Demic versus cultural diffusion in the Neolithic transition in Europe

Joaquim Fort
Universitat de Girona

4th FEPRE workshop
Newcastle University
14-16 April 2010

Background

Demic diffusion = motion of individuals (farmers)
Cultural diffusion = motion of ideas (farming), that were transmitted from groups of Fs into HGs

First mathematical model of the Neolithic transition: Ammerman & Cavalli-Sforza (1971, 1973)
This was a demic model [based on Fisher's equation].

During 40 years, the dispute between demic and cultural models has persisted. But only demic models have been formalized using mathematical equations.

Motivation

Archaeological data imply a rate of about 1 km/yr for the spread of farming accross Europe.

Ammerman & Cavalli-Sforza, and more refined demic models: demic diffusion predicts about 1 km/yr.

How many km/yr does cultural diffusion predict?

How to model cultural transmission?

Leaving aside population dispersion for the moment:

$$\begin{cases} \text{farmers } (N): \quad P_N(t+1) = R_{0N} P_N(t) + I_N \\ \text{hunter-gatherers } (P): \quad P_P(t+1) = R_{0P} P_P(t) + I_P \end{cases}$$

R_{0N} , R_{0P} are net reproductive rates per generation

Lotka-Volterra: $I_N = \Gamma P_N P_P = -I_P$ (widely used in Ecology)

Preliminary results with this model were reported by Dr. Toni Pujol in the 3rd FEPRE workshop.

Later we noted some problems with this model.

In this talk we introduce better models.

$$\begin{cases} \text{farmers } (N)\text{:} \quad P_N(t+1) = R_{0N} P_N(t) + I_N \\ \text{hunter-gatherers } (P)\text{:} \quad P_P(t+1) = R_{0P} P_P(t) + I_P \end{cases}$$

Cultural transmission takes 2 forms

1) **Vertical** transmission is due to cross-matings:
I_N and I_P = number cross-matings per generation

2) **Horizontal/oblique** transmission is due to acculturation:

I_N and I_P = number of acculturated individuals /generation

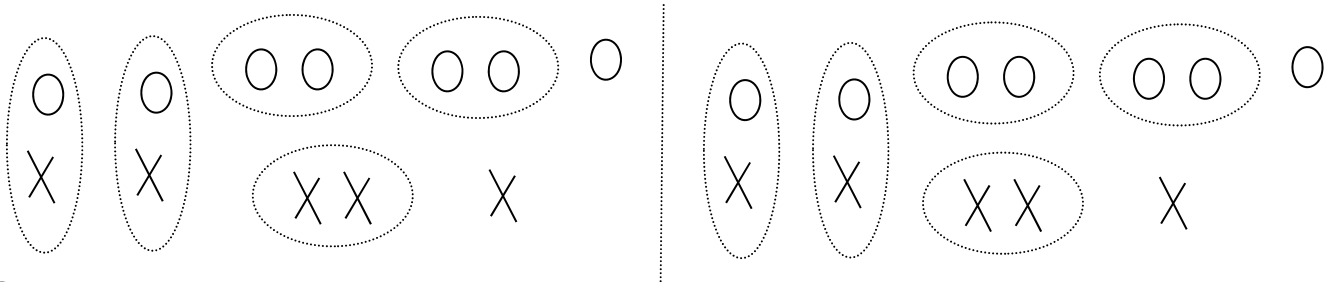
We begin with **vertical** transmission

Is a Lotka-Volterra term reasonable?

○ = N individual = farmer

x = P individual = hunter-gatherer

ellipse = mating



If both P_N and P_P are twice as large,
we expecte I_N to be twice as large

A Lotka-Volterra term, $I_N = \Gamma P_N P_P$, does NOT satisfy this!

How about a term with the form

$$I_N = \Gamma \sqrt{P_N P_P} \ ?$$

Is a square-root term reasonable?

If $P_N >> P_P$ (e.g. $P_N = 1000\ P_P$), we expect no additional matings if P_N is twice as large but P_P remains the same $\rightarrow I_N$ should be approx the same.

A square-rooot term, $I_N = \Gamma\sqrt{P_N P_P}$, does NOT satisfy this!

The only reasonable form I could find is:

$$I_N = \Gamma \frac{P_N P_P}{P_N + P_P}$$

- This is a phenomenologial or 'macroscopic' approach.
- A 'microscopic' approach based on mating frequencies (see, e.g., Cavalli-Sforza & Feldman, *Cultural transmission and evolution*) yields the same result !

Formal model of vertical transmission

'Microscopic' approach based on mating frequencies:

$$\begin{cases} P_N(t+1) = R_{0N} P_N(t) + R_{0N}\gamma \dfrac{P_N(t)P_P(t)}{P_N(t)+P_P(t)} \\ P_P(t+1) = R_{0P} P_P(t) - R_{0P}\gamma \dfrac{P_N(t)P_P(t)}{P_N(t)+P_P(t)} \end{cases}$$

The value of γ can be estimated from

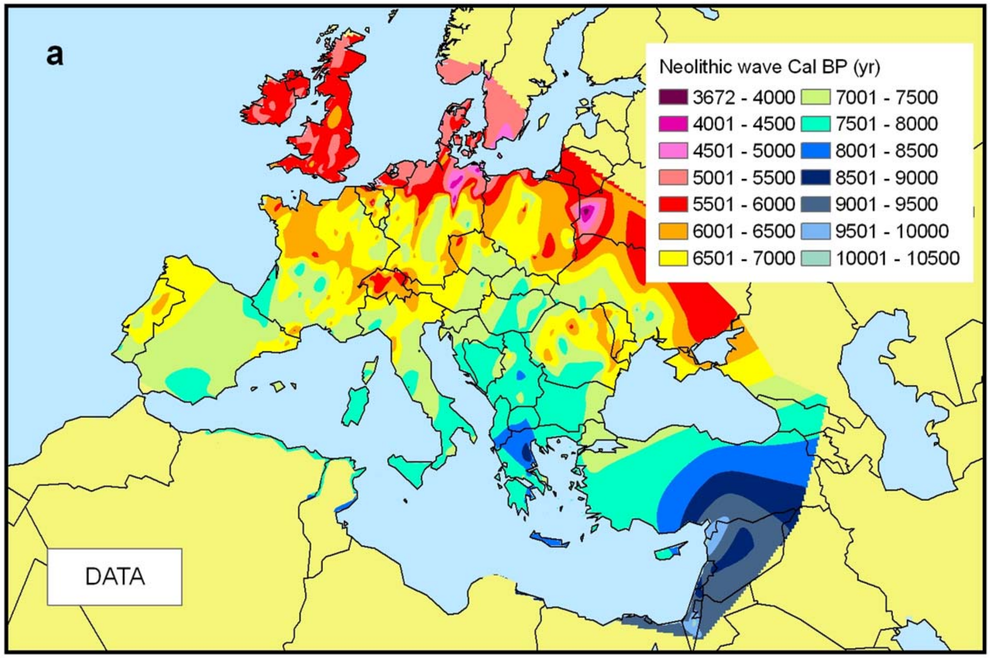
$$\gamma = p'(u)\frac{P_N + P_P}{P_N} \equiv p'(u)\frac{1}{u},$$

$$p'(u) = \text{probab. that P mates N} = \frac{\text{number of cross-matings (PN)}}{P_P}$$

Estimations of the vertical transmission parameter γ

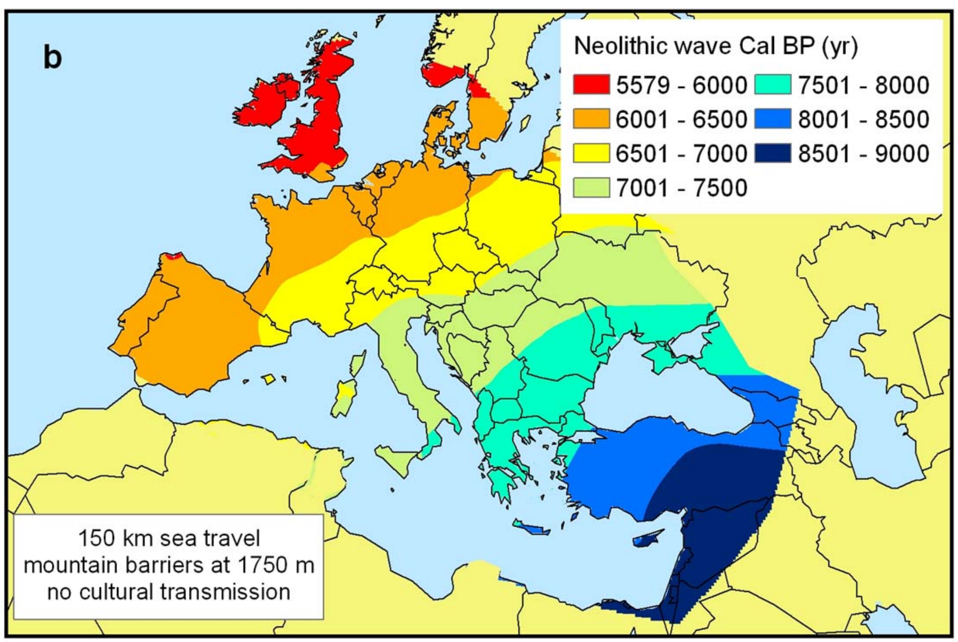
Preindustrial populations	$p'(u)$	P_N	P_P	γ
Wapishana and Macushi	46/156	114	156	0.698*
Nagadjunma andTjeraridjal	4/8	26	8	0.654
Tjalkadjara and Nangatadjara	4/32	6	32	0.792
Mandjindja and Ngadadjara	1/15	19	15	0.119
Ngalea and Kokata	1/13	3	13	0.410

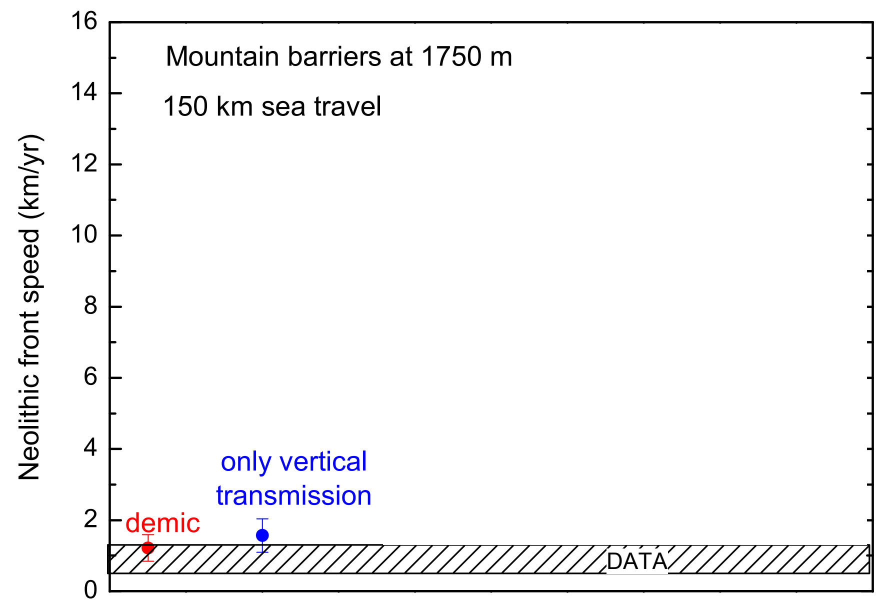
*value used in our simulations; other values do not change the conclusions



919 sites by Marc Vander Linden (similar results with Pinhasi's).

Simulation programs based on these models were writen by Toni Pujol.
The population dispersion was modelled as explained in previous FEPRE workshops (2008, 2009).





Please recall that

Cultural transmission takes 2 forms

1) **Vertical** transmission is due to cross-matings

2) **Horizontal/oblique** transmission is due to acculturation

We next include **horizontal/oblique** transmission

Horizontal/oblique transmission

Derivations by:

- Cavalli-Sforza & Feldman (1979)
- Boyd & Richerson (1985)
- etc.

$$\begin{cases} P_N(t+1) = P_N + f\,\dfrac{P'_N P_P}{P'_N + P_P} \\ P_P(t+1) = P_P - f\,\dfrac{P'_N P_P}{P'_N + P_P} \end{cases}$$

Local acculturation (d=0 km): $P'_N = P_N$

Non-local acculturation (d >0 km): $P'_N = P_N + P_N^{visit}$

Estimations of the horizontal/oblique transmission parameter *f*

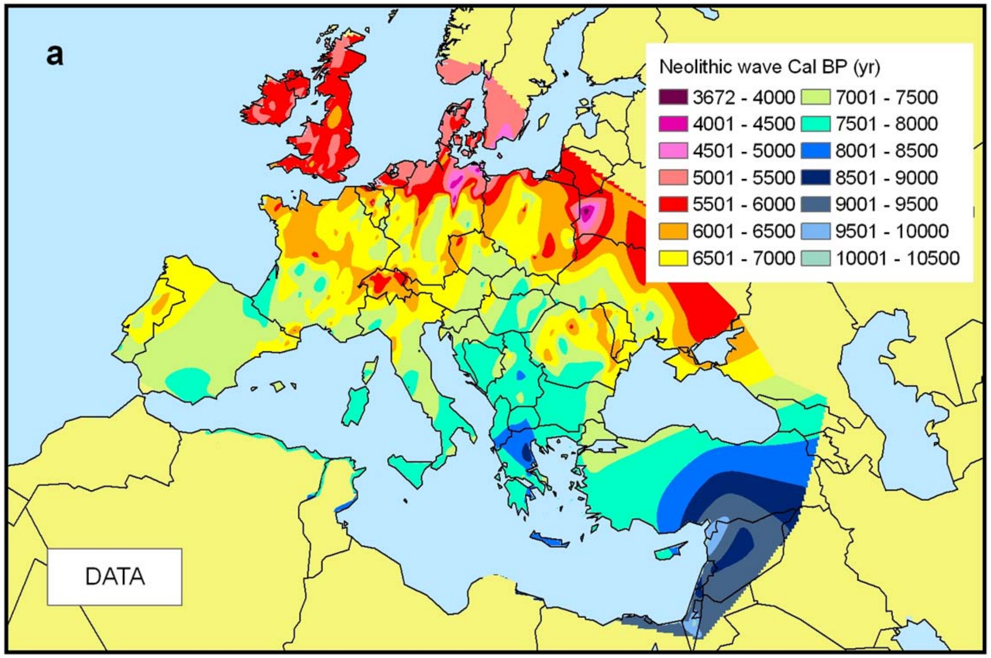
Populations	*f*
Serra de la Tramontana, Mallorca	0.901*
Koyaki G.R. (Maasai), Kenia	>1.15
Olkirmatian/Shompole G.R. (Maasai), Kenia	>1.97
Irkeepus, N.C.A. (Maasai), Tanzania	>13.1
Mukogogo, Kenia	22.7

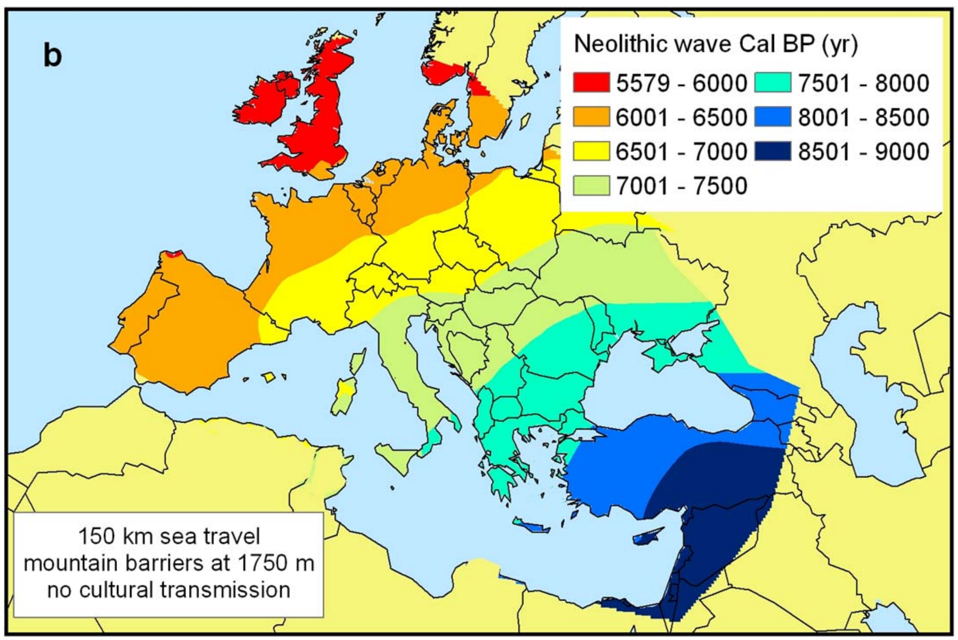
*value used in our simulations; other values do not change the conclusions

Estimations of the horizontal/oblique transmission distance *d*

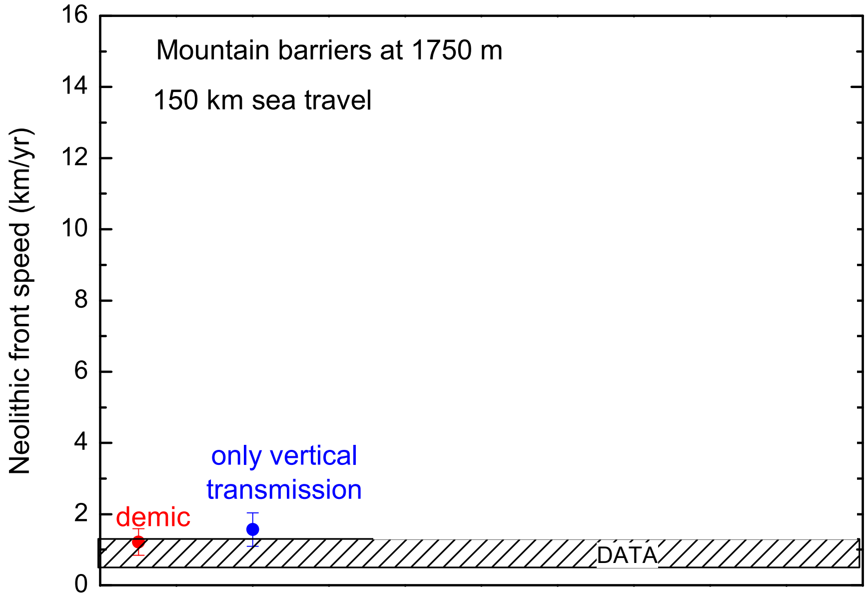
For hunter-gatherers, distances of about 700 km have been observed for carrying messages, about 500 km for trading exchanges, and about 200-500 km for ceremonial gatherings*

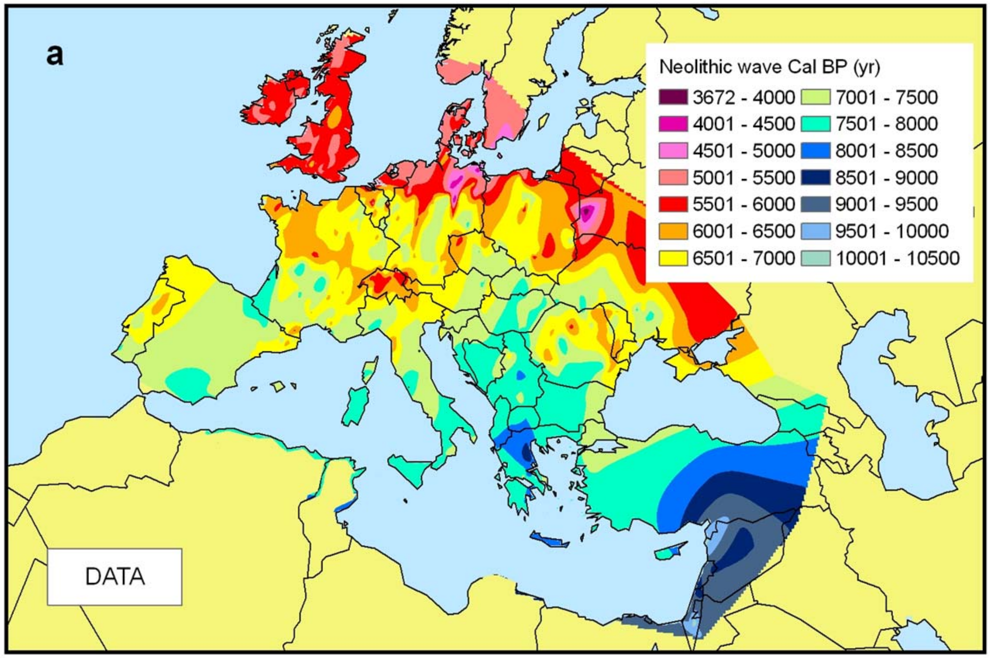
*Mulvaney, D. J. 'The chain of connection': the material evidence. In N. Peterson (ed.). *Tribes and boundaries in Australia* (Australian Institute of Aboriginal Studies, Canberra, 1976), pp. 72-94.

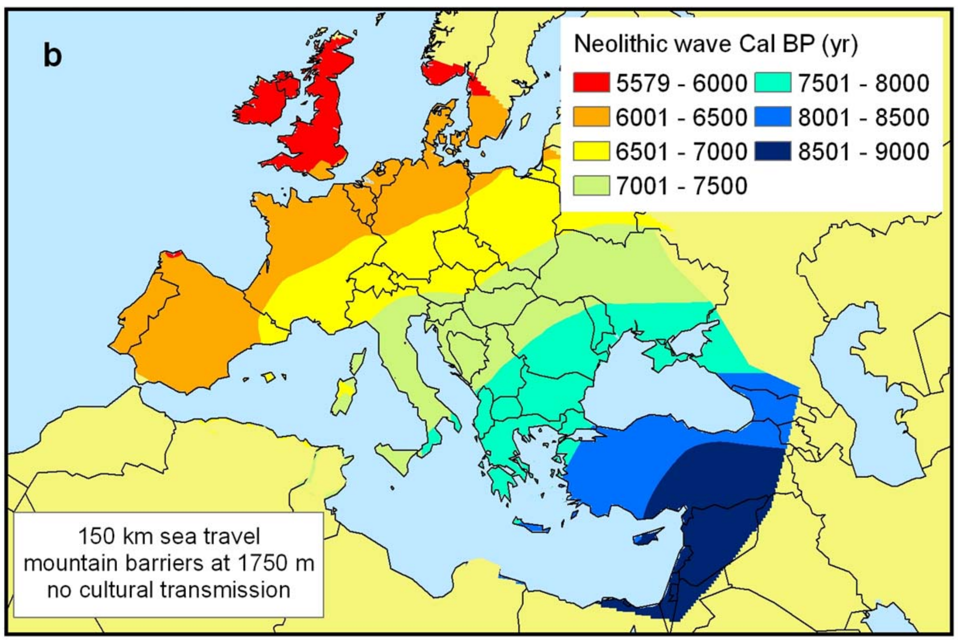




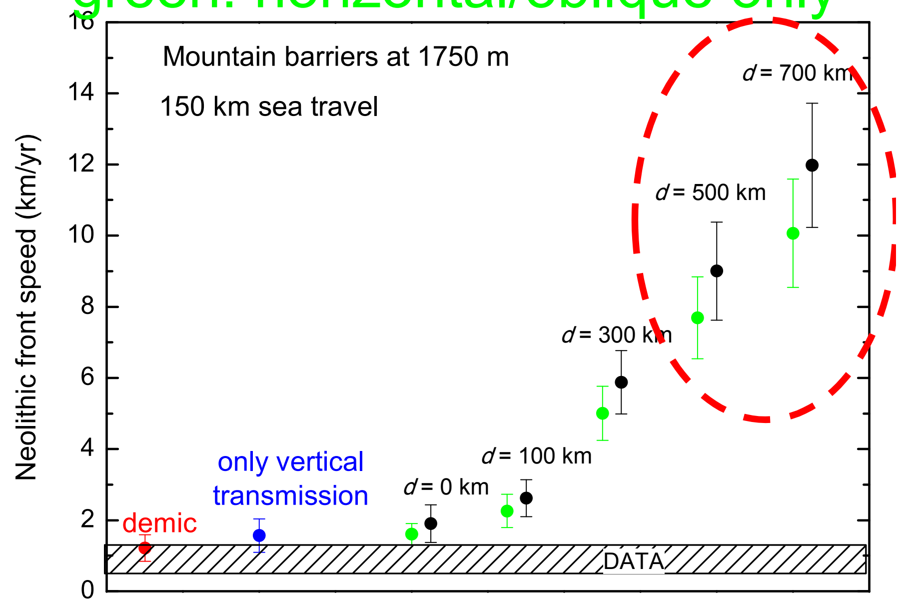
Recall the results with vertical transmission only:



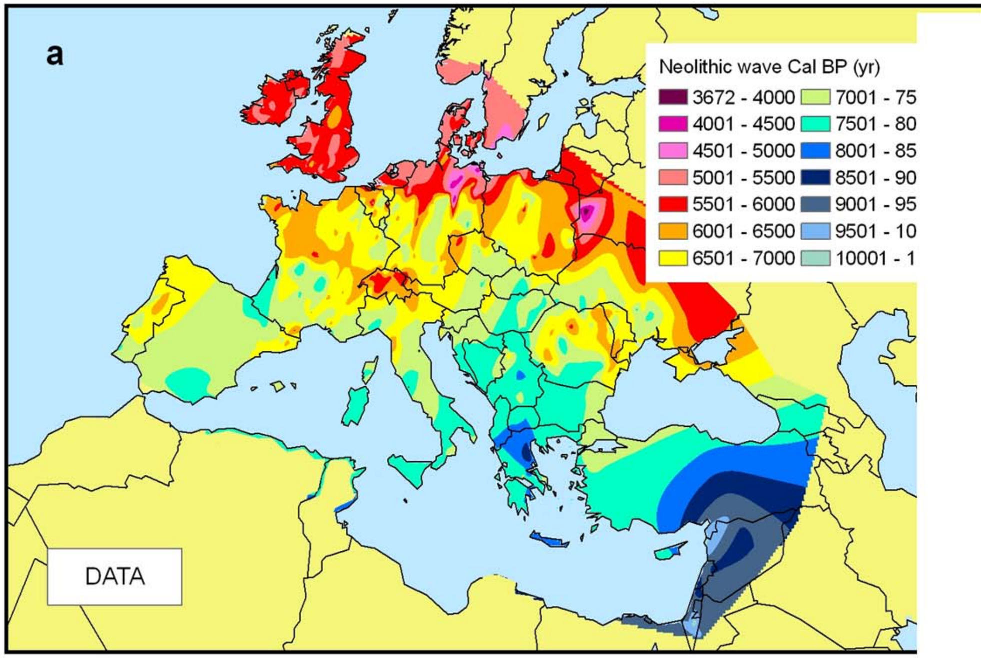


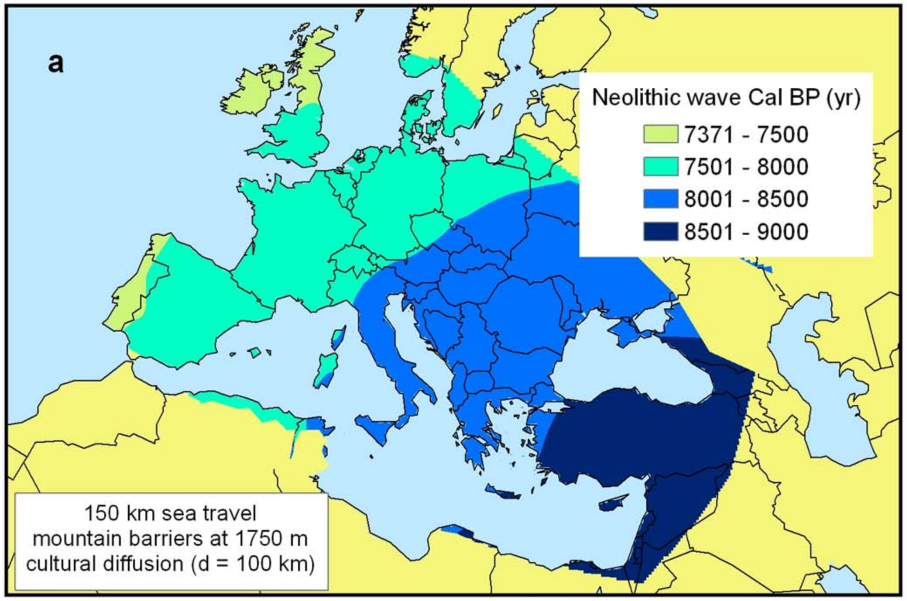


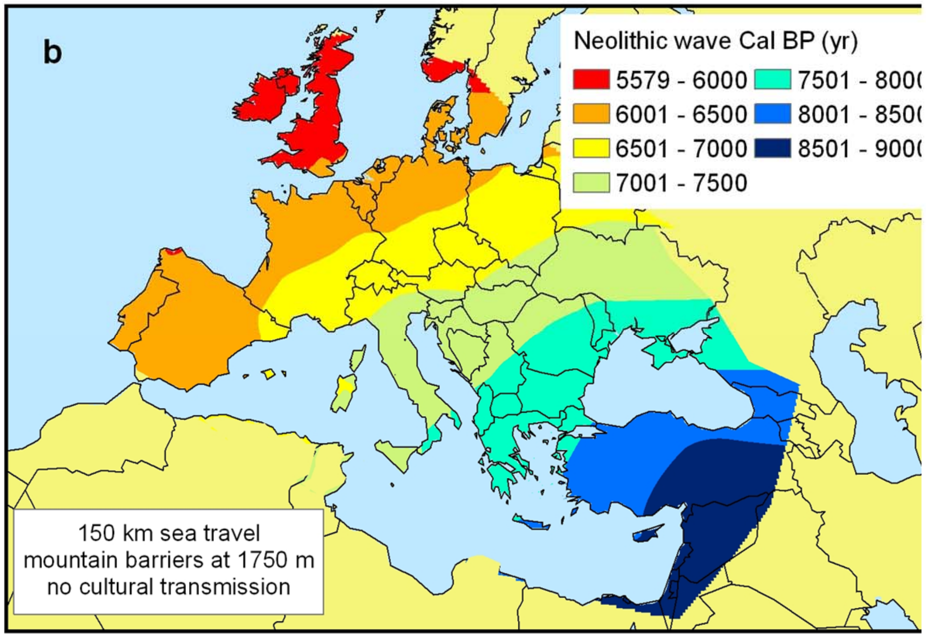
Bars in the figure below:
black: horizontal/oblique + vertical
<u>speed > 8 km/yr !!!</u>
green: horizontal/oblique only

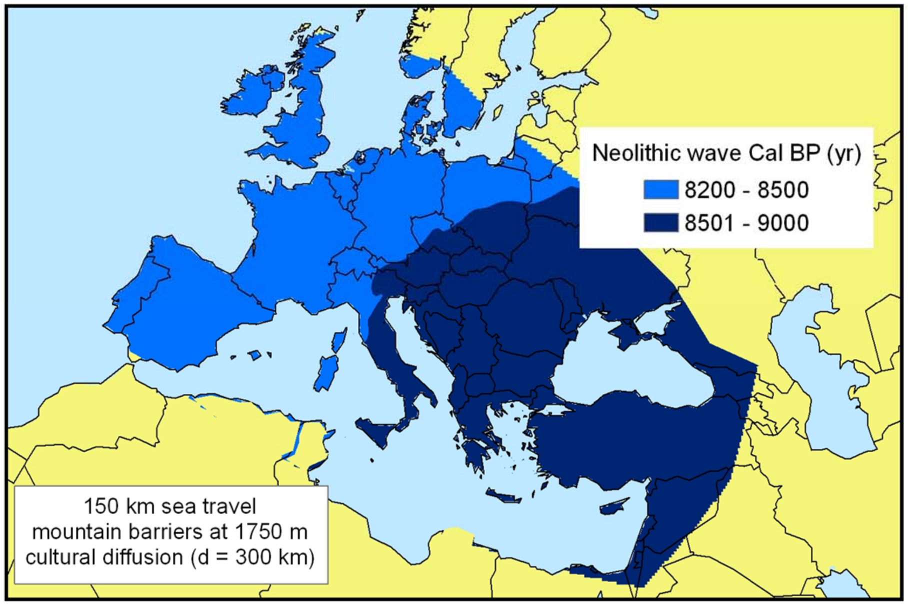


horizontal/oblique:





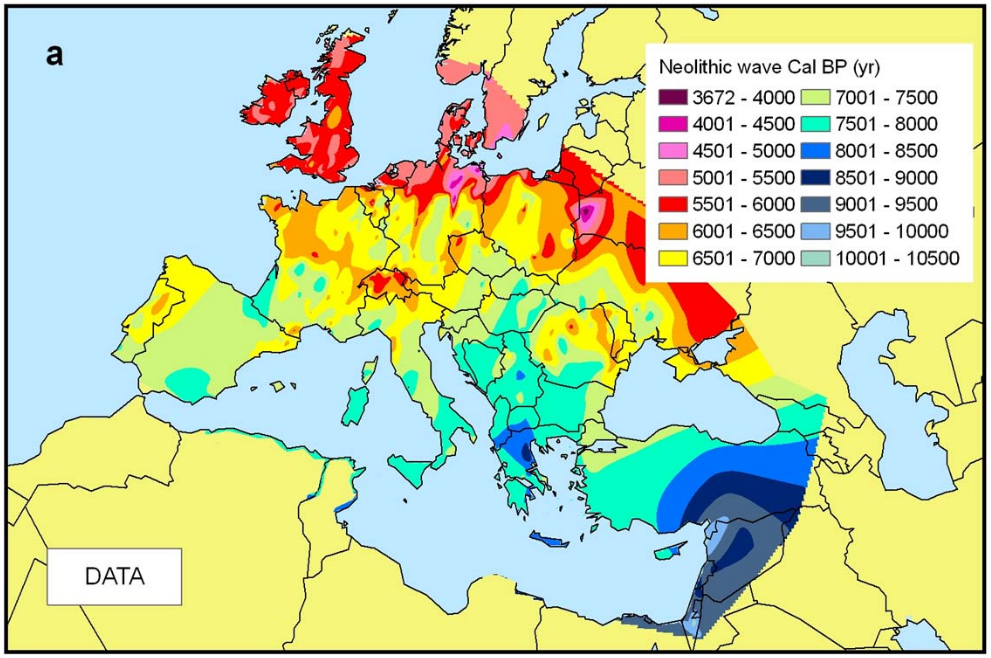




More refined model, including the distance dependency of horizontal transmision

distance range (km)	probability of visit
0-199	0.565
200-399	0.217
400-599	0.174
600-799	0.044

Data from Mulvaney, D. J. 'The chain of connection': the material evidence. In N. Peterson (ed.). *Tribes and boundaries in Australia* (Australian Institute of Aboriginal Studies, Canberra, 1976), pp. 72-94.



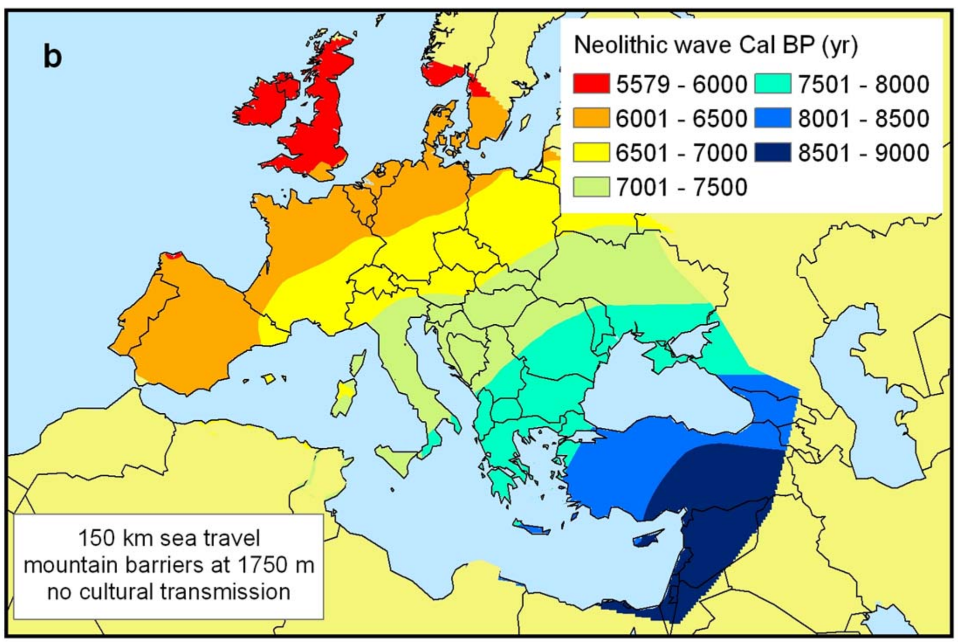
bars in the figure below:

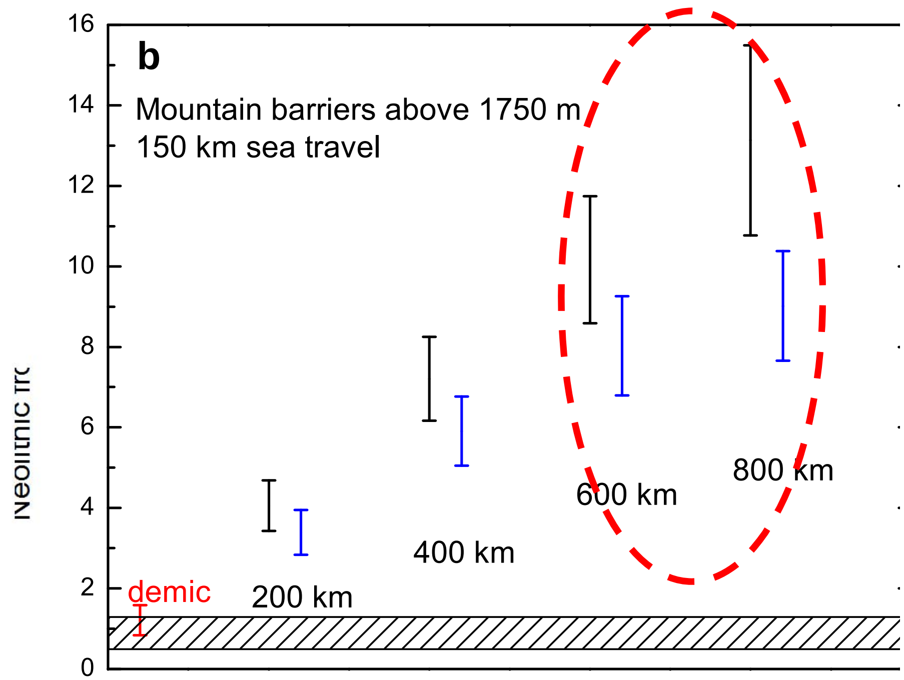
black: horizontal/oblique + vertical

<u>speed > 8 km/yr !!!</u>

blue: with distance dependency

<u>speed > 6 km/yr !!!</u>





More refined model, including the conformist effect of horizontal transmision

Model applied and discussed in many papers:

· Boyd & Richerson (1985) · Kandler & Steele (2009)

· Henrich (2001) $\rightarrow$ it explains the slow initial growth of innovation S-curves · etc.

$$\begin{cases} P_N(t+1) = P_N + \dfrac{P'_N P_P}{P'_N + P_P}\left(f + \alpha \left[2\dfrac{P'_N}{P'_N + P_P} - 1 \right] \right) \\ P_P(t+1) = P_P - \dfrac{P'_N P_P}{P'_N + P_P}\left(f + \alpha \left[2\dfrac{P'_N}{P'_N + P_P} - 1 \right] \right) \end{cases}$$

$$P'_N = P_N + P_N^{visit}$$

$\alpha = 0 \rightarrow$ previous model (unbiased transmission)

$u = P'_N / (P'_N + P_P) > 1/2 \rightarrow$ positively-biased

$u < 1/2 \rightarrow$ negatively-biased

Bound: $\alpha < f$ (otherwise (...)<0 for $u \approx 0$)

bars in the figure below:

black: horizontal/oblique + vertical

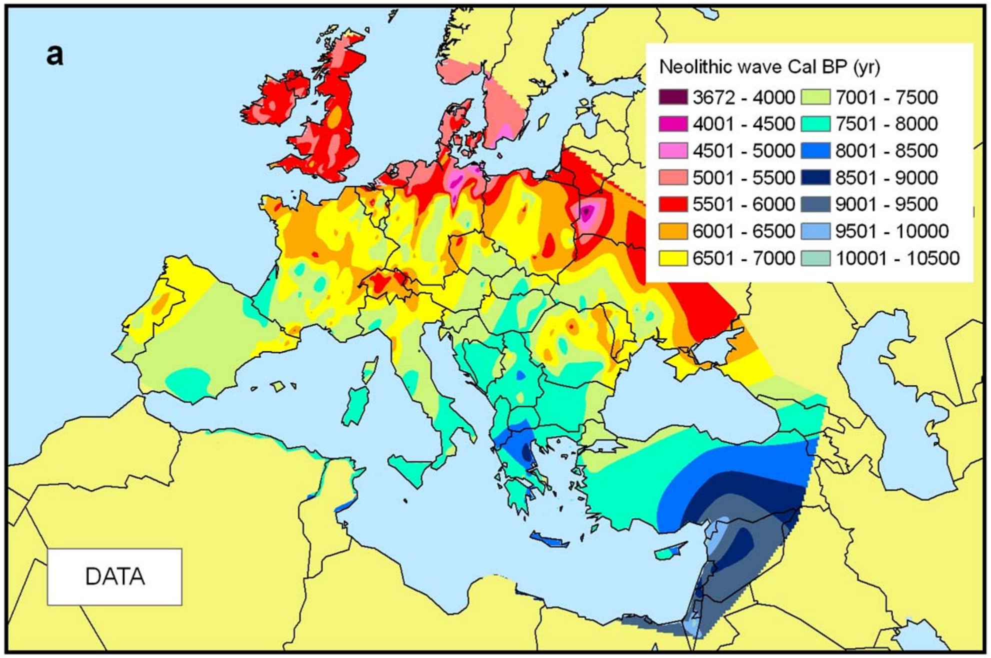
speed > 8 km/yr !!!

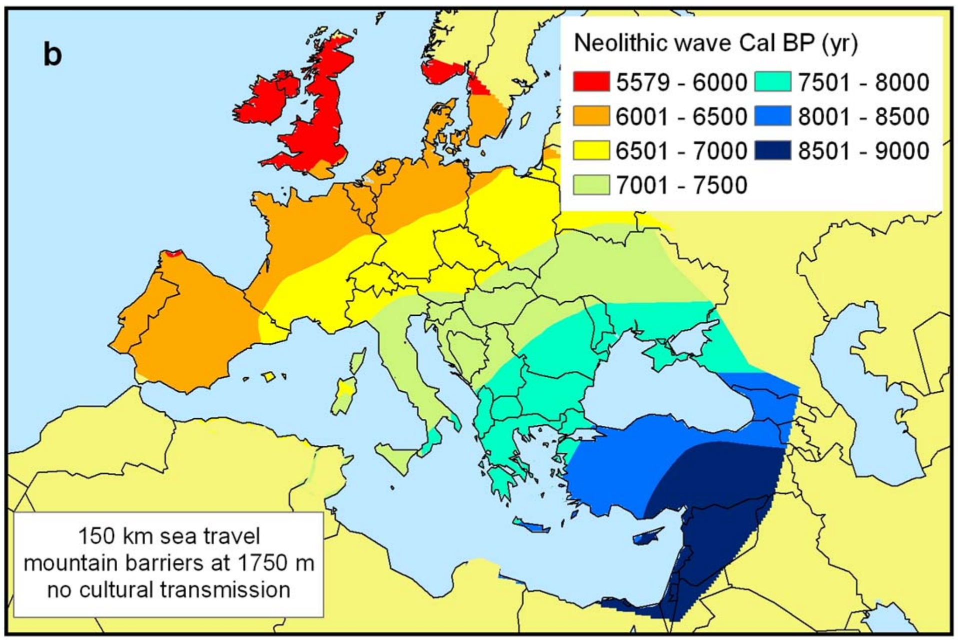
blue: with distance dependency

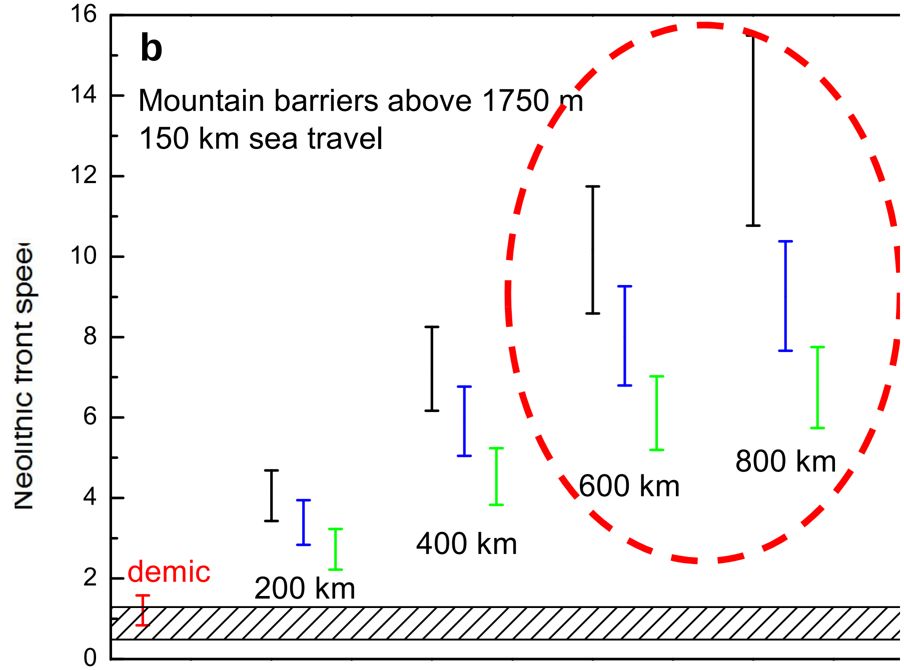
speed > 6 km/yr !!!

green: with conformist effect also

$(\alpha \approx f)$ **speed > 5 km/yr !!!**







Still more refined models...

1) Ecological boundaries (no farming above 52º latitude)
same results concerning the front speeds

2) Population movement dependent on local ecologies (diffusivity decreasing with latitude, as in Davison et al. 2006) same results concerning the front speeds

3) Hunter-gatherers moving domestic resources and knowledge $P'_N = P_N + P_N^{visit} + \beta P_P$ *β=fraction of visiting hunter-gatherers*

faster speeds → The conclusions do not change

Motivations

Archaeological data imply a rate of about 1 km/yr for the spread of farming accross Europe.

Demic diffusion predicts about 1 km/yr.

How many km/yr does cultural diffusion predict?

Conclusions

VERTICAL cultural diffusion: about 1 km/yr

HORIZONTAL/OBLIQUE cultural diffusion: >5km/yr

VERTICAL diffusion is compatible with the archaeological data (and with genetic clines!)

HORIZONTAL/OBLIQUE diffusion is not!