# Simulating Expansive Phenomena in Archaeology

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# Simulating Expansive Phenomena in Archaeology

An example from Ecology:

**N(t)** = number of **predators** at time t
**P(t)** = number of **preys** at time t

**N (t+1) = N(t) + I**
**P (t+1) = P(t) – I**

**I** = interaction
**I > 0** → predator N(t) increases, prey P(t) decreases

Lotka-Volterra: **I = c N(t) P(t)** → I = 0 if N(t) = 0 or P(t) = 0

Useful in Chemistry, Ecology, Economics…

So this is a typical model:

$$N(t+1) = N(t) + c\,N(t)\,P(t)$$
$$P(t+1) = P(t) - c\,N(t)\,P(t)$$

For expansive phenomena, this model is **not** adequate because the population densities depend on space (x,y) besides time (t), i.e.: expansive phenomena are non-homogeneous systems.

How to model expansive phenomena?

1) Use population densities (per unit area), not population numbers:

**n(x,y,t)** = number of predators / $km^2$

**p(x,y,t)** = number of preys / $km^2$

2) Add reproduction [F(n), F(p)] & Dispersal to the Eqs. above:

$$n(x,y,t+1) = n(x,y,t) + c\,n(x,y,t)\,p(x,y,t) + F(n) + Dispersal$$
$$p(x,y,t+1) = p(x,y,t) - c\,n(x,y,t)\,p(x,y,t) + F(p) + Dispersal$$

net reproduction

So this is a typical space-time model in Ecology, etc.:

**n (x,y,t+1) = n(x,y,t) + c n(x,y,t) p(x,y,t) + F(n) + <u>Dispersal</u>**

**p (x,y,t+1) = p(x,y,t) – c n(x,y,t) p(x,y,t) + F(p) + <u>Dispersal</u>**

This model has been also applied to Genetics & Archaeology:

$n$ = number of farmers / km$^2$

$p$ = number of hunter-gatherers / km$^2$

Rendine S, Piazza A, Cavalli-Sforza LL, Am. Nat. (1986):

$$\begin{cases} \dfrac{\partial n}{\partial t} = c\,n\,p + F(n) + D_N \nabla^2 n \\ \dfrac{\partial p}{\partial t} = -c\,n\,p + F(p) + D_P\,\nabla^2 p \end{cases}$$

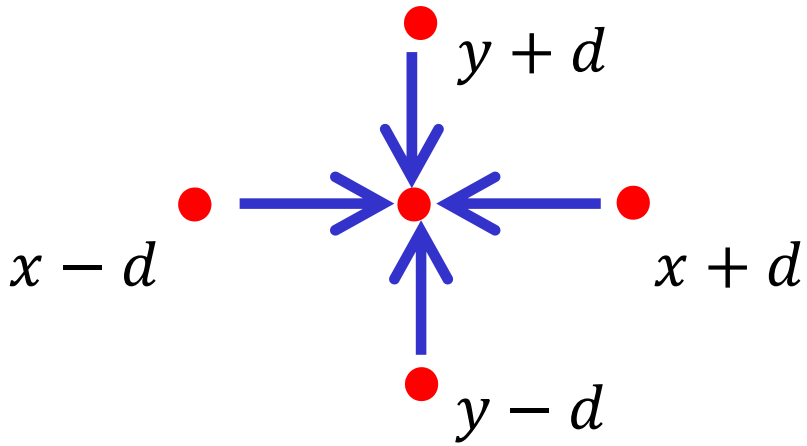
acculturation of hunter-gatherers into farmers

$$\frac{\partial n}{\partial t} = c\, n\, p \; + \; F(n) + D_N \nabla^2 n$$

What is this dispersal term?

If all individuals move the same distance:

$$D_N \nabla^2 n = \frac{n(x-d,y)}{4} + \frac{n(x+d,y)}{4} + \frac{n(x,y-d)}{4} + \frac{n(x,y+d)}{4} - n(x,y)$$



$$\frac{\partial n}{\partial t} = c\, n\, p + F(n) + D_N \nabla^2 n$$

What is this population growth term?

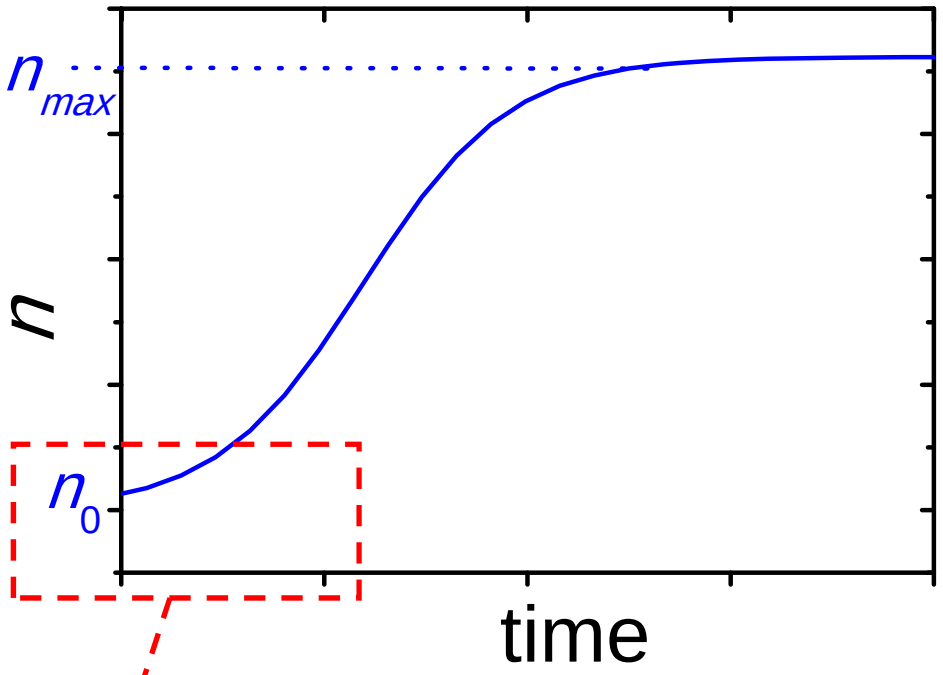
$F(n)$ = net reproduction = births – deaths

What is the function $F(n)$ ?

Logistic growth: $F(n) = an\left(1 - \frac{n}{n_{max}}\right)$

Single homogeneous population:

$$\frac{dn}{dt} = an\left(1 - \frac{n}{n_{max}}\right)$$

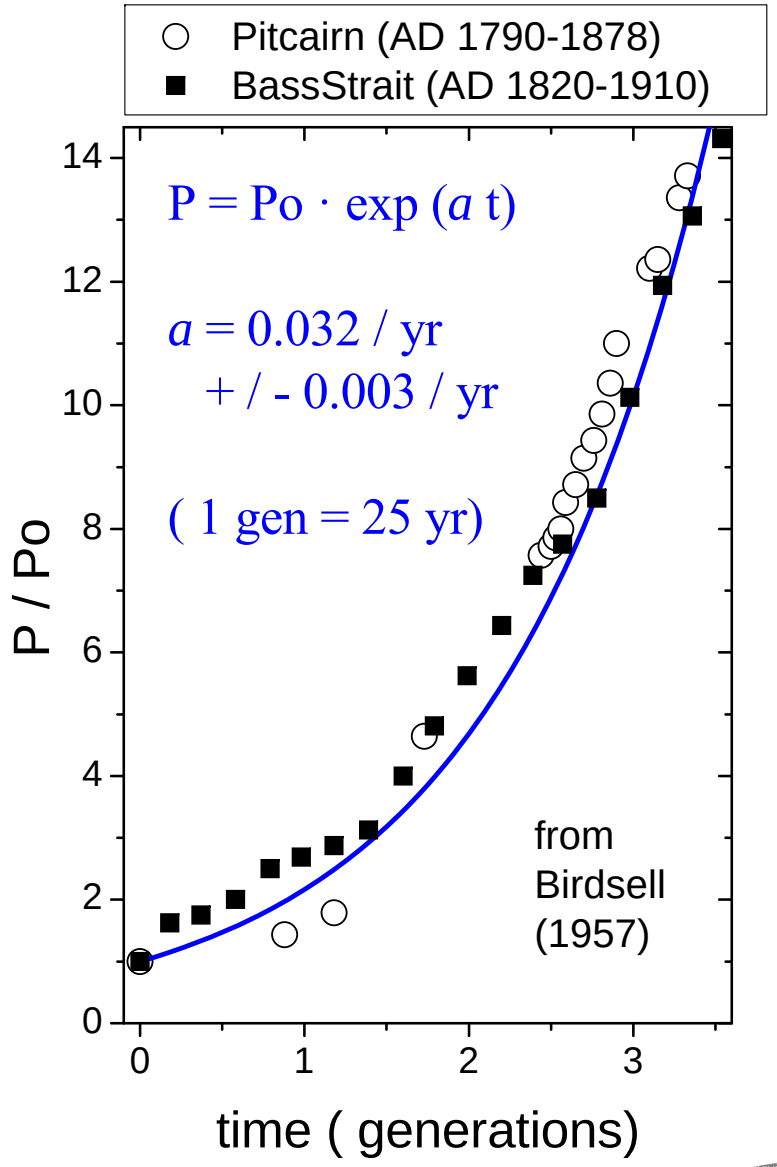



$n_{max}$ = carrying capacity

$a$ = initial growth rate

If $n \ll n_{max} \rightarrow \frac{dn}{dt} \simeq an \rightarrow n = n_0 \exp(at)$

# 2 human populations:



# Fisher's model (Ammerman+Cavalli-Sforza):

Only 1 population (farmers):

$$\frac{\partial n}{\partial t} = F(n) + D_N \nabla^2 n$$



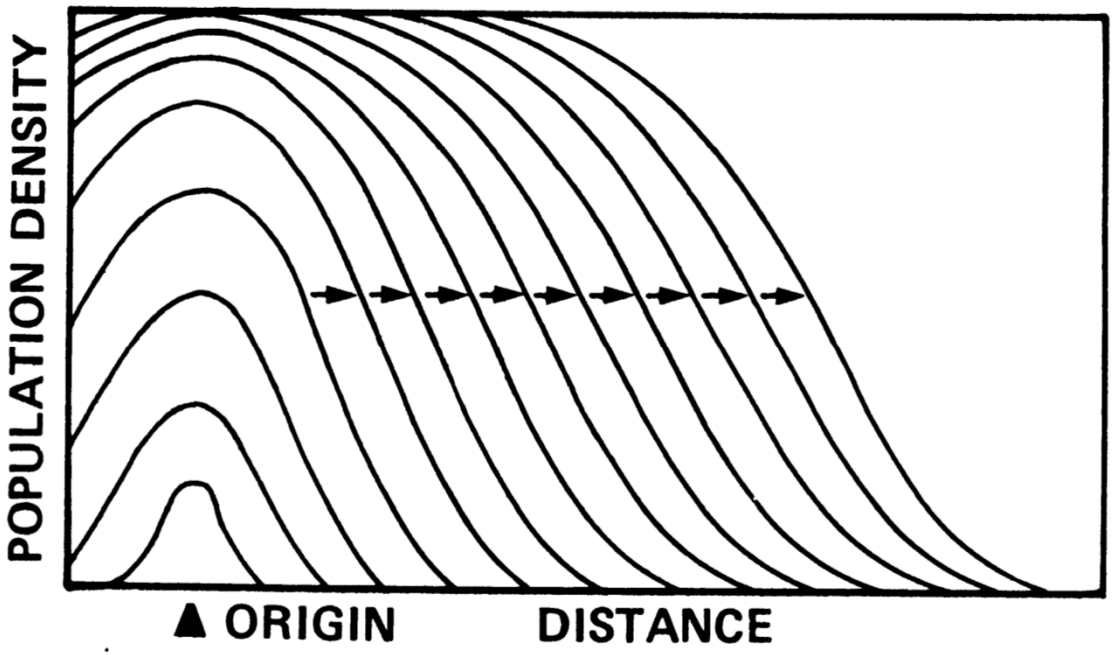



FIGURE 5.2. Fisher's model of a population wave of advance. This graphic representation shows the rise in local population density expected with increasing distance

# Some models with a single population:

- **Fisher's model and the Neolithic transition in Europe:**
  Ammerman & Cavalli-Sforza (1973, 1984).

- **Effect of the delay time:**
  Fort & Méndez, *Phys. Rev. Lett.* (2002).

- **The Neolithic transition in Oceania:**
  Fort, *Antiquity* (2004).

- **Postglacial palaeolithic recolonization in Europe:**
  Fort, Pujol & Cavalli-Sforza, *Cambridge Archaeol. J.* (2005).

- **Colonization of North America:**
  Hamilton & Buchanan, *PNAS* (2007).

- **etc., etc.**

# Model with 2 populations:

$$\begin{cases} \dfrac{\partial n}{\partial t} = c\, n\, p \;+\; F(n) + D_N \nabla^2 n \\ \dfrac{\partial p}{\partial t} = -c\, n\, p + F(p) + D_P\, \nabla^2 p \end{cases}$$

**Rendine, Piazza, Cavalli-Sforza, *Am. Nat.* (1986)** applied this model to:

· Simulate several waves of advance (including the Neolithic one) and

· Test the validity of principal component analysis to generate maps from genetic data (**Menozi, Piazza & Cavalli-Sforza, *Science* 1978**).

# Some other models with several populations:

- **Conditions for the formation of genetic clines:**
  Aoki, Shida & Shigesada, *Theor. Popul. Biol.* (1996).

- **Formation of cultural boundaries:**
  Ackland, Signitzer, Stratford & Cohen, *PNAS* (2007).

- **The neolithization time:**
  Fort, Pérez-Losada & al., *New J. Phys.* (2008).

- **Neolithic transition in the Indian subcontinent:**
  Patterson, Sarson, Sarson, Shukurov, *J. Arch. Sci.* (2010).

- **Neolithic slowdown in Northern Europe:**
  Isern & Fort, *J. Arch. Sci.* (2012).

- **etc., etc.**

# CASE STUDIES - METHODOLOGY

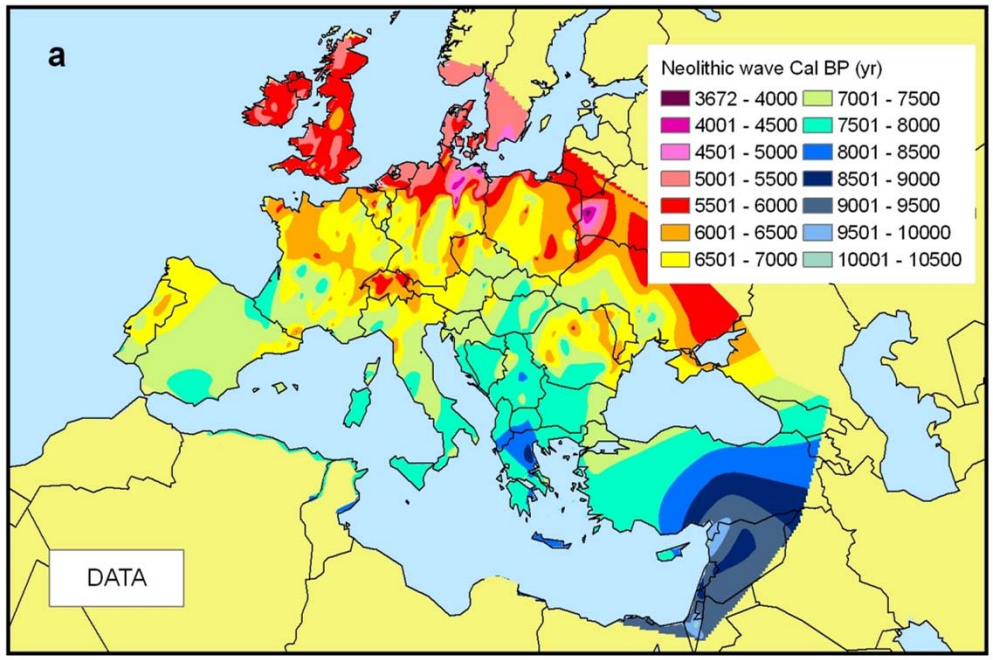
A) The **first evidences of agriculture (CS6)**

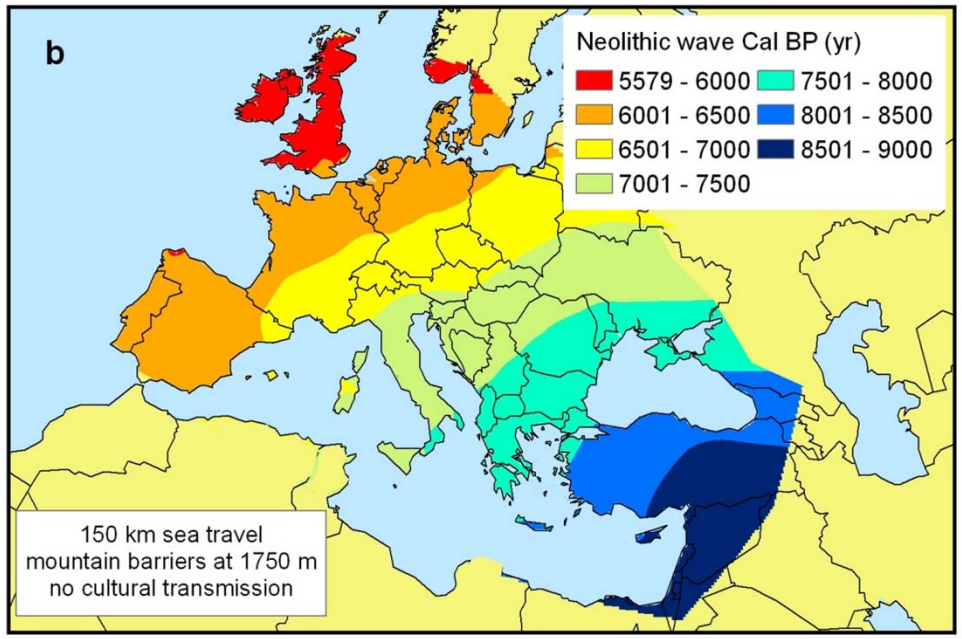
**Isern (10 minutes)**

# Cultural transmission

1. Vertical transmission =
   = interbreeding between farmers & hunter-gatherers.
   How does it affect the Neolithic front speed?
1.1. Using equations: Fort, Phys. Rev. E. (2011)
1.2 Using simulations: Pujol, Fort & vander Linden (unpubl.)

2. Horizontal transmission =
   = imitation of farmers by hunter-gatherers.
   How does it affect the front speed and width?
2.1. Using equations: Fort, submitted (2012)
2.2 Using simulations: Pujol, Fort & vander Linden (unpubl.)



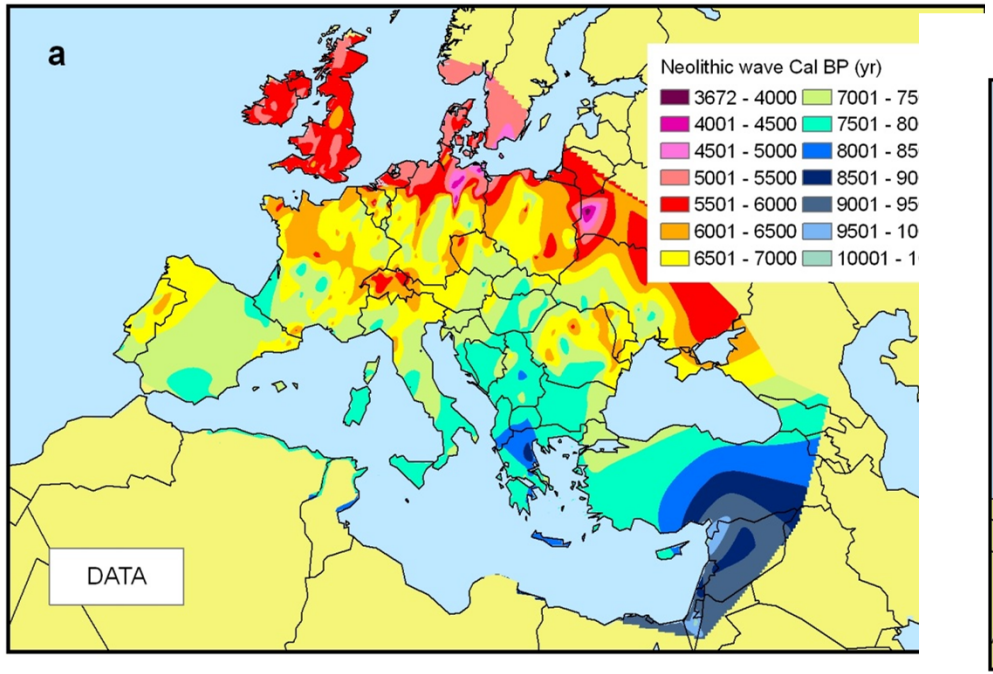



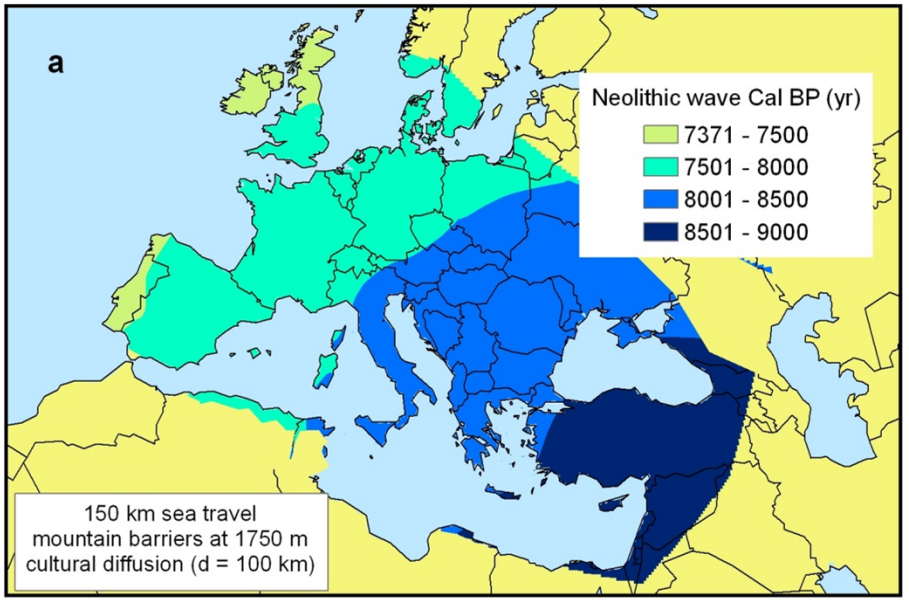

Data:
919 sites by
vander Linden.

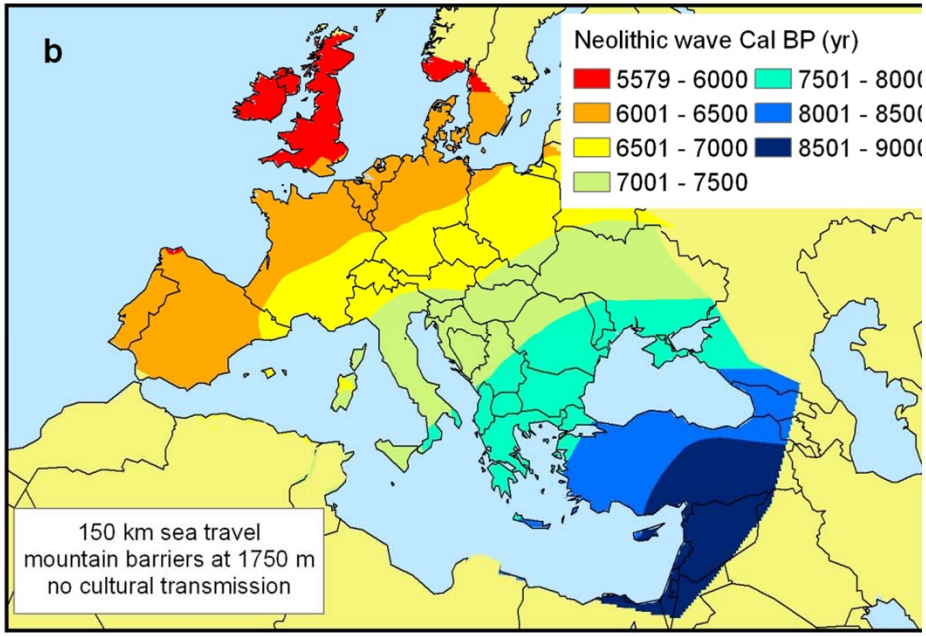
Simulation programs
written by Pujol.

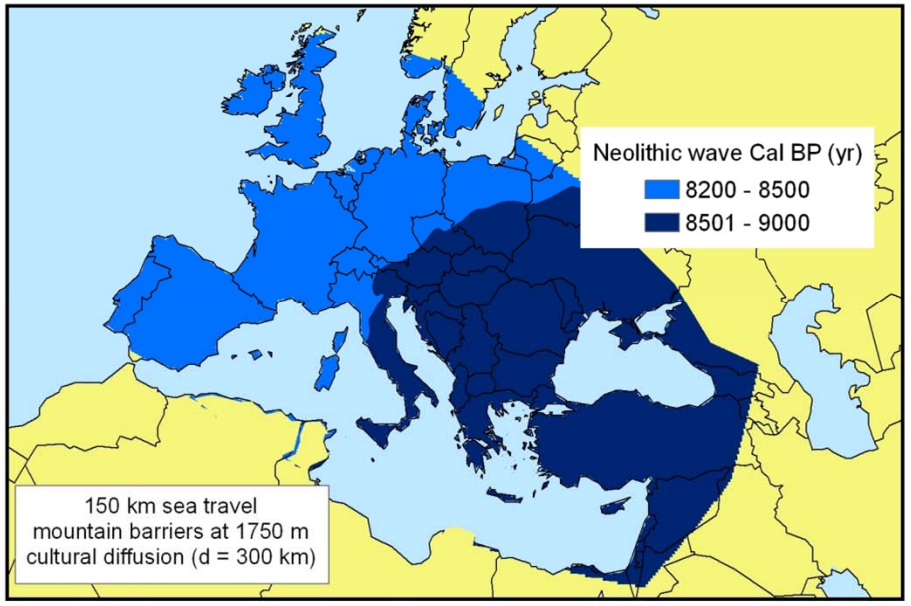
1. Vertical transmission
does not change
much the demic
results

# 2. Horizontal transmission



# Results (deliverables):

## 1. <u>At the group level</u> (Universitat de Girona, G8):

The SimulPast project is acknowledged in:

1. Isern & Fort, *New J. Phys*. (2010)
2. Fort, *Phys. Rev. E* (2011)
3. Pérez-Losada & Fort, *J. Arch. Sci*. (2011)
4. Isern & Fort, *Europhys. Lett*. (2011)
5. Amor & Fort, *Phys. Rev. E* (2011)
6. Fort, Pujol & vander Linden, *Amer. Antiq*. (2012)
7. Isern & Fort, *J. Arch. Sci*. (2012)
8. Pérez-Losada & Fort, *submitted* (2012)
9. Isern, Fort & vander Linden, *submitted* (2012)
10. Fort, *submitted* (2012)

# Results (deliverables):

## 2. <u>At the cluster level</u> (Cultural transmission cluster):

At this level, progress will depend on some critical factors:

| | Neolithic Transition in the Iberian peninsula | Bronze/Iron transition in Europe | Neolithic transition in Asia |
|---|---|---|---|
| <u>Work in progress?</u> | YES | YES | NO |
| Database available? | YES, preliminary (G3) | January 2013 (G6) | NO (G1) |
| Simulations by G8 useful? | YES | YES (partially at least) | **<u>YES</u>** |
| Adequate experience by G8? | YES | YES (partially at least) | **<u>YES</u>** |