we highlight how computational models may complement the previous approaches.



The reproduction ‘in silico’ of past phenomena such as human migrations, with identification of key parameters and study of their impact, is a powerful way to bring out causal mechanisms. Emergence of specific patterns on the basis of plausible mechanisms, with self-organized structures that would have eluded other modeling attempts, is one of the key advantages of computational models.



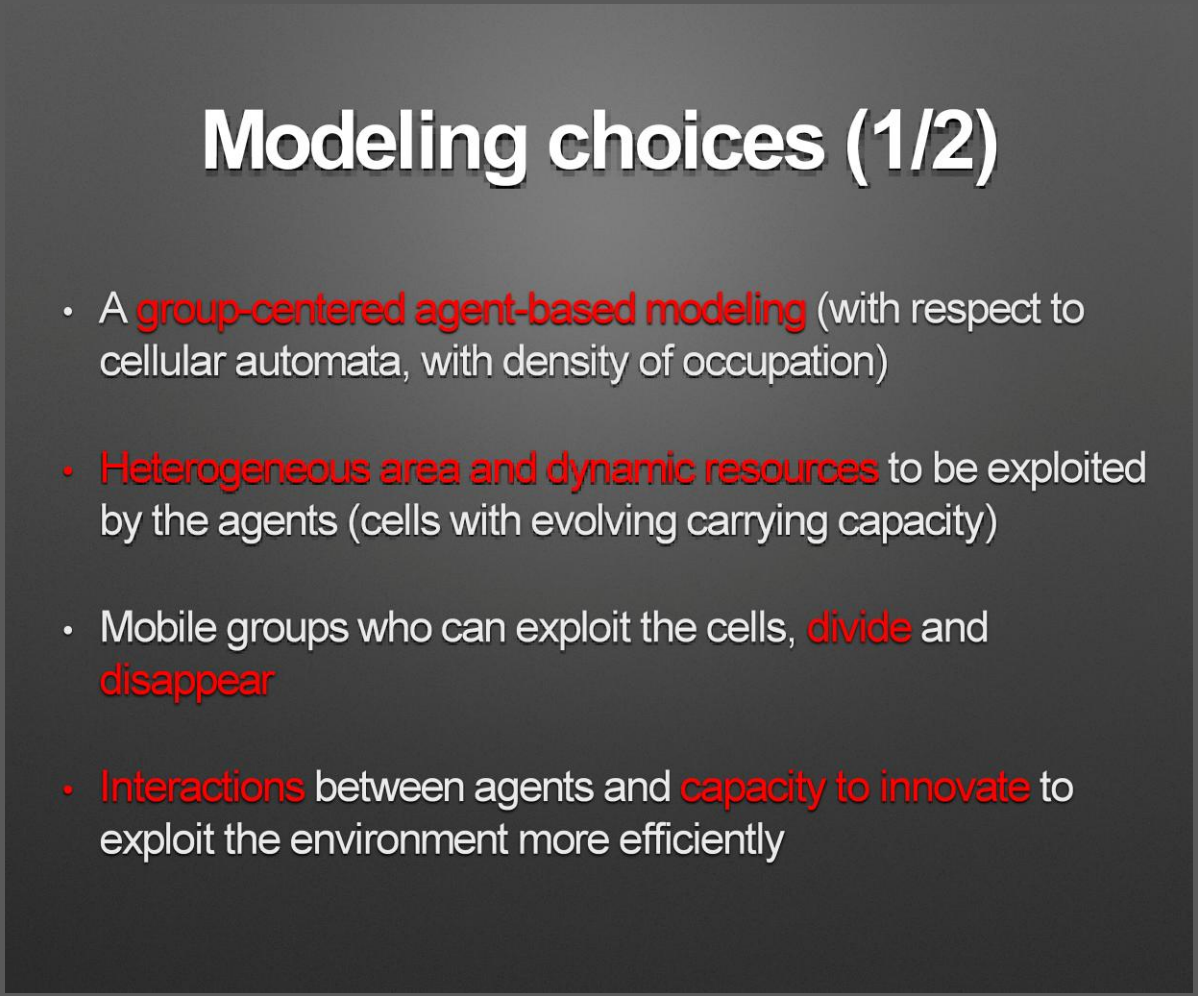
We are developing a model named HUME, which results from interactions between "thematicians" and "modelers". It derives from a previous model designed by Young, and which aimed at identifying the factors behind various forms of spatial colonization.



The HUME model addresses the "Out of Africa" migrations (but see the end of this presentation for extension to Bantu migrations).

It simplifies what occurred in reality long ago by adopting a stylized space in which a transition from empty to occupied land takes place through the migration of a number of human groups entering the space from one of its corners.

We should emphasize that the model does not focus on the socio-cognitive evolutions behind the migrations, but rather on the parameters which result in specific migratory patterns across the land, this adopting Young's perspective.



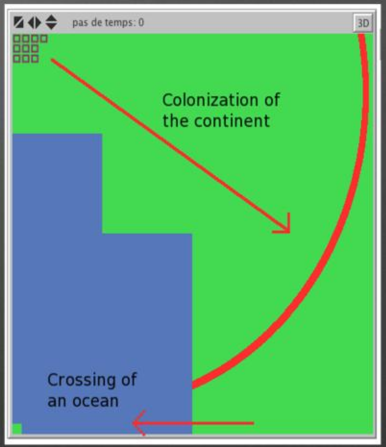
A number of choices had to be made in order to obtain a fully specified model. One of the advantages of computational models is indeed to force their designers to provide an algorithmic description for every aspects of the phenomenon under study.

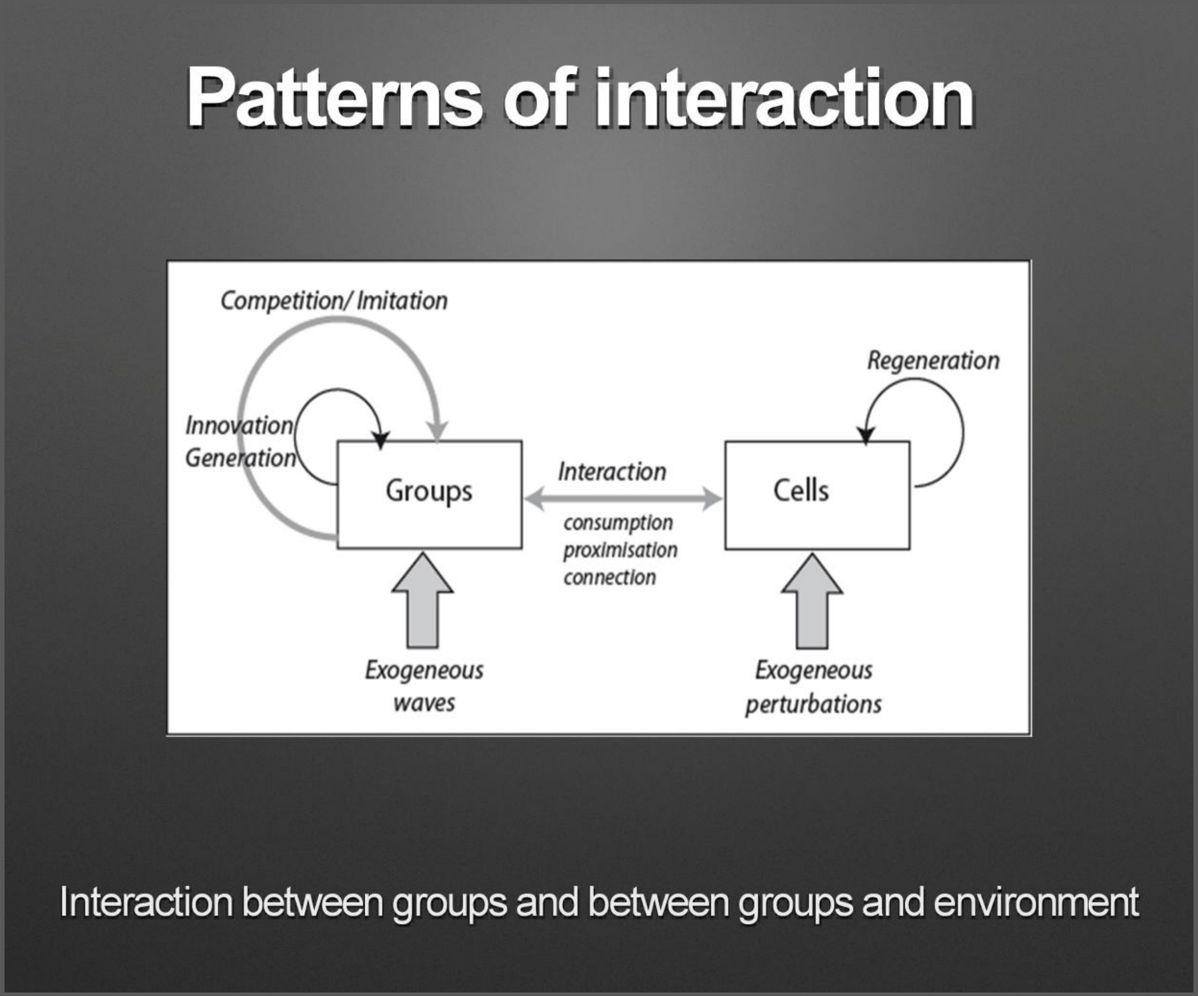
Here, we for example adopted a multi-agent framework rather than a cellular automata, and chose to forget individuals to equate agents to human groups, as our ancestors were living in groups of around 25 to 50 individuals scattered in vast regions of the planet.

We also identified that heterogeneous land cells in terms of resources to be exploited by groups would be a significant factor. When other modelers like Hazelwood and Davison or Parisi designed specific non-homogeneous distributions in their models, ours were stochastic to reflecting climatic and environmental changes during the period of colonization.

Modeling choices (2/2)

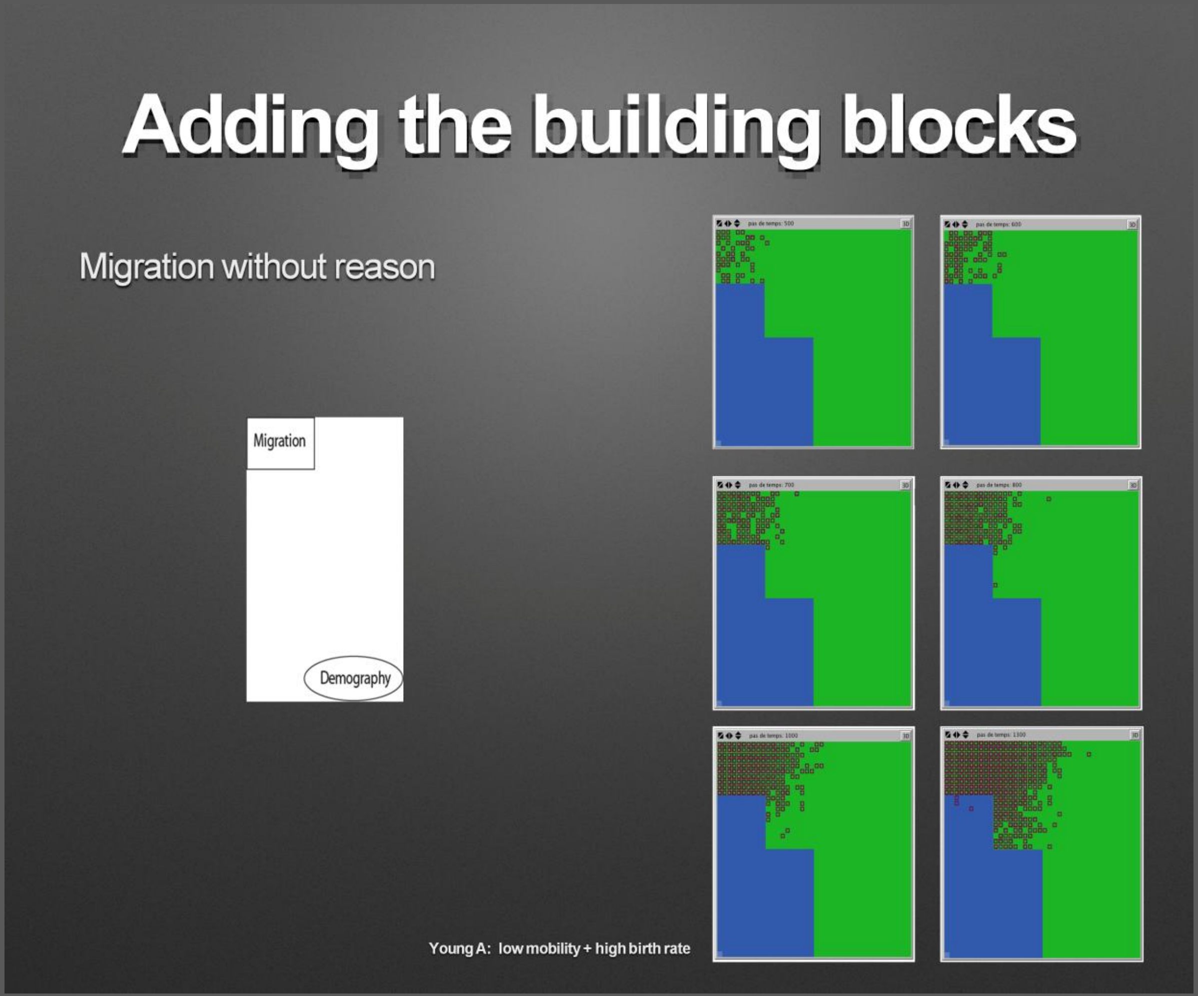
- 52*52 cells grid
- Resources initially uniformly distributed
- An island, difficult to reach from the continent
- 10 waves of 10 groups arriving in an empty area (tap)



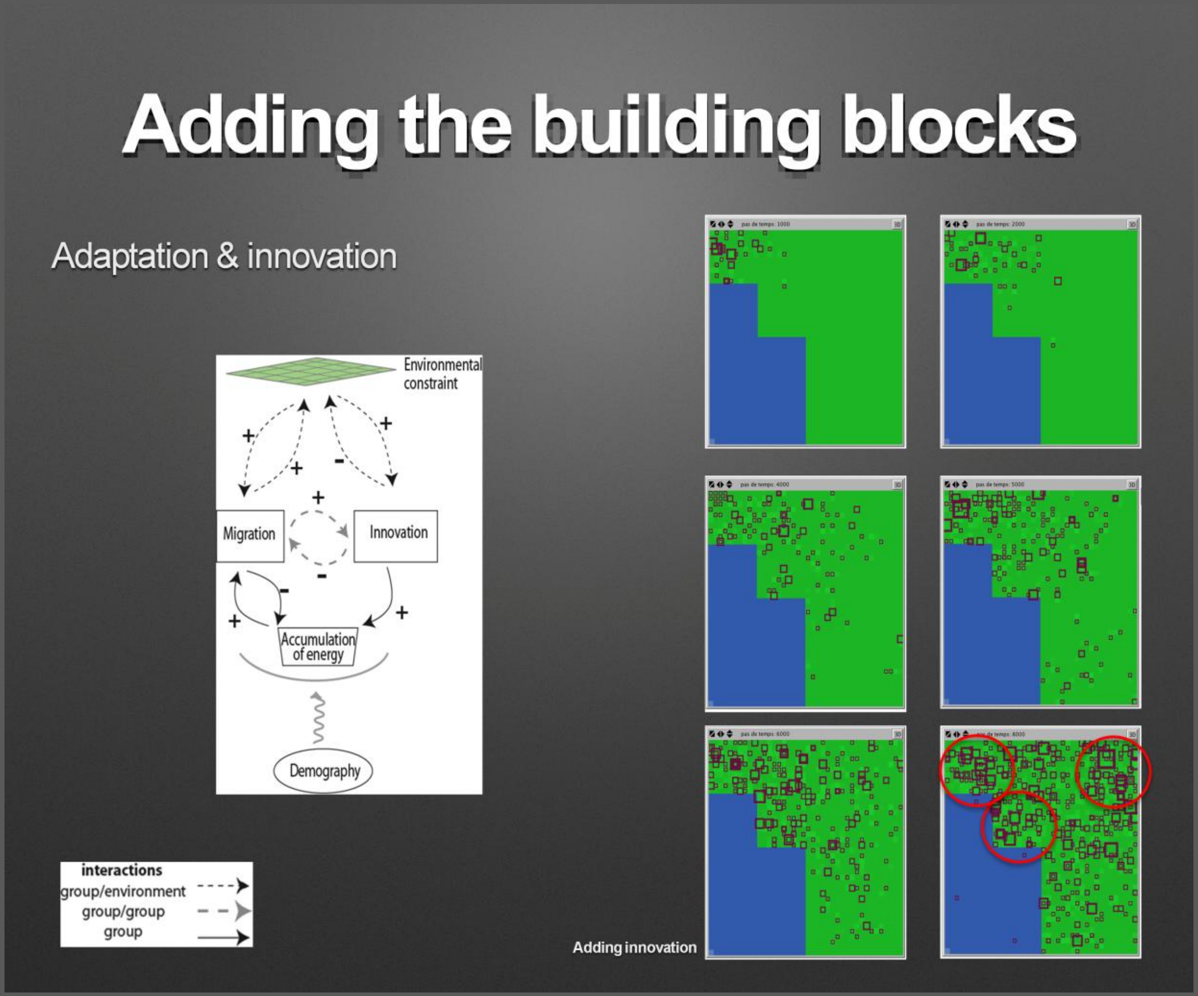


Different stylized mechanisms among groups/agents as well as between them and the environment were designed:

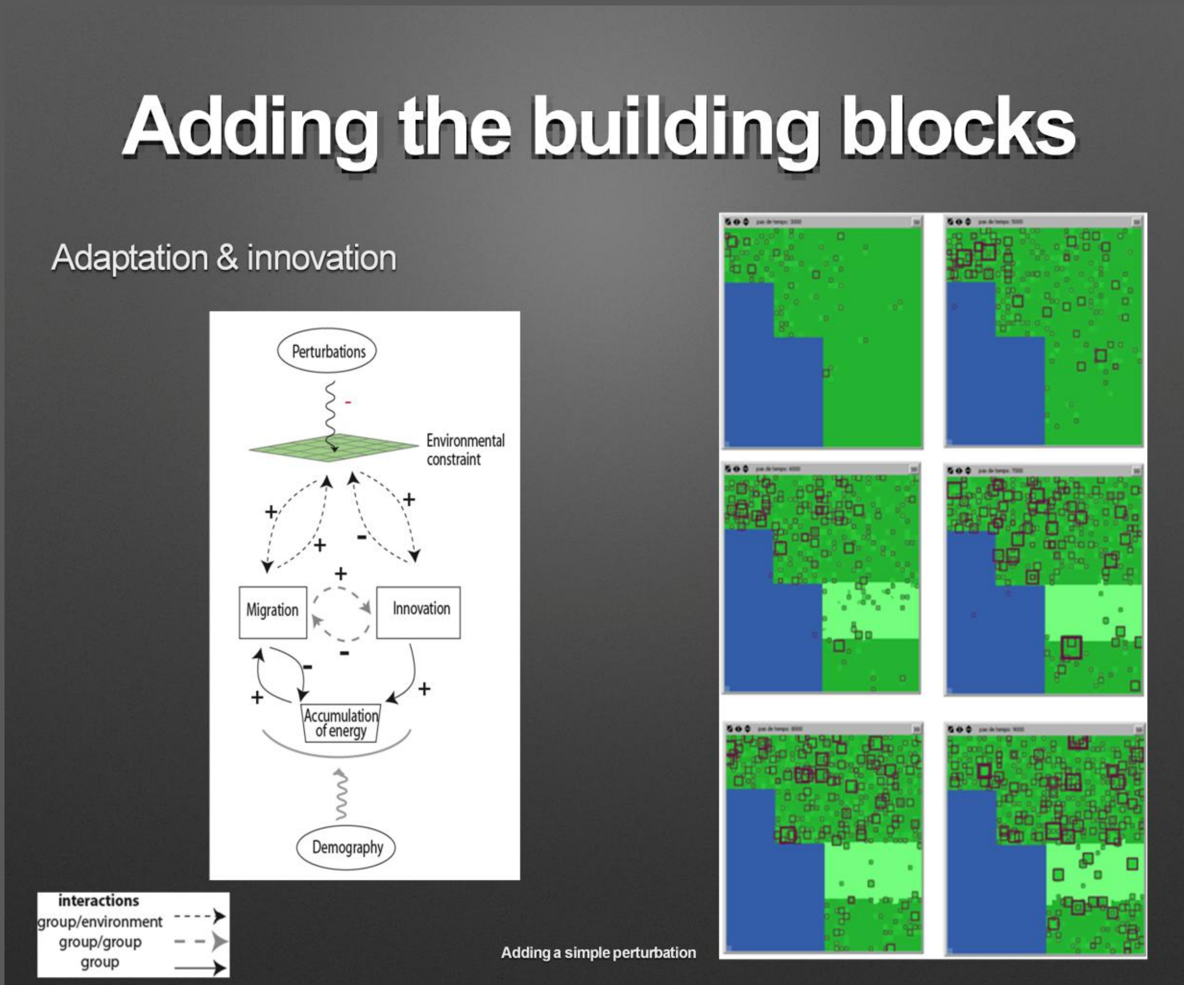
- Groups can consume resources of the cell they occupy, which slowly regenerates and can also vary according to exogenous perturbations. Accumulated energy is consumed during moves across the lands
- Groups can innovate and become more efficient at exploiting resources, but can also learn from groups occupying the same cell as them.



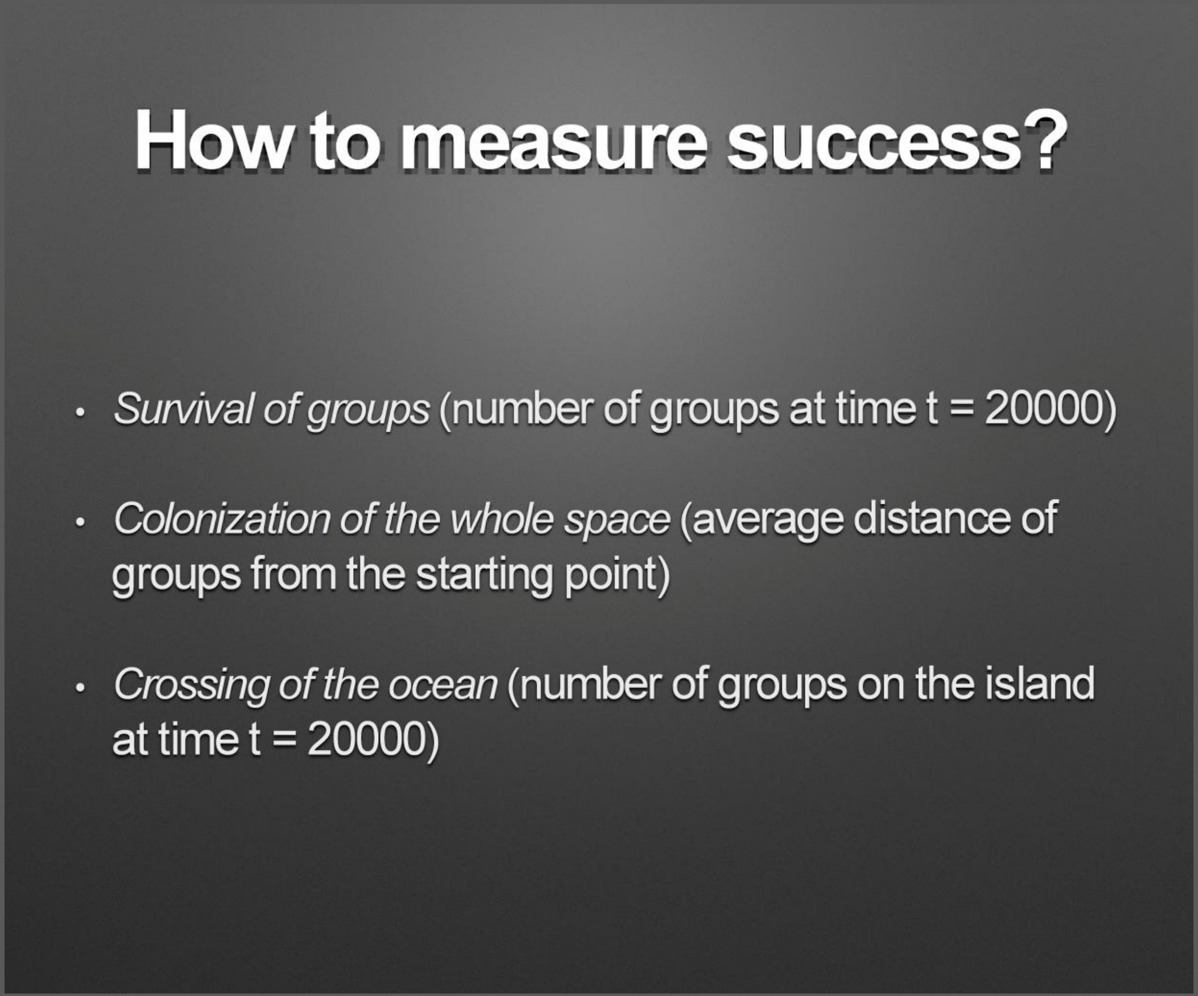
We followed a compositional approach, in the sense that we started from simple models with only the most necessary components to simulate a demographic expansion, before gradually adding other “building blocks” capturing phenomena such as accumulation of energy, innovation or exogenous perturbations. This was helpful to focus on the specific consequences of each component of the model.



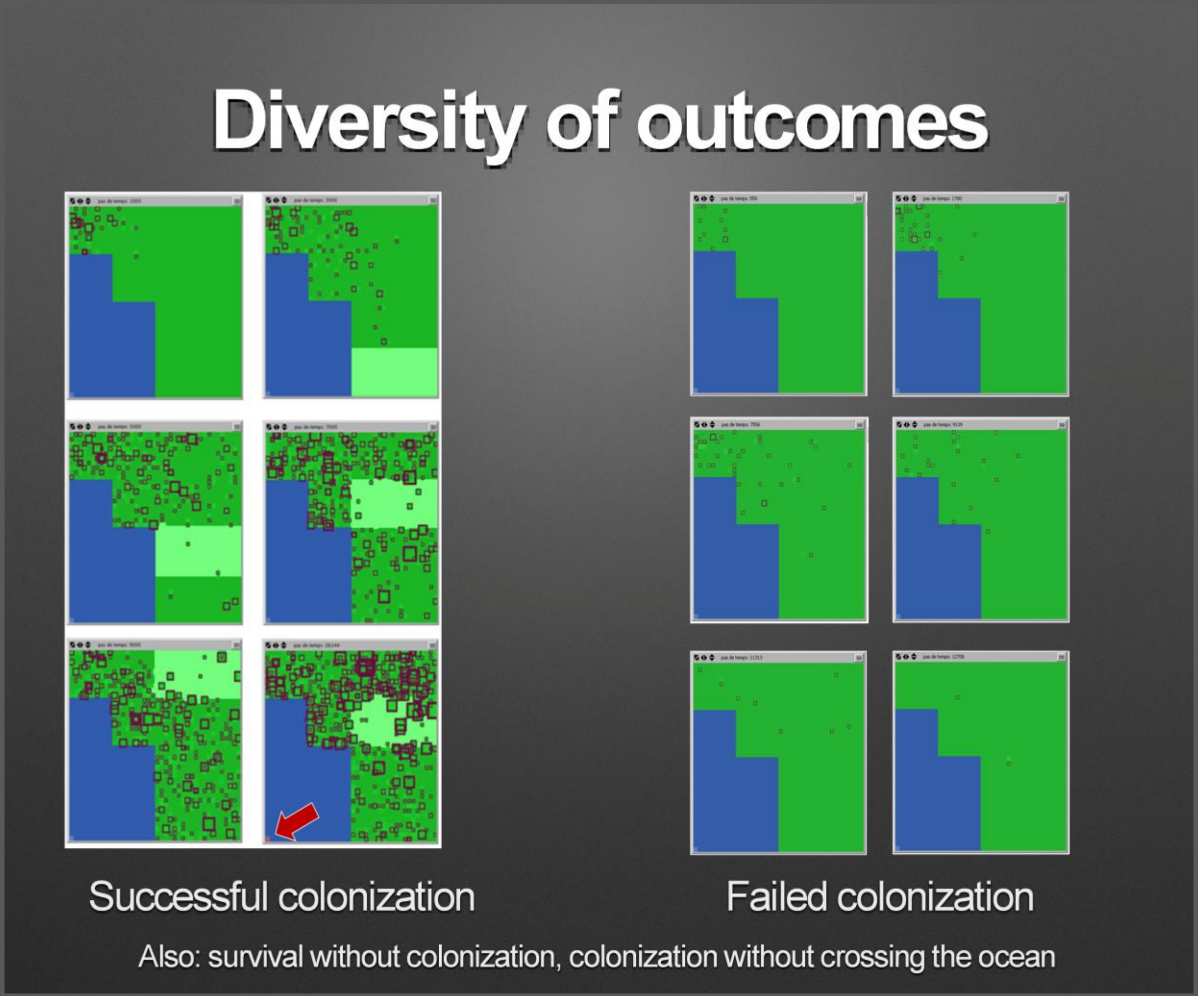
Adding innovations and better exploitation of the environment leads to higher local densities of population, related to the success of a group and its descendants.



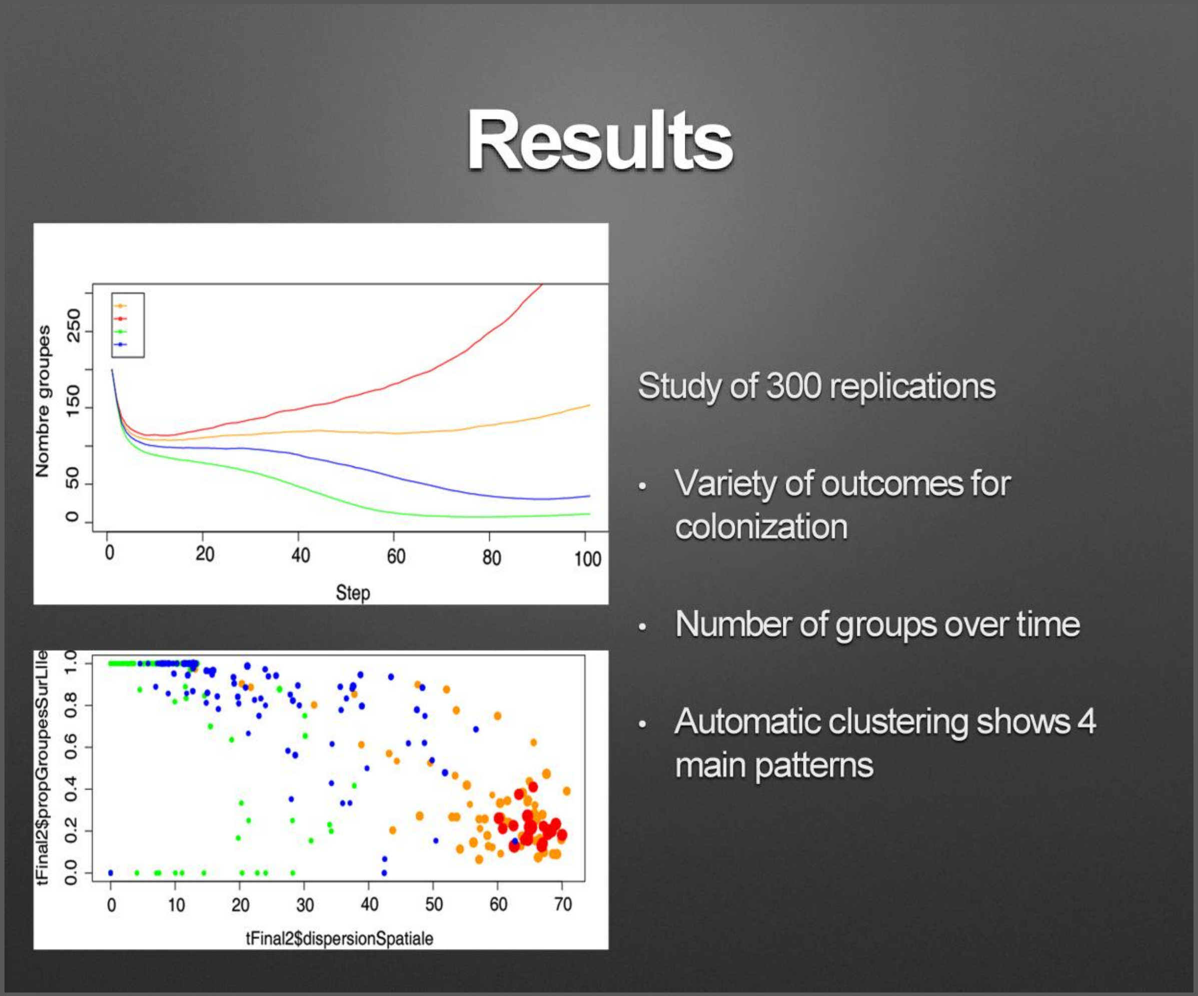
Adding exogenous perturbations allows observing how human groups react to them and global changes in spatial patterns of colonization.



Since exploring real migratory routes (such as the previously mentioned Southern dispersal route) cannot be expected from a stylized model, we focused on the parameters potentially explaining the success of a colonization event. This relates to the question why our direct ancestors managed to reach lands other human species had failed to inhabit. We focused on three measures related to temporal and spatial dimensions of the colonization. Reaching an island in the stylized space after crossing an ocean where no resources could be collected was a reference to the colonization of Australia.



Given the stochasticity of the model, a fixed set of parameters for moves, consumption, innovation etc. led to a variety of outcomes: successful colonization with sea-crossing, successful colonization without sea-crossing to the island, disappearance of the human population etc.

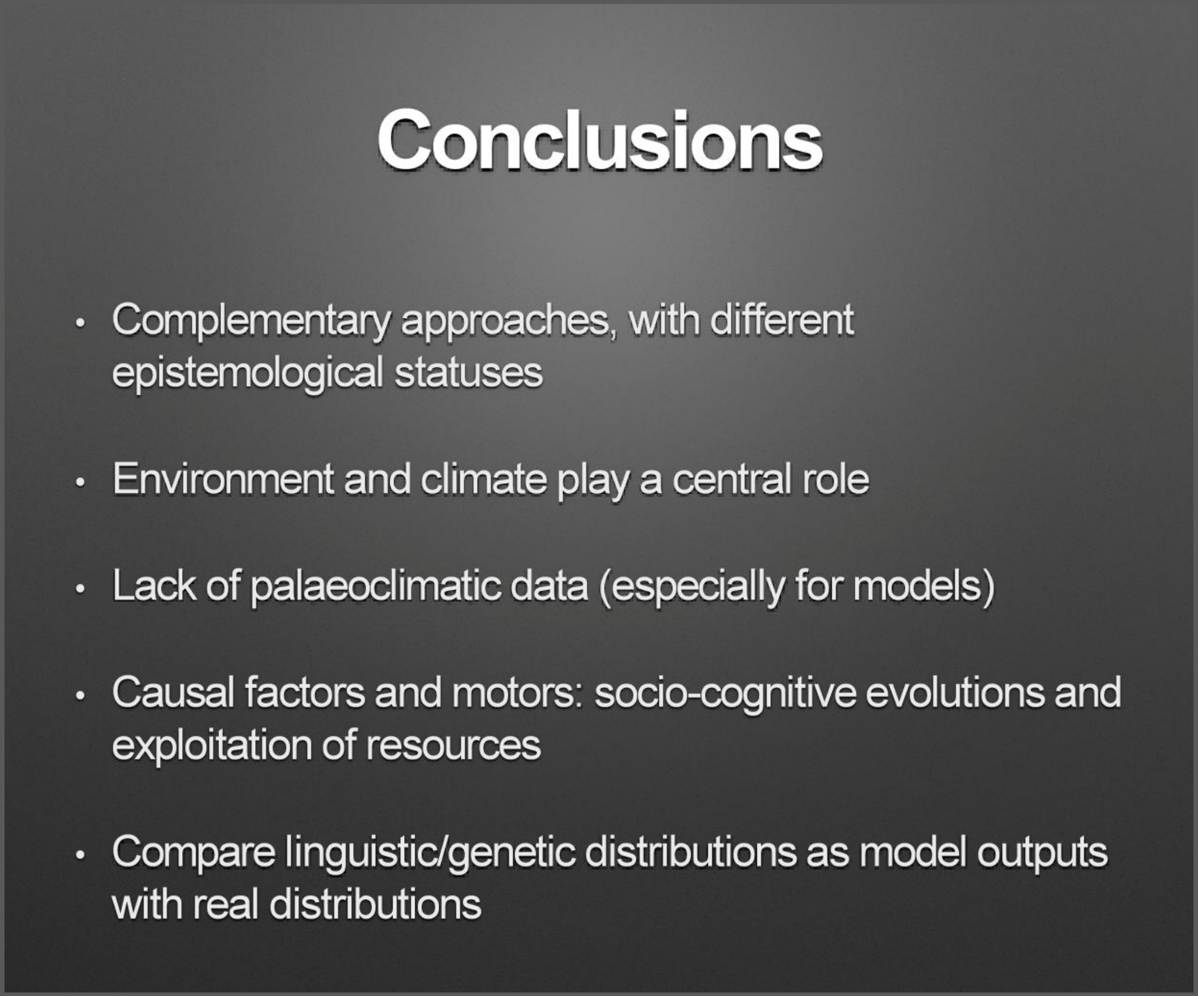


A number of replications were studied and their results could be classified in different ways. When considering the number of groups over time, spatial dispersion and successful sea-crossings, automatic clustering of the simulation outcomes showed that 4 distinct pattern could be differentiated.

A sensitivity analysis has yet to be performed to better understand the conditions of colonization success.

At the same time, the HUME model is now further developed to address the case of Bantu migrations. While this migratory event share grounds with the "Out of Africa" migrations, the interactions between Bantu farmers and forest foragers have to be specifically accounted for. Our target in the so-called HUME-BIP model (BIP: Bantu interacting with Pygmies) is to understand whether interactions with Pygmies led to crossing the forest rather than bypassing it. How the obstacle was dealt with by Bantu farmers is indeed an unresolved question today.

The model can also be complemented in different ways, for example either by tracking the genealogy of groups or by adding linguistic markers to them to compare real linguistic distributions to those produced by the simulations.



Different approaches can be simultaneously considered to study the migrations of the first two transitions of the ANR Transmondyn. In all of them, environment and climate are very significant. Especially 70,000 years ago, at a time where social structures and technological developments were quite different from today, adapting to the environment and its changes was of primary importance.

Along these lines, a strong limitation to the previous models is the lack of paleoclimatic datasets. Considering real climatic changes rather than artificial perturbations would move the simulations closer to reality. Despite this limit however, various other directions can be taken, which can help us to better understand past human migrations.