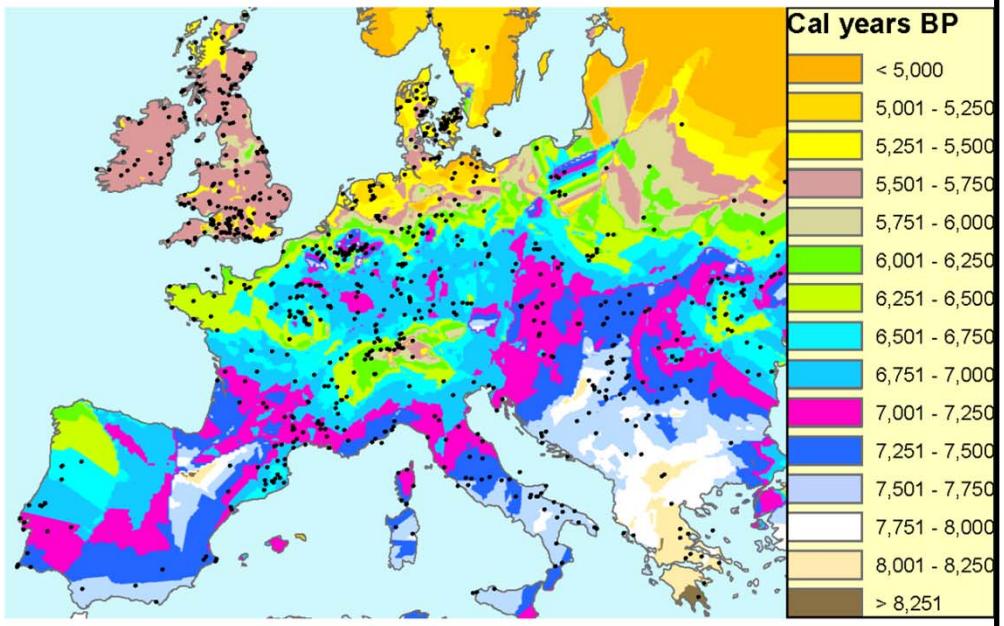
Modelling Neolithic transitions at continental and regional scales

Joaquim Fort
Universitat de Girona (Catalonia, Spain)

Simulating the Neolithic workshop
Institute of Archaeology
University College London
February 19th, 2015

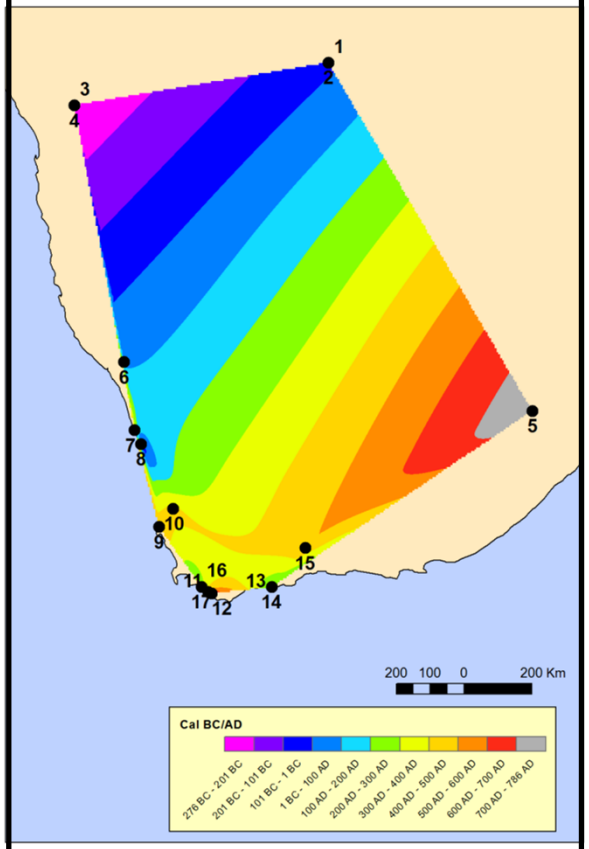
Neolithic transitions

Europe



hunting-gathering →<u>farming</u>
and stockbreeding

Southern Africa



hunting-gathering
→ <u>herding</u>

Models of Neolithic transitions

- Demic diffusion = spread of farming populations = dispersal + net reproduction
- Cultural diffusion = spread of ideas = acculturation of hunter-gatherers
- Demic-cultural models

Acculturation

Cavalli-Sforza & Feldman (*book* 1979)
Boyd & Richerson (*book* 1985)
Fort (*PNAS* 2012)

Population numbers after *(P')* and before *(P)* cultural transmission (during 1 generation):

$$\begin{cases} \text{farmers } (F): \quad P_F' = P_F + f\dfrac{P_F P_H}{P_F + \gamma P_H} \\ \text{hunter} - \text{gatherers } (H): \quad P_H' = P_H - f\dfrac{P_F P_H}{P_F + \gamma P_H} \end{cases}$$

f = intensity of cultural transmission

γ = preference of *H*s to copy *F*s rather than *H*s (if $\gamma < 1$)

Lotka-Volterra equations

$$P_F' = P_F + \eta P_F P_H \quad (1)$$
$$P_H' = P_H - \eta P_F P_H \quad (2)$$

They have 2 problems:

1) They are not derived from cultural transmission theory

2) Number of HGs converted per farmer according to Eq. (1): $\frac{P_F' - P_F}{P_F} \to \infty$! No maximum!

if $P_H \to \infty$

Cavalli-Sforza & Feldman (*book* 1979)
Fort (*PNAS* 2012)

$$\begin{cases} P_F' = P_F + f\dfrac{P_F P_H}{P_F + \gamma P_H} \approx P_F + C\,P_F \\ P_H' = P_H - f\dfrac{P_F P_H}{P_F + \gamma P_H} \approx P_H - C\,P_F \end{cases}$$

$C = \frac{f}{\gamma}$

if $P_H \gg P_F$:

$\frac{P_F' - P_F}{P_F} = C$ is the number of *H*s converted by farmer

$\frac{P_F' - P_F}{P_F}$ is not ∞, in contrast to Lotka-Volterra eqs.

The front speed does not depend on f and γ separately, but only on the number of HGs converted by farmer, $C = \frac{f}{\gamma}$.

Demic-cultural models

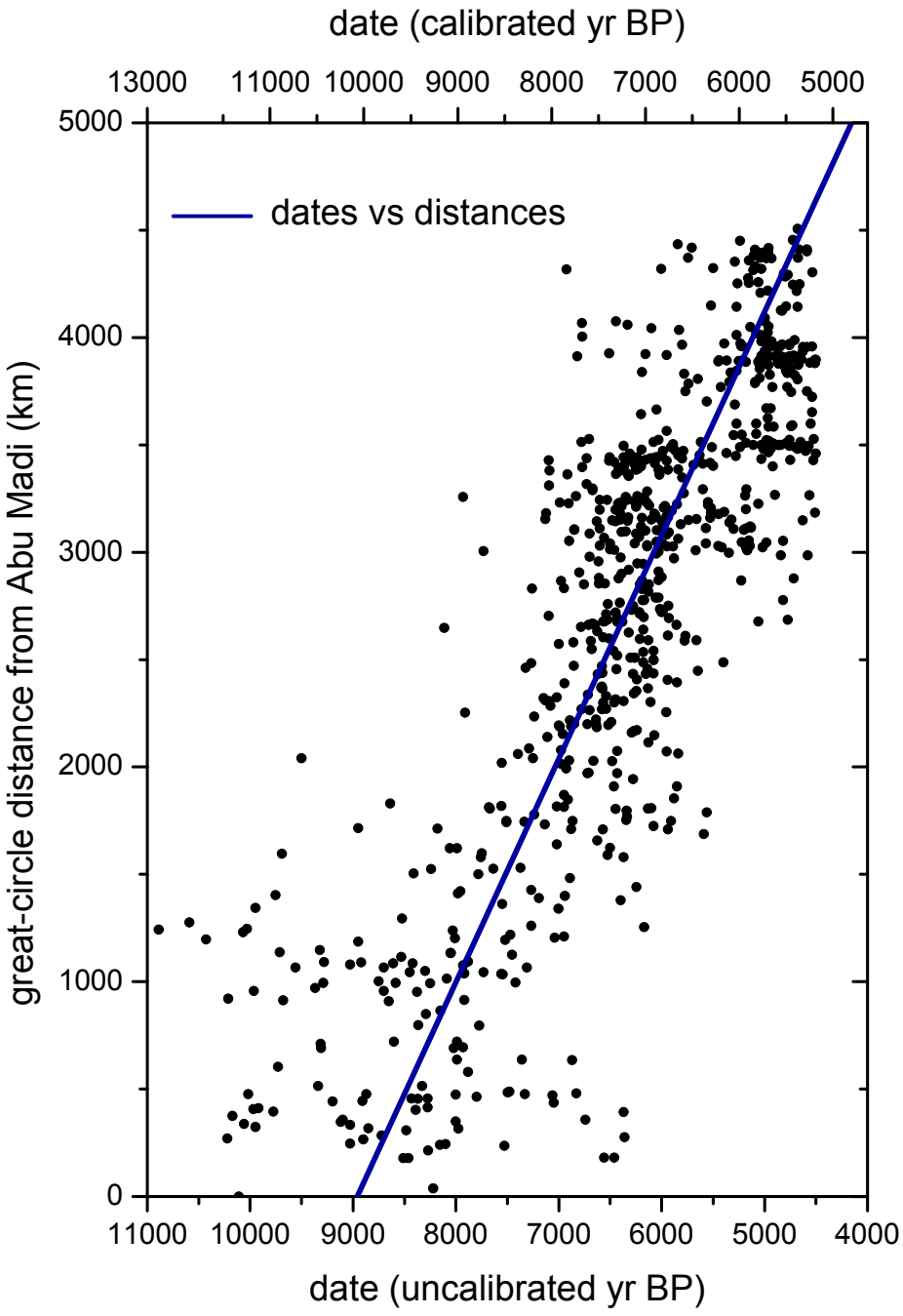
Fort (*PNAS* 2012)

Steps:

1. reproduction (logistic)
2. cultural transmission (acculturation)
3. dispersal (distance kernel)

The order of events does not change the speed

This cycle is repeated many times (once per generation)



Up to now we have discussed models.

What is the observed speed?

0.9-1.3 km/yr

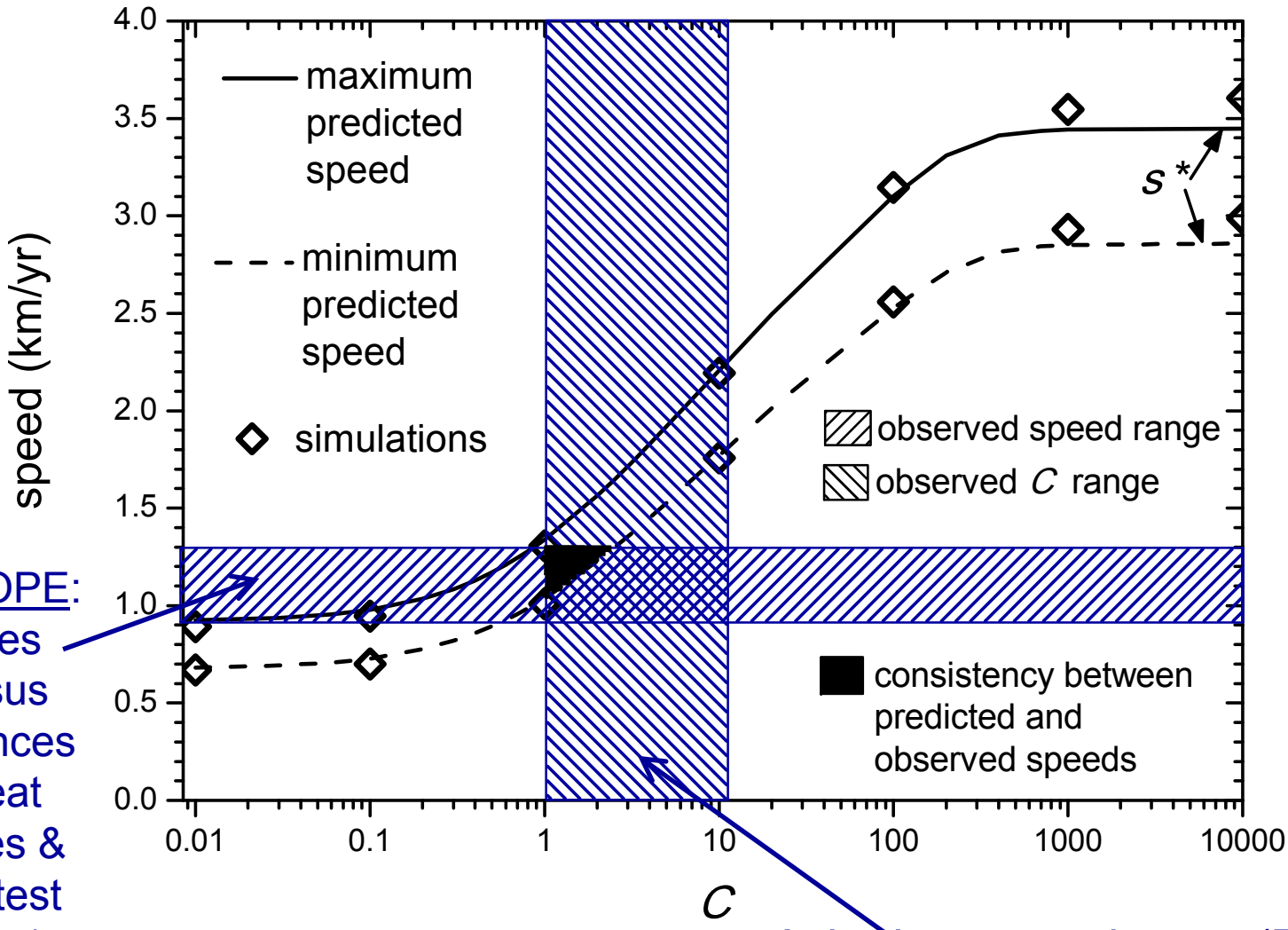
735 sites in Europe & Near East

r = 0.83 (highest-r origins, great circles & shortest paths)

Pinhasi, Fort & Ammerman,

PLoS Biol. (2005)

Effect of acculturation intensity *C* on the front speed in Europe



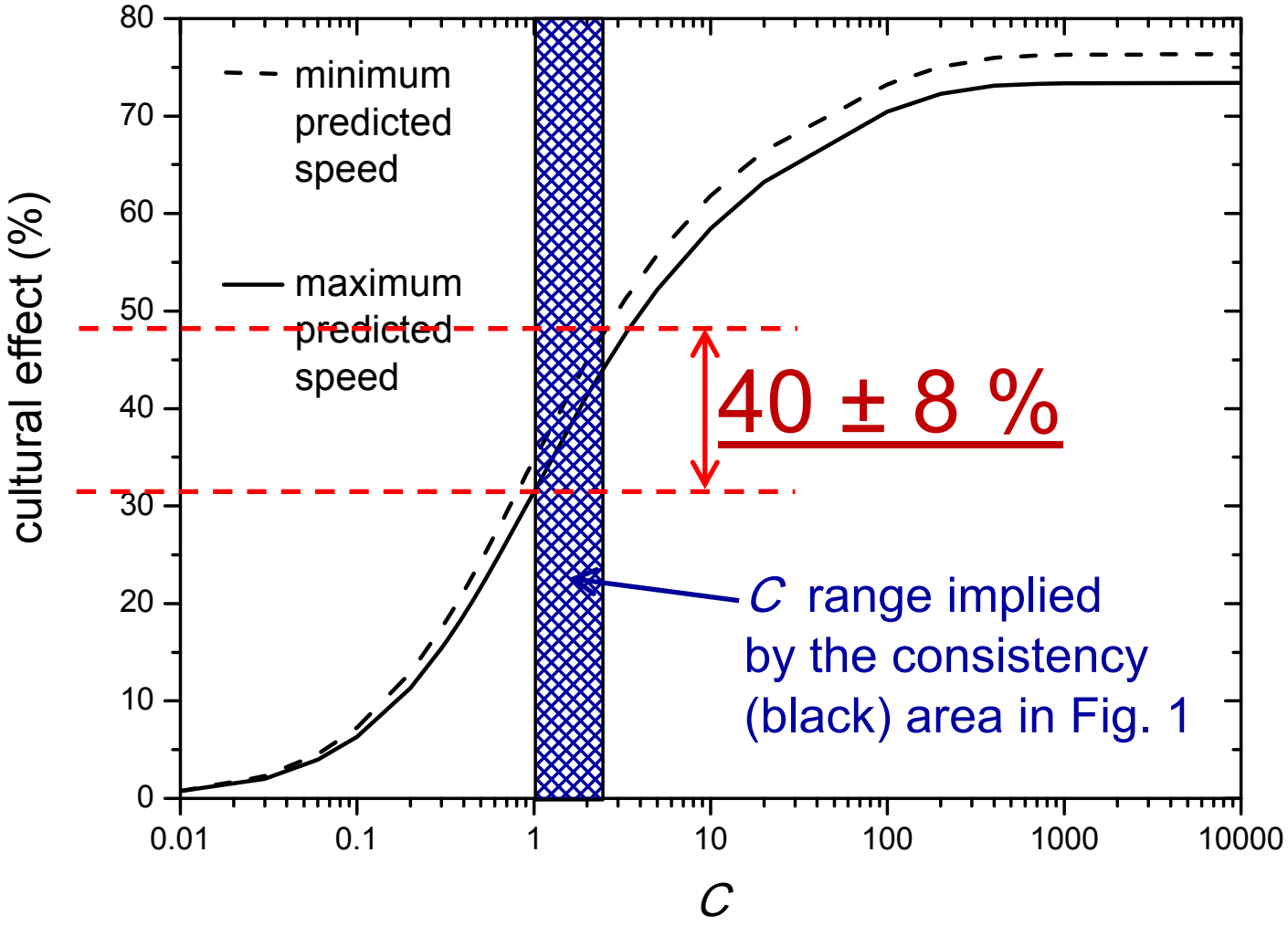
EUROPE: Dates versus distances (great circles & shortest paths)

Fort, *PNAS* (2012)

Ache hunter-gatherers (Paraguay)

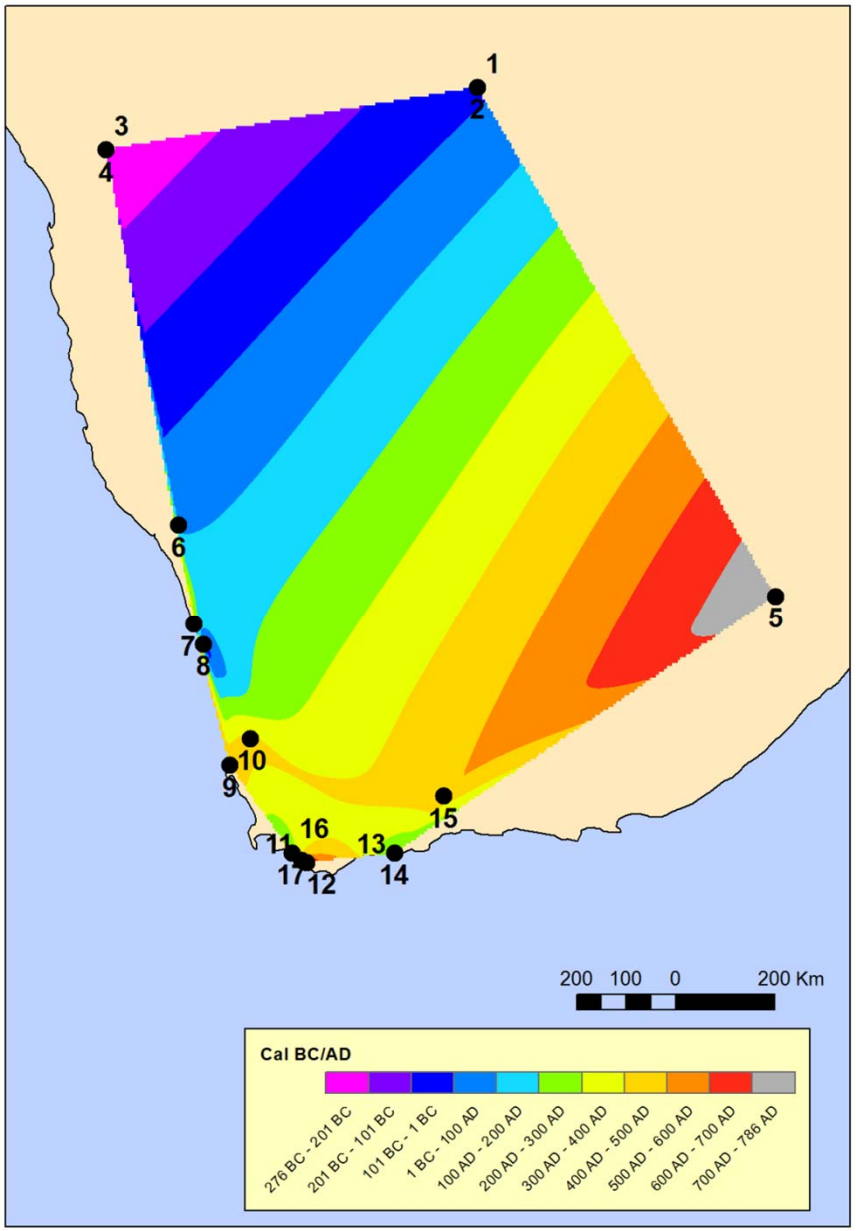
Effect of cultural diffusion in Europe

Effect (%) = (speed – demic speed) /speed · 100



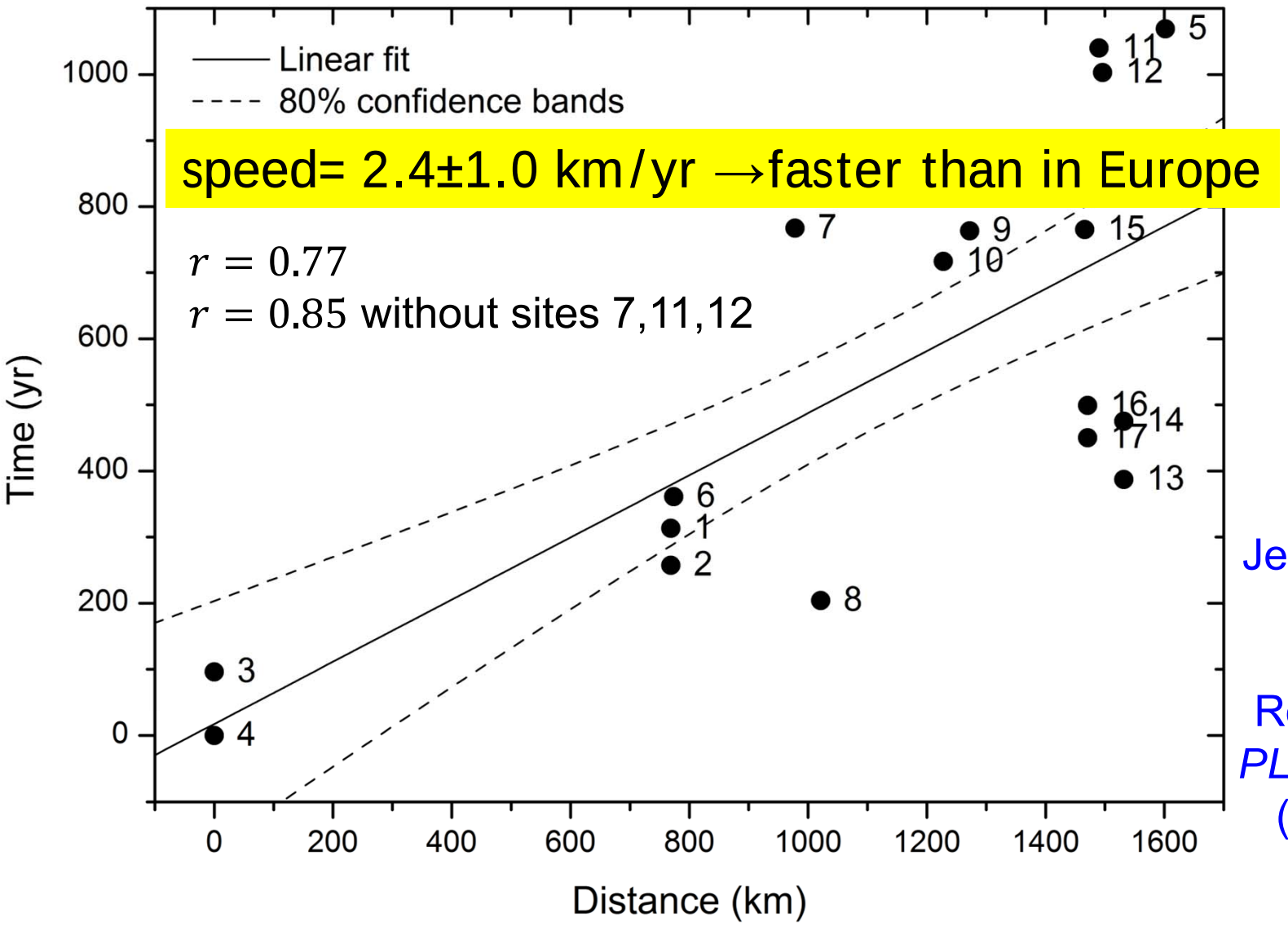
Fort, *PNAS* (2012)

The Neolithic transition in southern Africa



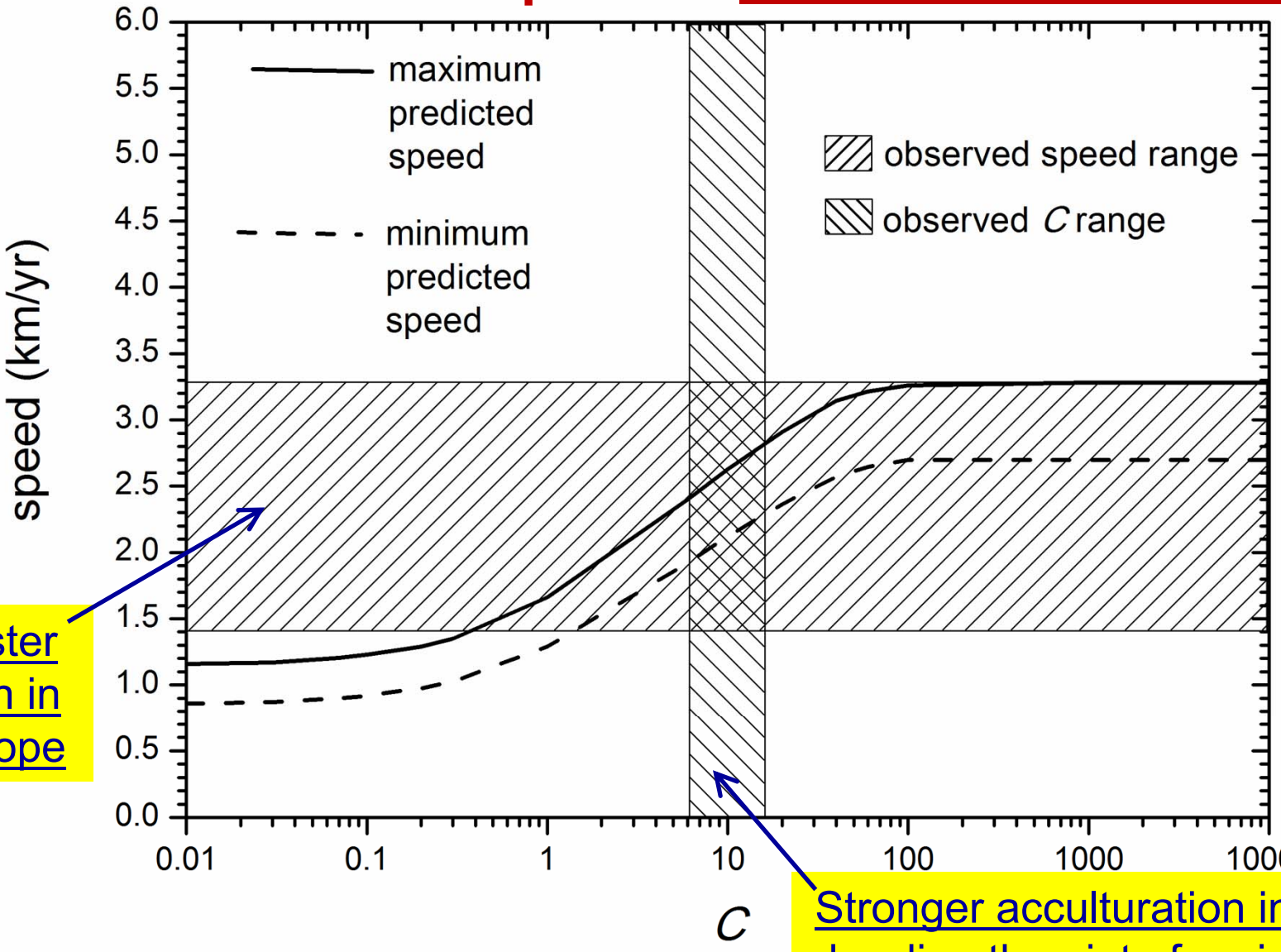
Jerardino, Fort, Isern, Rondelli, *PLoS One* (2014)

The Neolithic transition in southern Africa



Jerardino, Fort, Isern, Rondelli, *PLoS One* (2014)

Effect of acculturation intensity *C* on the front speed in southern Africa



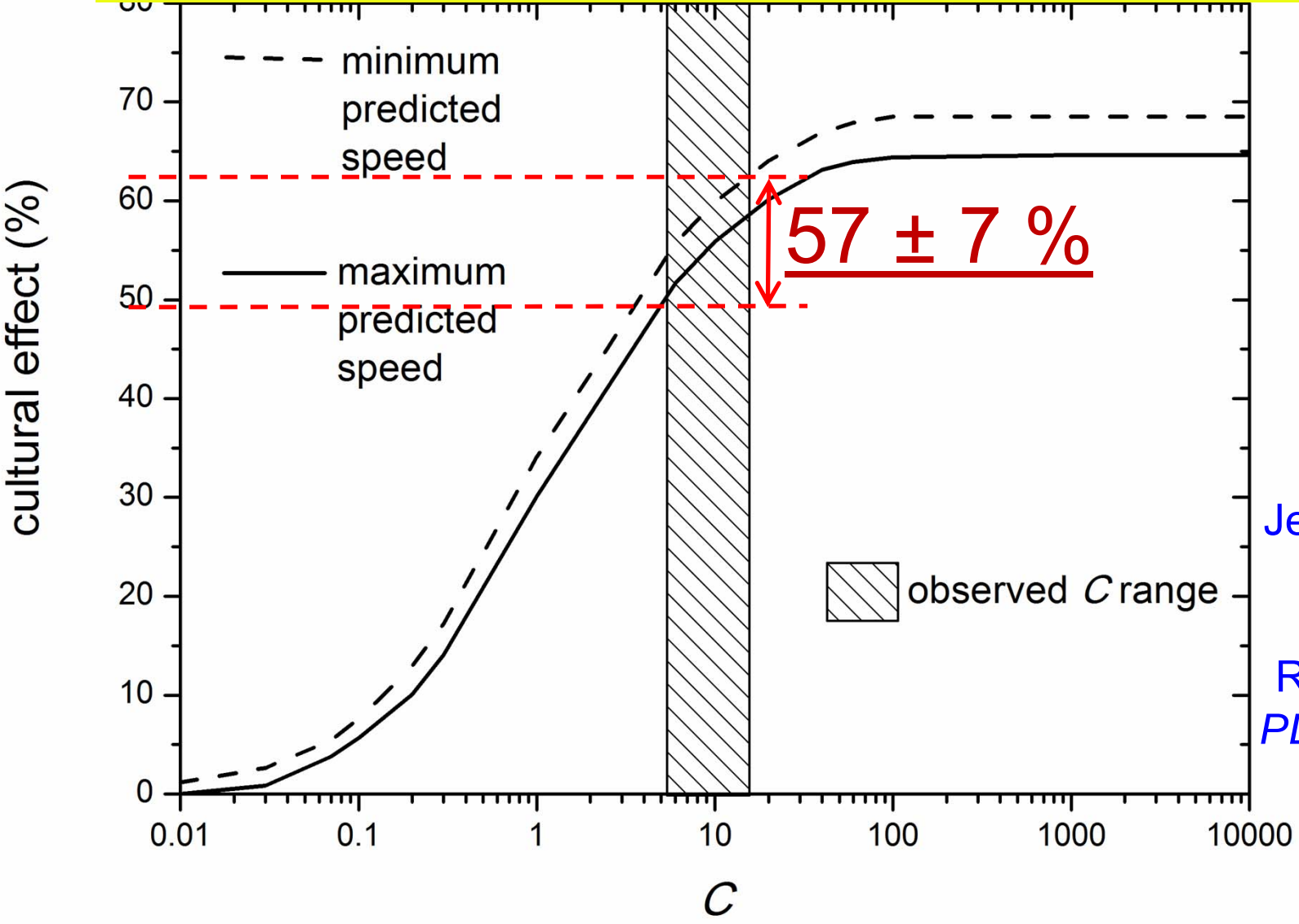
Faster than in Europe

Jerardino, Fort, Isern, Rondelli, *PLoS One* (2014)

Stronger acculturation into herding than into farming

Effect of cultural diffusion in southern Africa

Effect (%) = (speed – demic speed) /speed · 100



Jerardino, Fort, Isern, Rondelli, *PLoS One* (2014)

Neolithic transitions

- Europe: 1.1±0.2 km/yr

- Southern Africa (Khoikhoi): 2.4±1.0 km/yr

  Jerardino, Fort, Isern & Rondelli, Plos One 2014

- Southwest Asia: 0.7±0.1 km/yr

  Gangal, Sarson & Shukurov, Plos One 2014

- Africa (Bantu): ?

  data: Russell, Silva & Steele, Plos One 2014

- Other ??

Local features in Europe

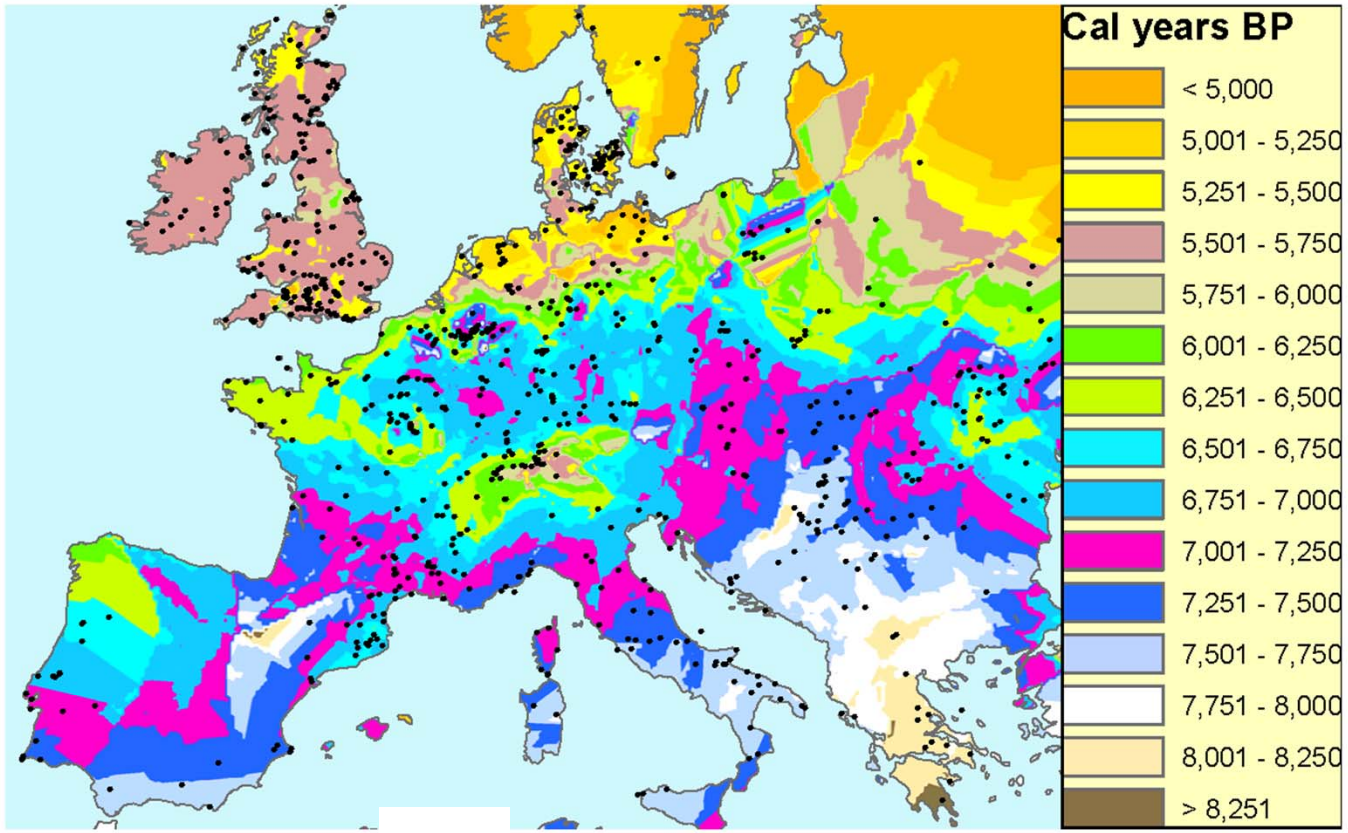
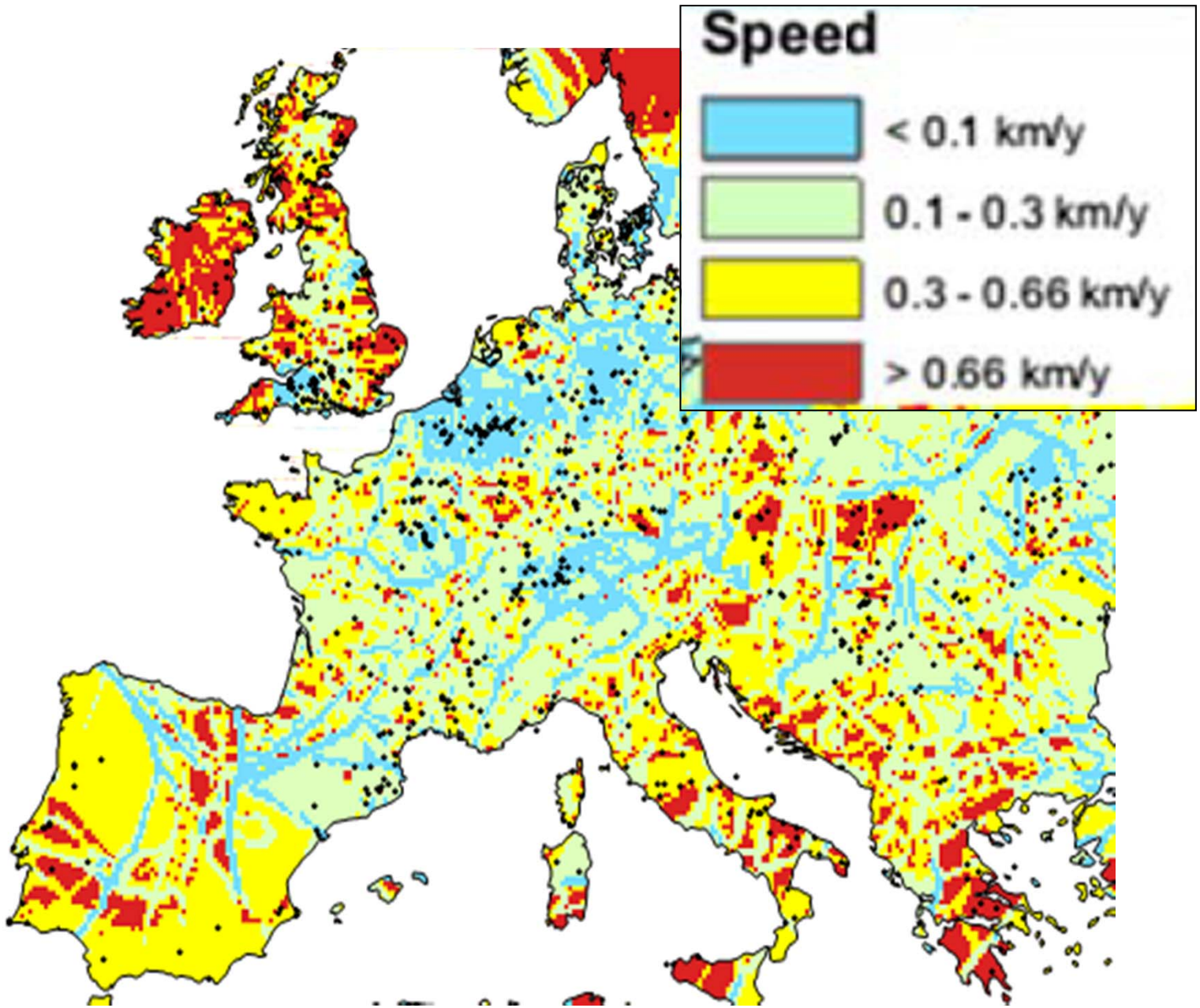
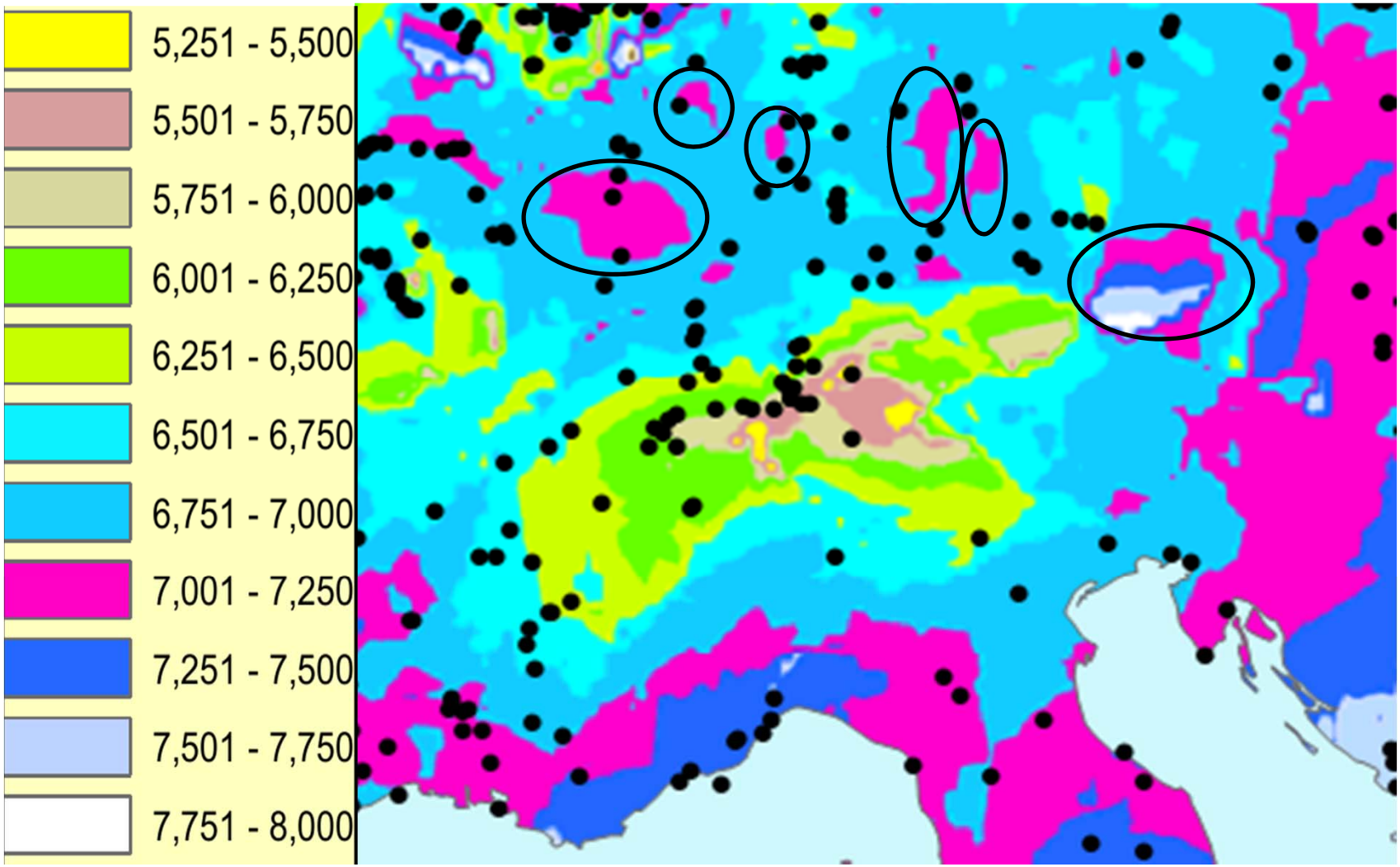


Fig. 1

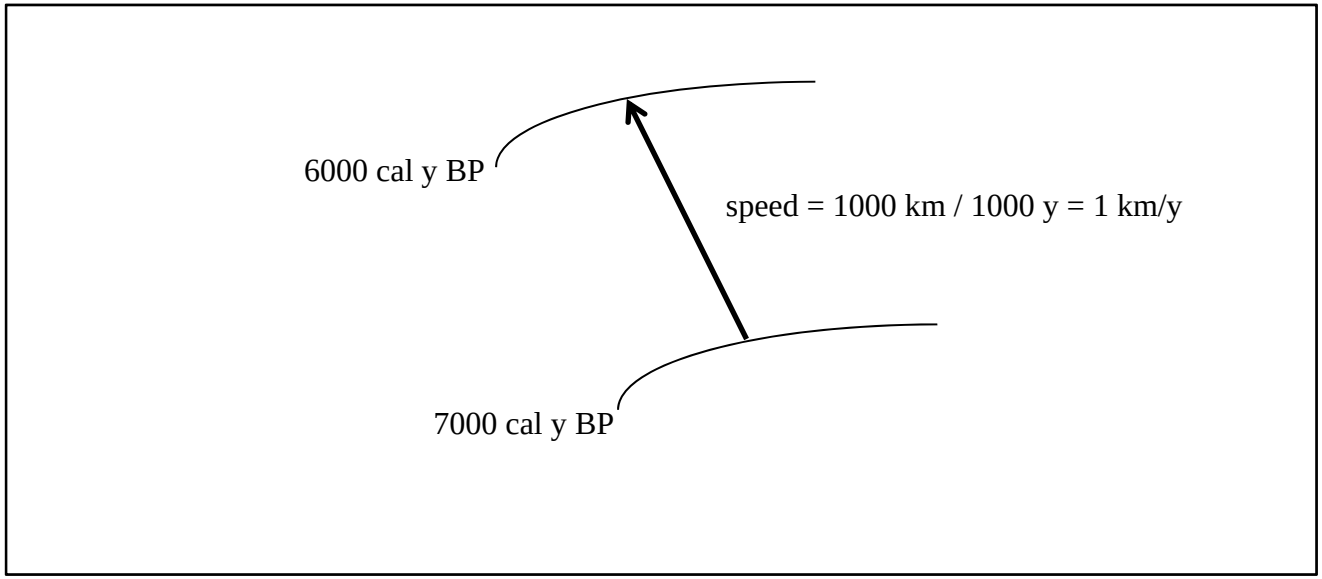
Fort, *J. R. Soc. Interface* (2015)

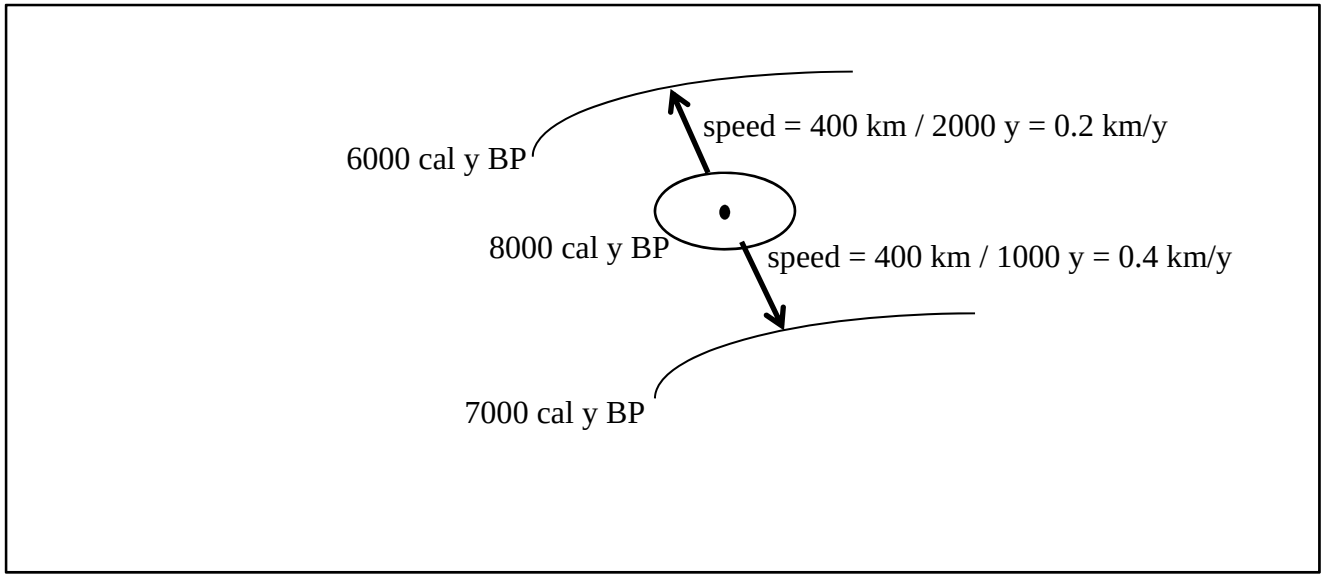


Fort,
J. R. Soc. Interface
(2015)

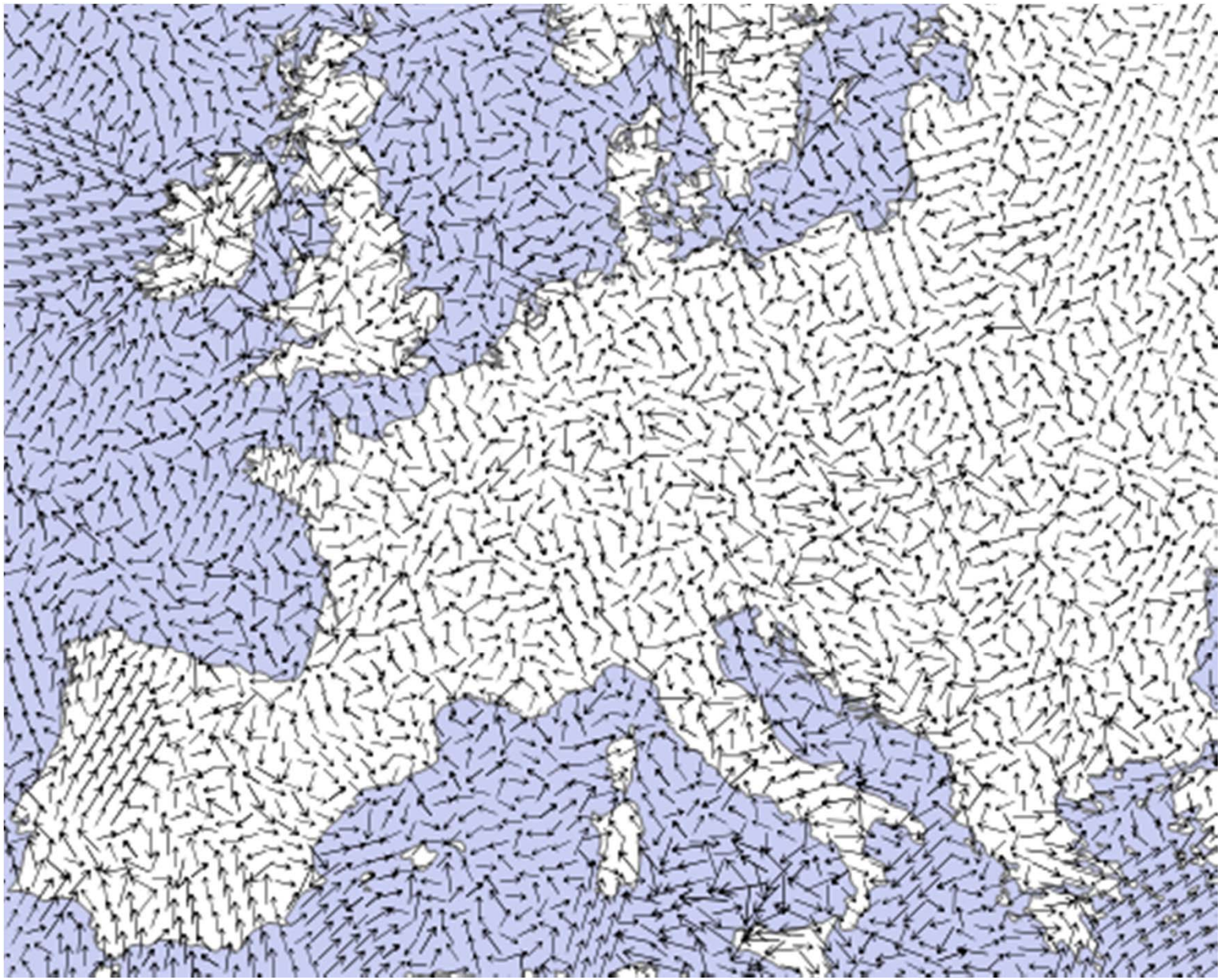


Fort, *J. R. Soc. Interface* (2015)

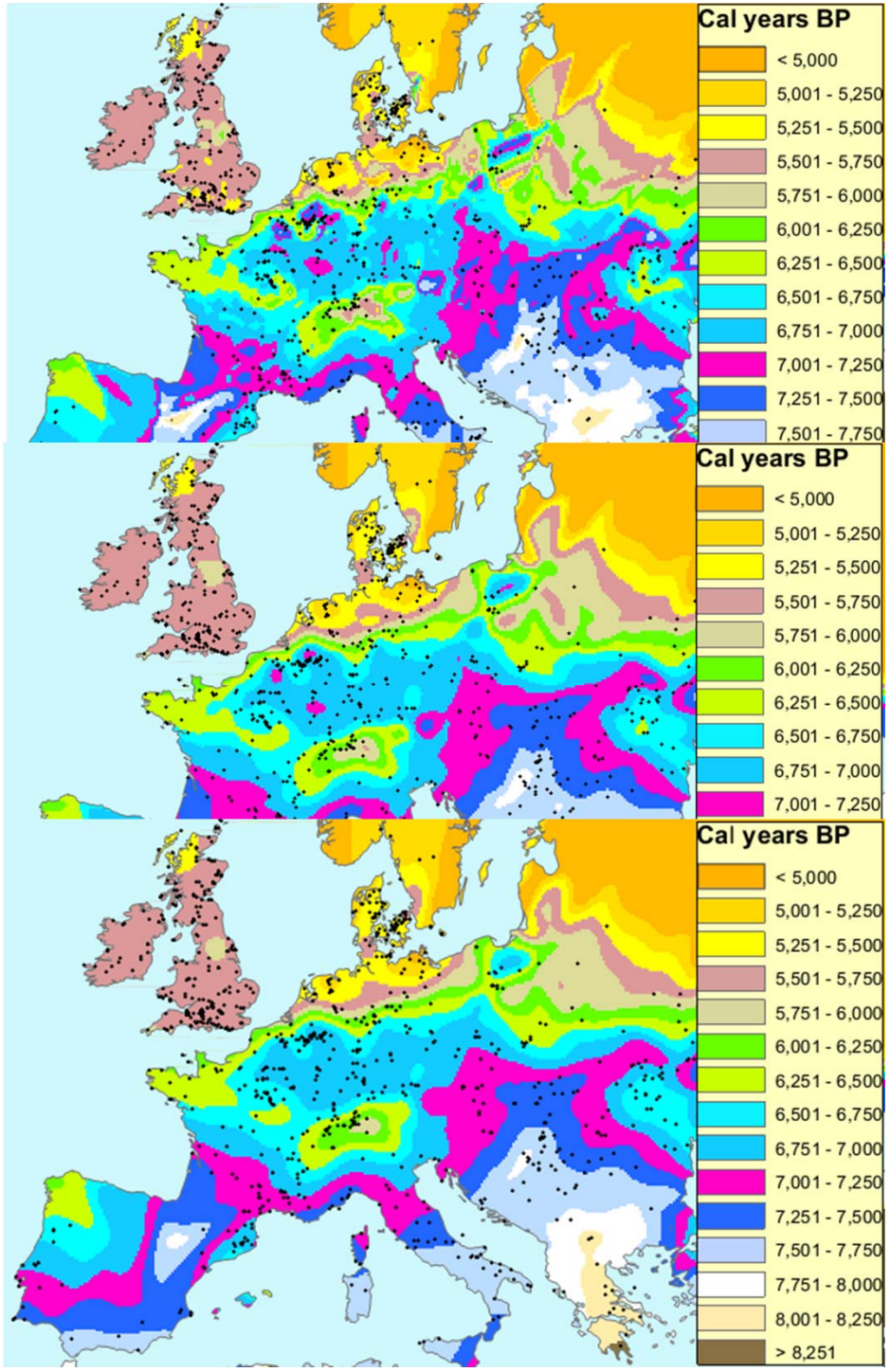




Fort,
J. R. Soc. Interface
(2015)



Fort,
J. R. Soc. Interface
(2015)

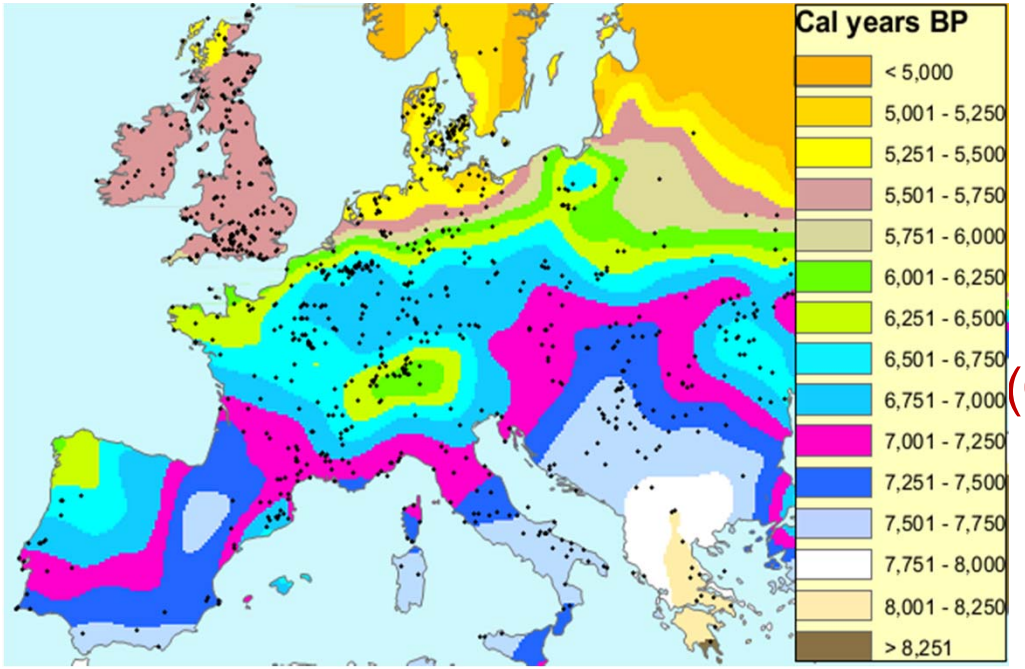


smoothing
1 time

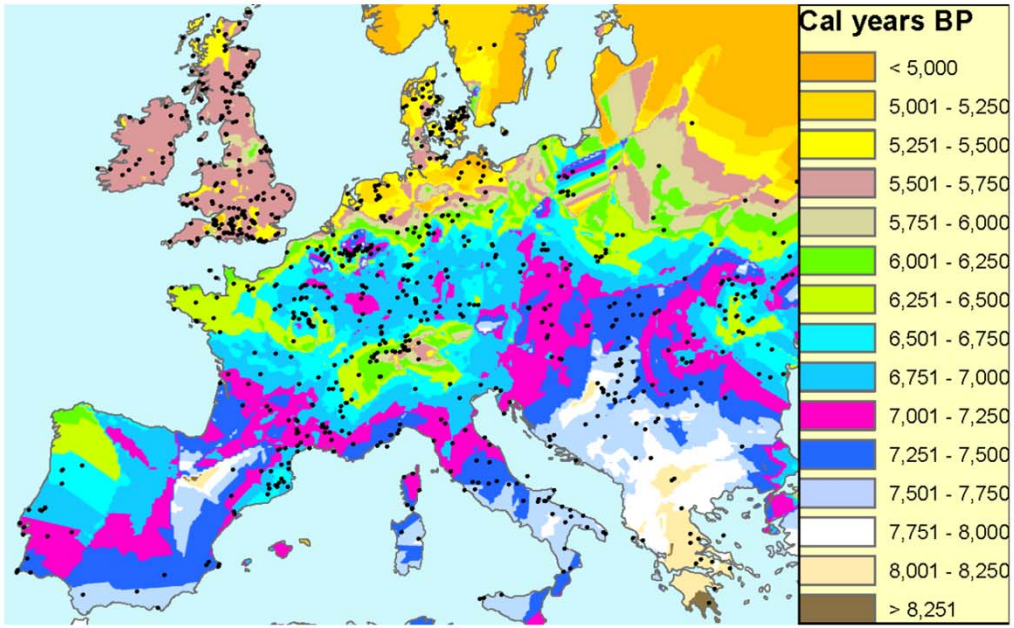
10 times

20 times

Fort,
J. R. Soc. Interface
(2015)



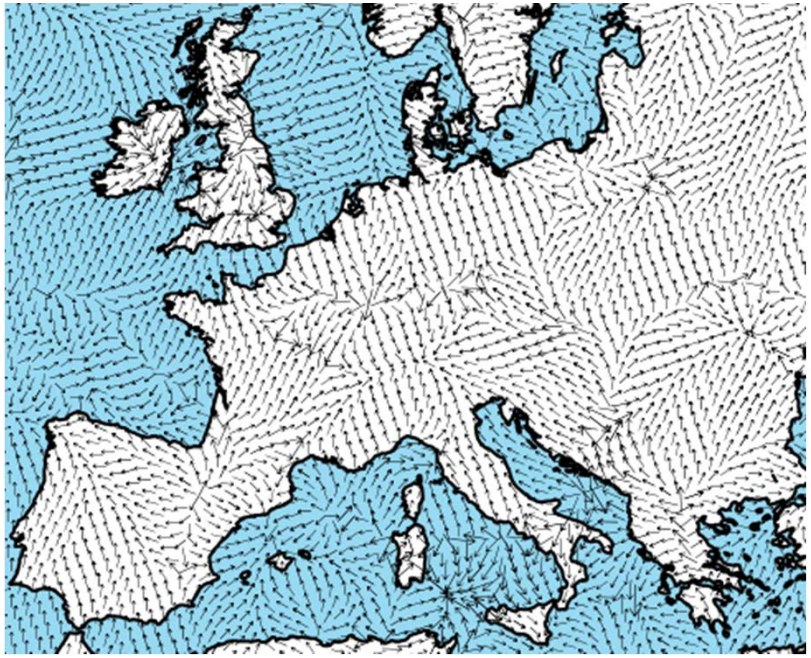
smoothing
40 times
(60 times→ same results)



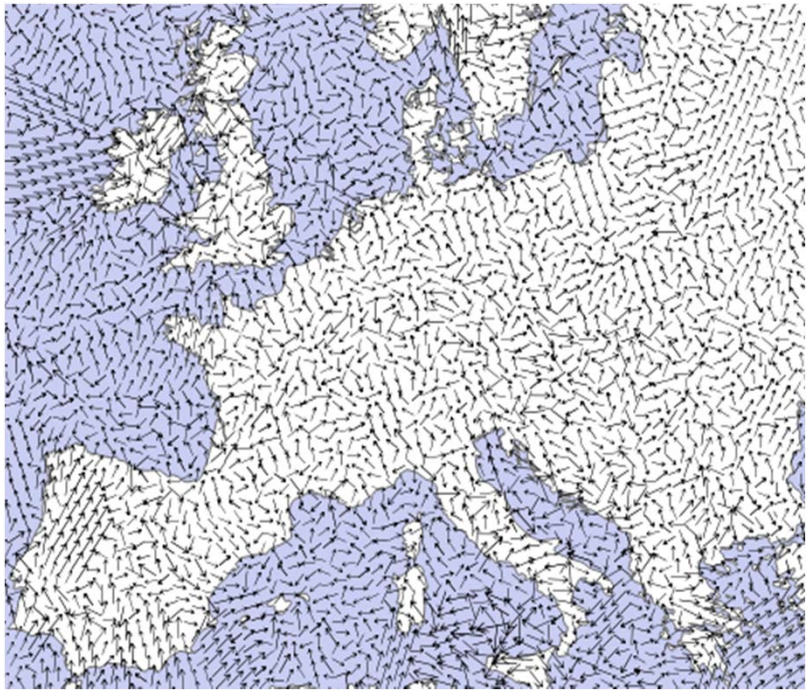
No
smoothing

Fort,
J. R. Soc. Interface
(2015)

Fig. 1

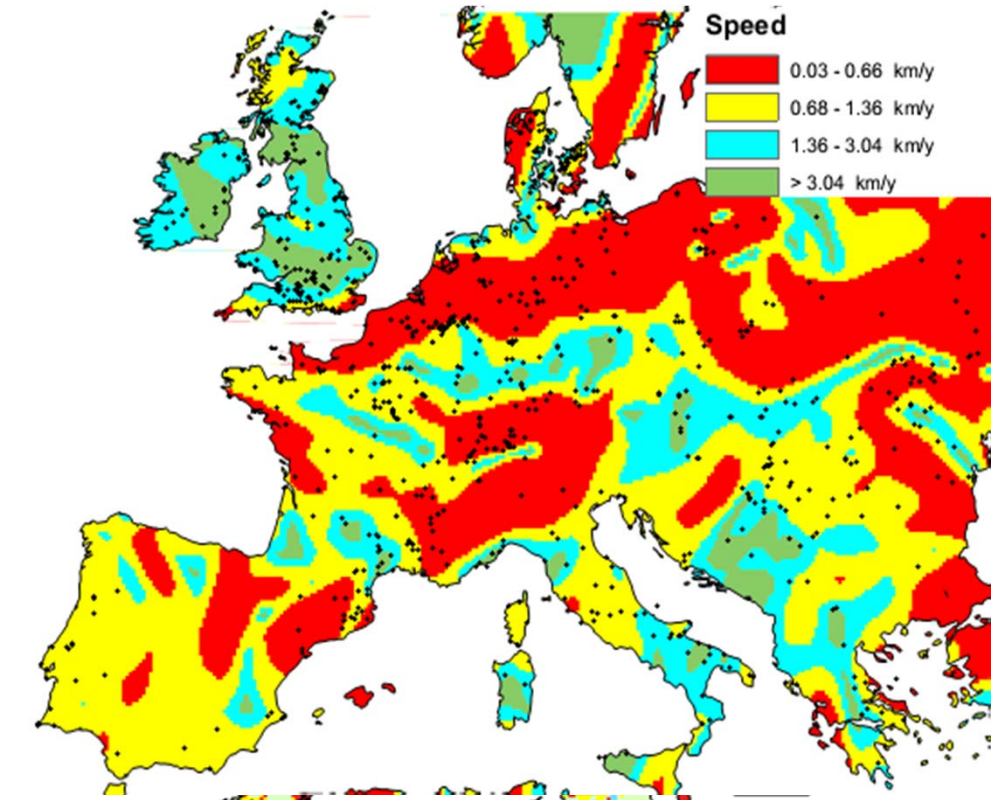


smoothing
40 times
(60 times→ same results)

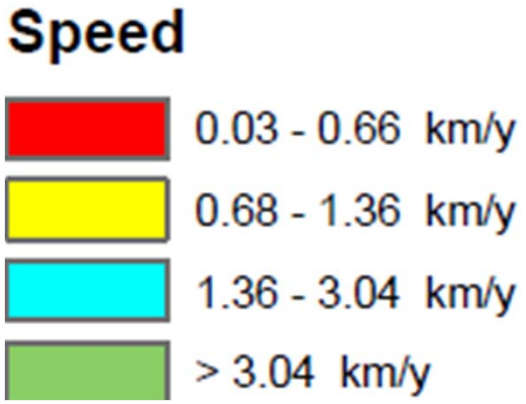


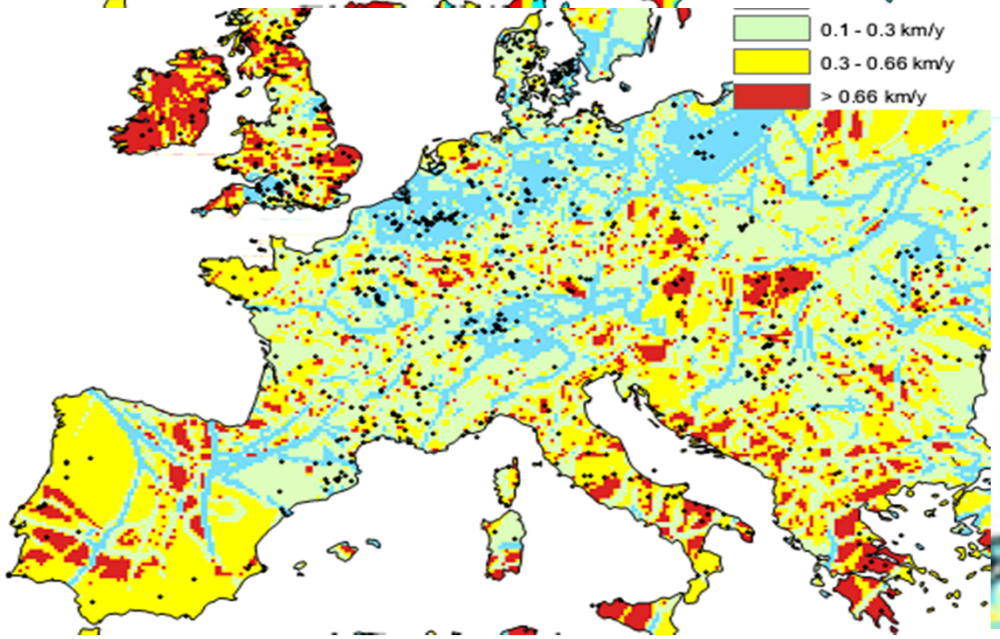
No smoothing

Fort,
J. R. Soc. Interface
(2015)

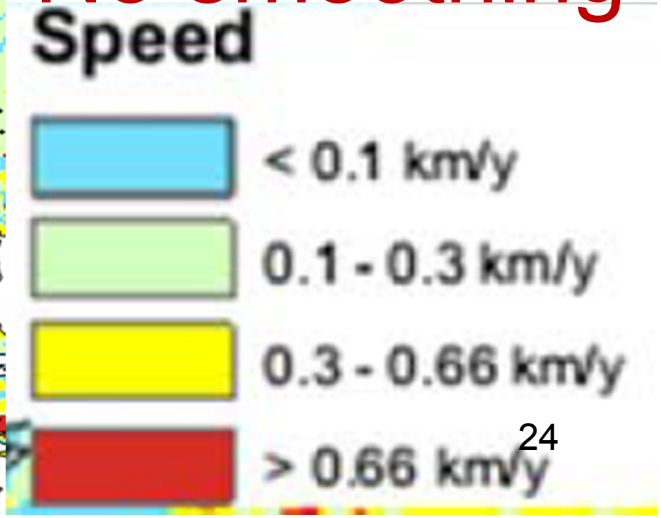


smoothing
40 times



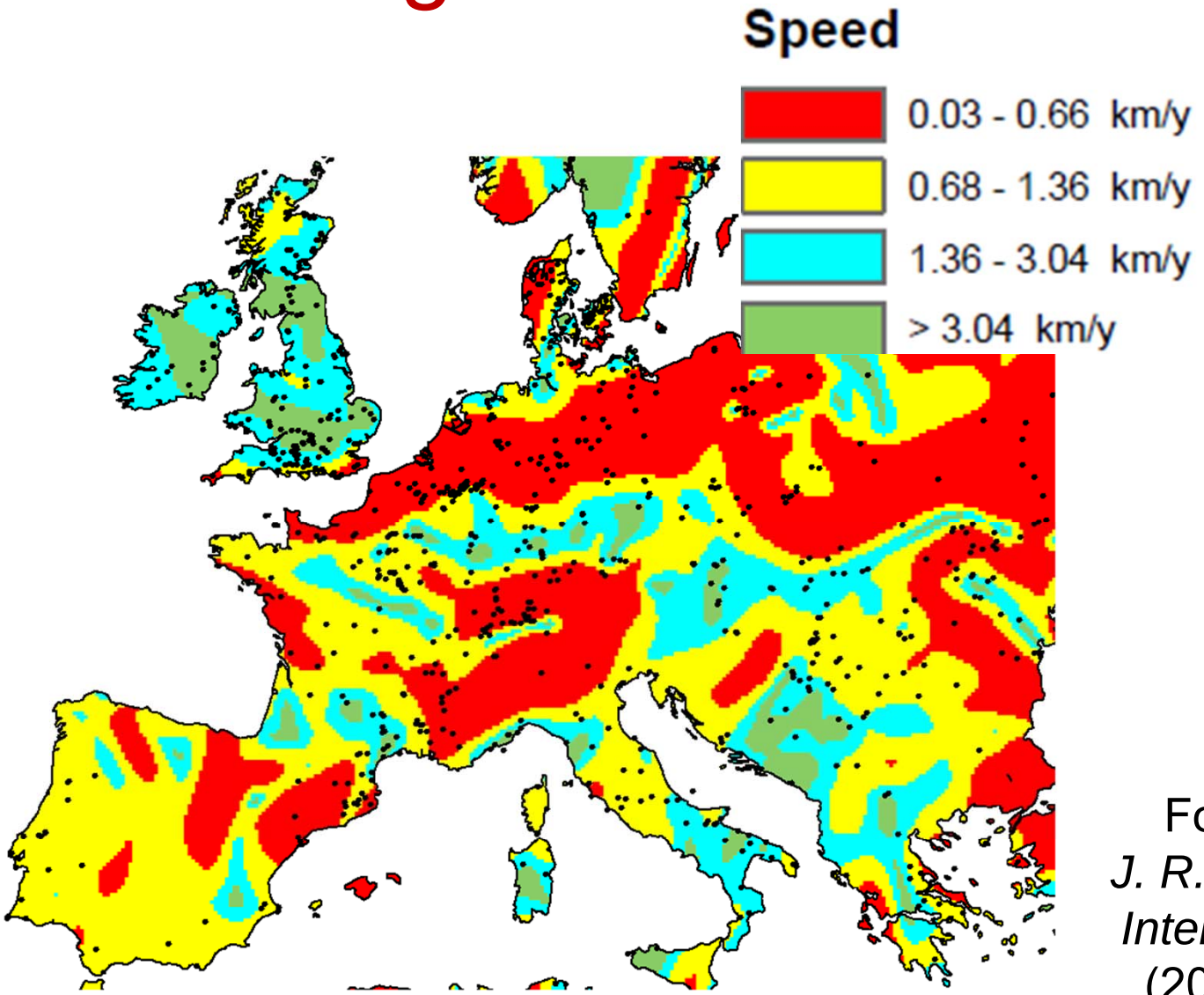


No smoothing



Fort,
J. R. Soc. Interface
(2015)

Smoothing 40 times



Fort, *J. R. Soc. Interface* (2015)

Fig. 3

Comparison to other authors (1)

Some authors have computed regional speeds:

· Henderson, Baggaley, Shukurov et al., *Antiquity* (2014) do not compute local speeds (because they focus on coastlines).

· Bocquet-Appel, Naji, Vander Linden and Kozlowski, *J. Arch. Sci.* (2012) do not compute local speeds (because they focus on cultures).

· But their results and ours seem to agree qualitatively.

Comparison to other authors (2)

Henderson, Baggaley, Shukurov et al., *Antiquity* (2014):

· They do not compute local speeds (because they focus on coastlines).

· They fit a uniform background speed (constant in all of Europe) plus additional speeds due to rivers/coasts (a constant for each river/sea).

· They also note the fastness of the spread between the slow (red) regions in Northern Europe and the Alps (Danube-Rhine).

Comparison to other authors (3)

British Islands:

· Very fast speeds, as noted by Bocquet-Appel et al. (2012) by a different approach (namely, using the average of the two earliest dates in each square of 35 km x 35 km).

· Dual entrance into England, from the South and from the North, which has been previously observed in a set of maps of the spatial density of calibrated dates separated 100 years (Collard, Edinborough, Shennan & Thomas, *J. Arch. Sci.* 2010).

Comparison to other authors (4)

Alps, Northern Europe and the Black Sea (red regions):

· Our speeds cannot be directly compared to Bocquet-Appel et al. (2012), because they did not compute speeds locally but over wide regions (8 regions covering Europe). **See the next slide.**

· However, their results and ours seem consistent. E.g., the slowness in the three red regions is seen qualitatively in their isochrone map. **See the next slides.**

Comparison to other authors (5)

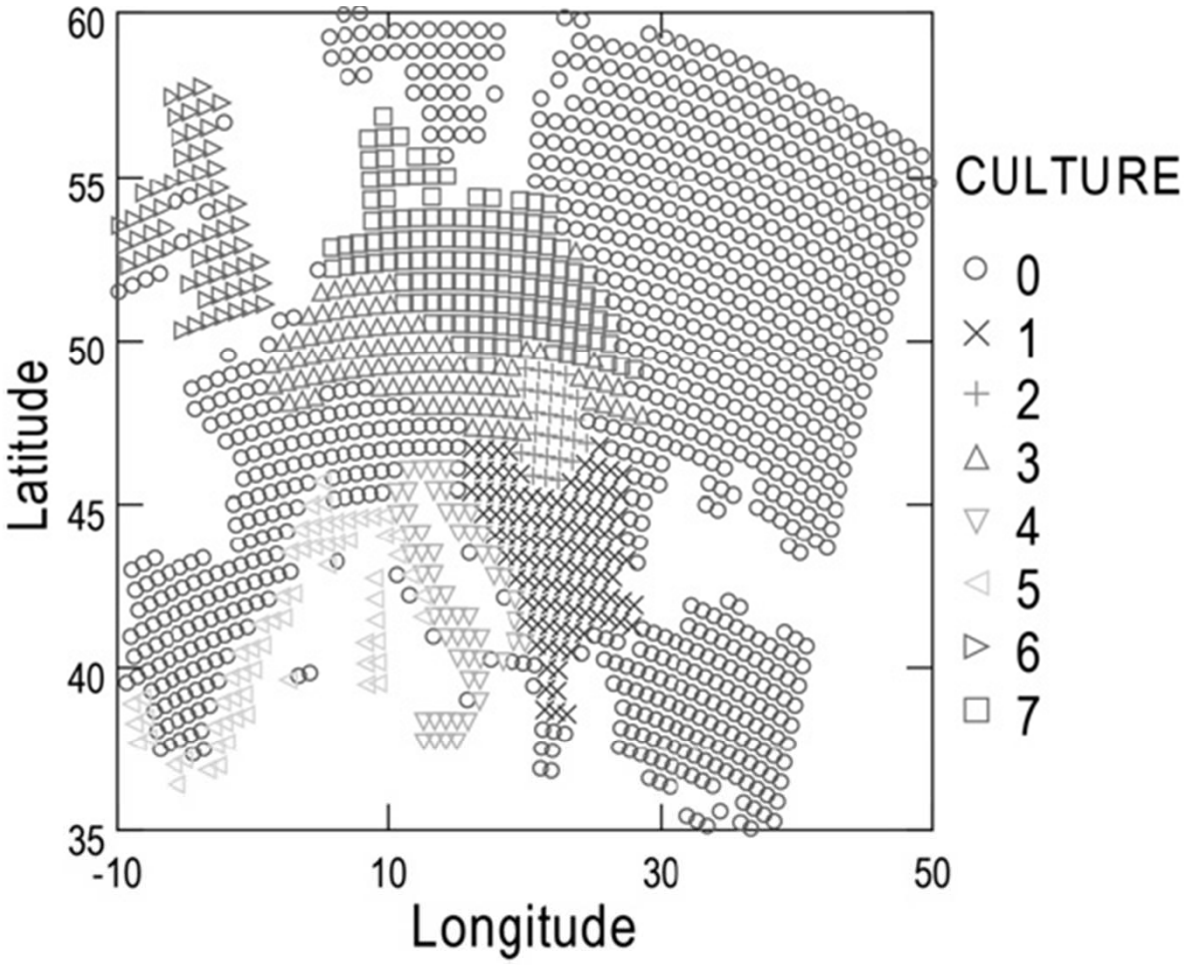
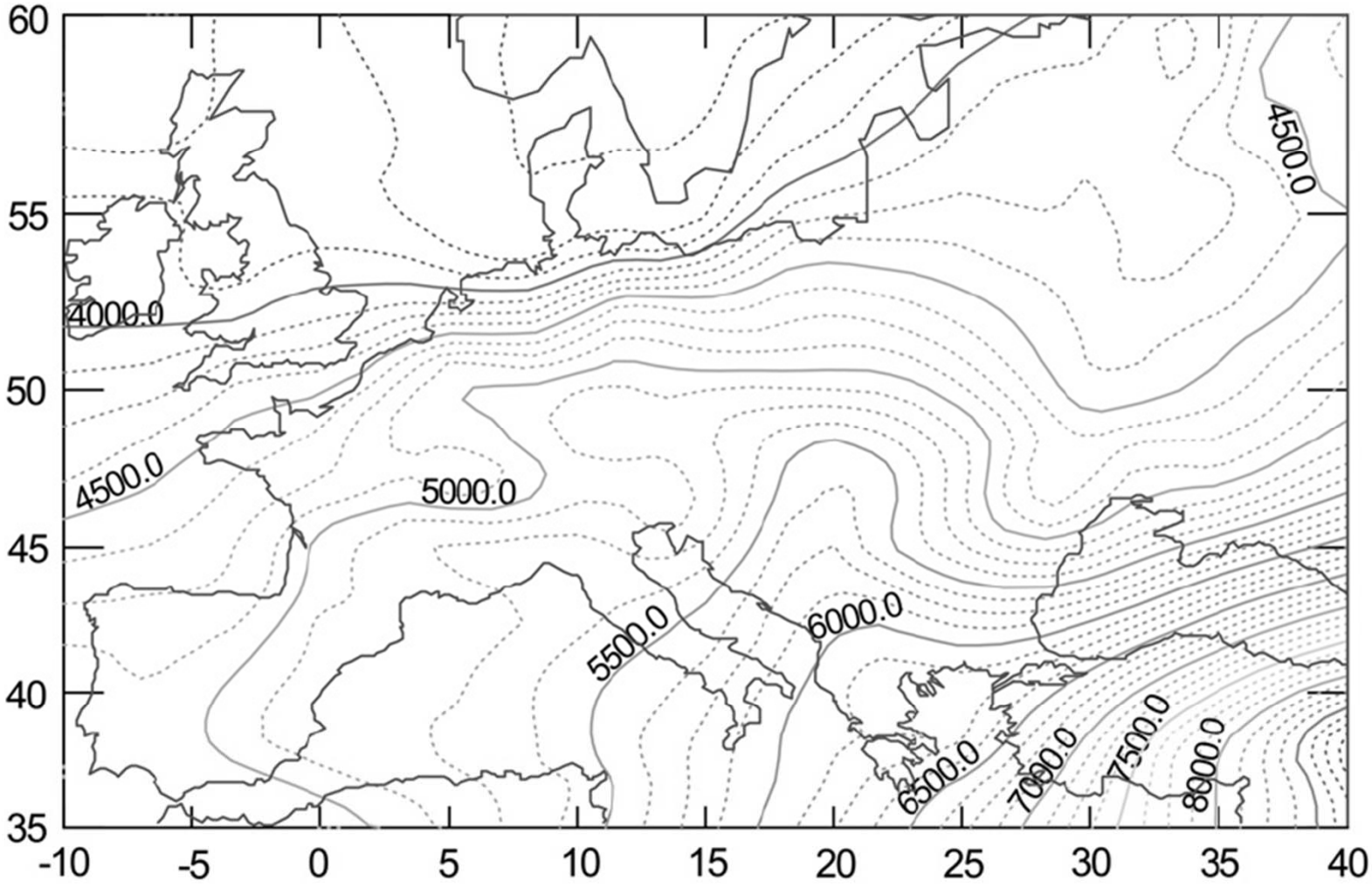


Fig. 2. Schematic distributions of the ceramic cultures on the map. Legend : 0 = undefined, 1 = PP, 2 = ELP, 3 = LBK, 4 = BAIW, 5 = WC, 6 = CBT, 7 = TRBK.

Comparison to other authors (6)

J.-P. Bocquet-Appel et al. / Journal of Archaeological Science xxx (2011) 1–16



entation of the isochrones (CalBC) of the farming expansion obtained by contouring the gradients on the map (see Bocquet Appel et

The previous maps show observed speeds.

What are the speeds from the models?

1. Purely cultural model

2. Purely demic model

3. Demic-cultural model

Purely cultural model

·Population 1 (Mbuti, band): $\{P_k\}$={0.59, 0.37, 0.04}, $\{R_k\}$={2.5, 7.5, 12.5}km $\rightarrow$ 0.17-0.36 km/y.

·Population 2 (Mbuti, band II): $\{P_k\}$={0.12, 0.30, 0.43, 0.15}, $\{R_k\}$={2.5, 7.5, 12.5, 17.5}km $\rightarrow$ 0.30-0.57 km/y.

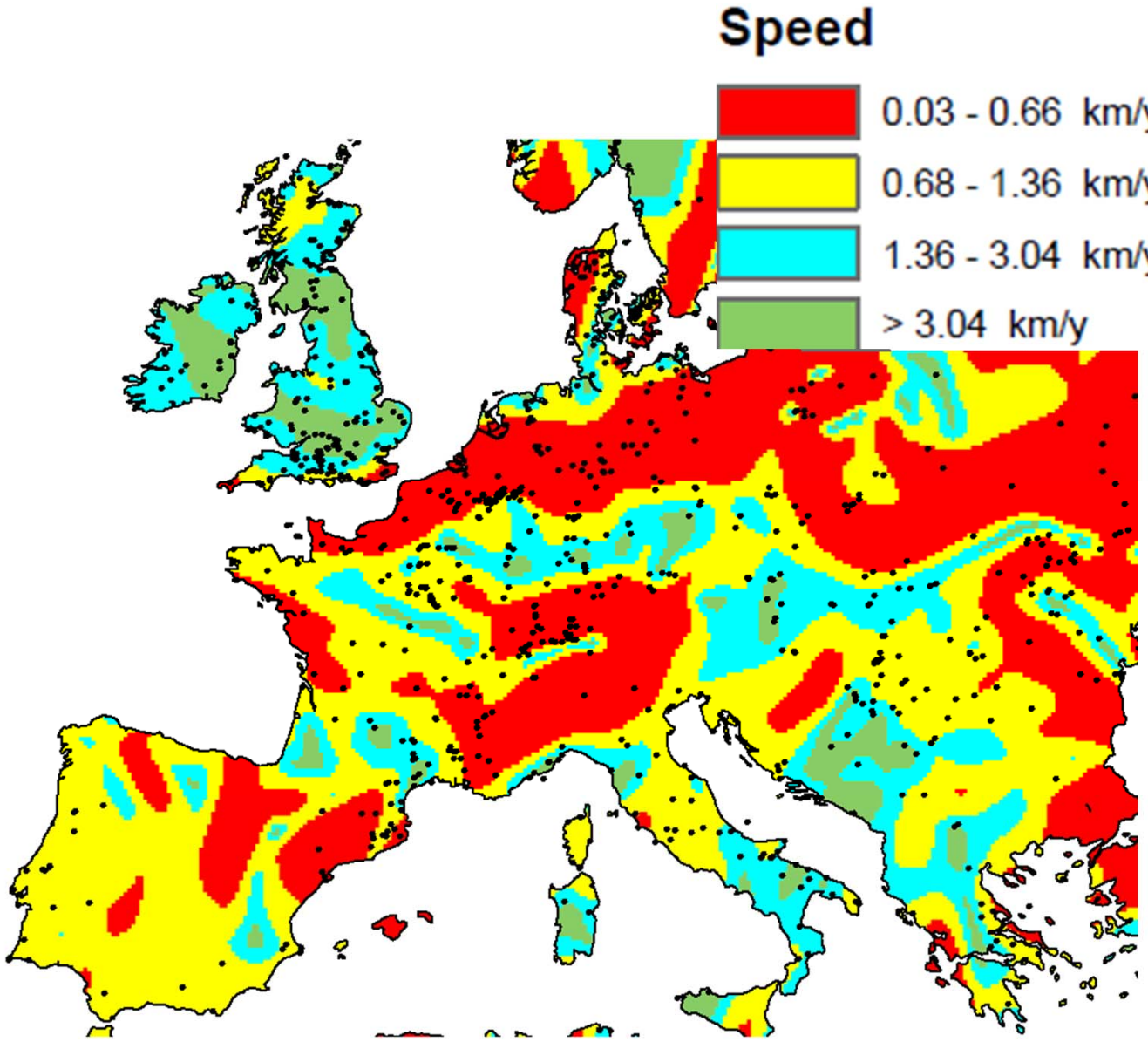
·Population 3 (Mbuti, band III): $\{P_k\}$={0.20, 0.41, 0.26, 0.08, 0.05}, $\{R_k\}$={2.5, 7.5, 12.5, 17.5, 22.5}km $\rightarrow$ 0.32-**0.66 km/y**. **MAX**

·Population 4 (Aka): $\{P_k\}$={0.12, 0.25, 0.11, 0.04, 0.03, 0.16, 0.05, 0.05, 0.05, 0.14}, $\{R_k\}$={0.05, 0.1, 0.2, 0.25, 0.3, 0.4, 2, 3, 5, 6}km $\rightarrow$ 0.09-0.19 km/y.

·Population 5 (Baka): $\{P_k\}$={0.48, 0.04, 0.13, 0.14, 0.18, 0.03}, $\{R_k\}$={0, 0.5, 0.8, 1.5, 1.7, 2.7}km $\rightarrow$ **0.03**-0.07 **km/y. MIN**

Overall range: **0.03-0.66 km/y** (cultural model)

Interpretation of the observed speeds



→**cultural**

Fort,
J. R. Soc. Interface
(2015)

Fig. 3

Purely demic model

·Population A (Gilishi 15): $\{p_j\}$={0.54, 0.17, 0.04, 0.25}, $\{r_j\}$={2.4; 14.5, 36.3, 60.4}km → 0.87-1.15 km/y.

·Population B (Gilishi 25): $\{p_j\}$={0.40, 0.17, 0.17, 0.26}, $\{r_j\}$={2.4; 14.5, 36.3, 60.4}km → 0.92-1.21 km/y.

·Population C (Shiri 15): $\{p_j\}$={0.19, 0.07, 0.22, 0.52}, $\{r_j\}$={2.4; 14.5, 36.2, 60.4}km → 1.14-**1.48 km/y**. **MAX**

·Population D (Yanomano): $\{p_j\}$={0.19, 0.54, 0.17, 0.04, 0.04, 0.02}, $\{r_j\}$={5, 30, 50, 70, 90, 110}km → 1.12-1.48 km/y.

·Population E (Issongos): $\{p_j\}$={0.42; 0.23; 0.16; 0.08; 0.07; 0.02; 0.01; 0.01}, $\{r_j\}$={2.3, 7.3, 15, 25, 35, 45, 55, 100}km → **0.68**-0.92 **km/y**. **MIN**

Overall range: **0.68 -1.48 km/y** (purely demic model)

s_{obs} = observed speed

s_D = speed predicted by the purely demic model

Cultural effect (in %) = $E = \frac{s_{obs} - s_D}{s_{obs}} 100$

$s_{D\,min} = 0.68$ km/y $\rightarrow E_{max} = (1 - \frac{0.68}{s_{obs}})100 \rightarrow$

E_{max} < 50% if s_{obs}<1.36 km/y:
mainly demic regions (yellow)

Interpretation of the observed speeds

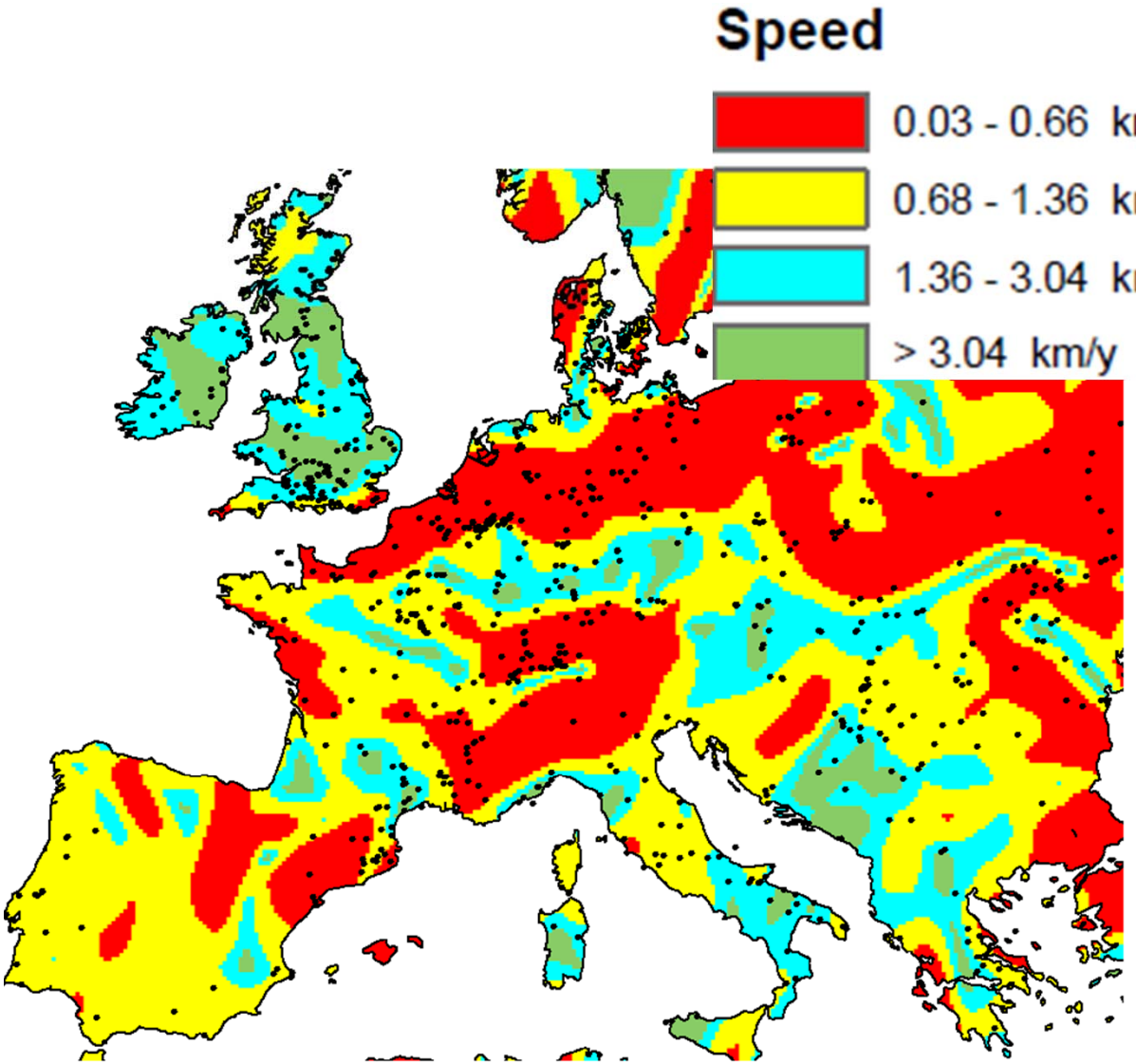


Fig. 3

→ cultural

→ **mainly demic**

→ either mainly demic or mainly cultural

Fort, *J. R. Soc. Interface* (2015)

Demic-cultural model

Its **fastest speed** is obtained for:

· The strongest observed intensity of cultural transmission ($C = 10.9$),

· The fastest cultural kernel (population 3),

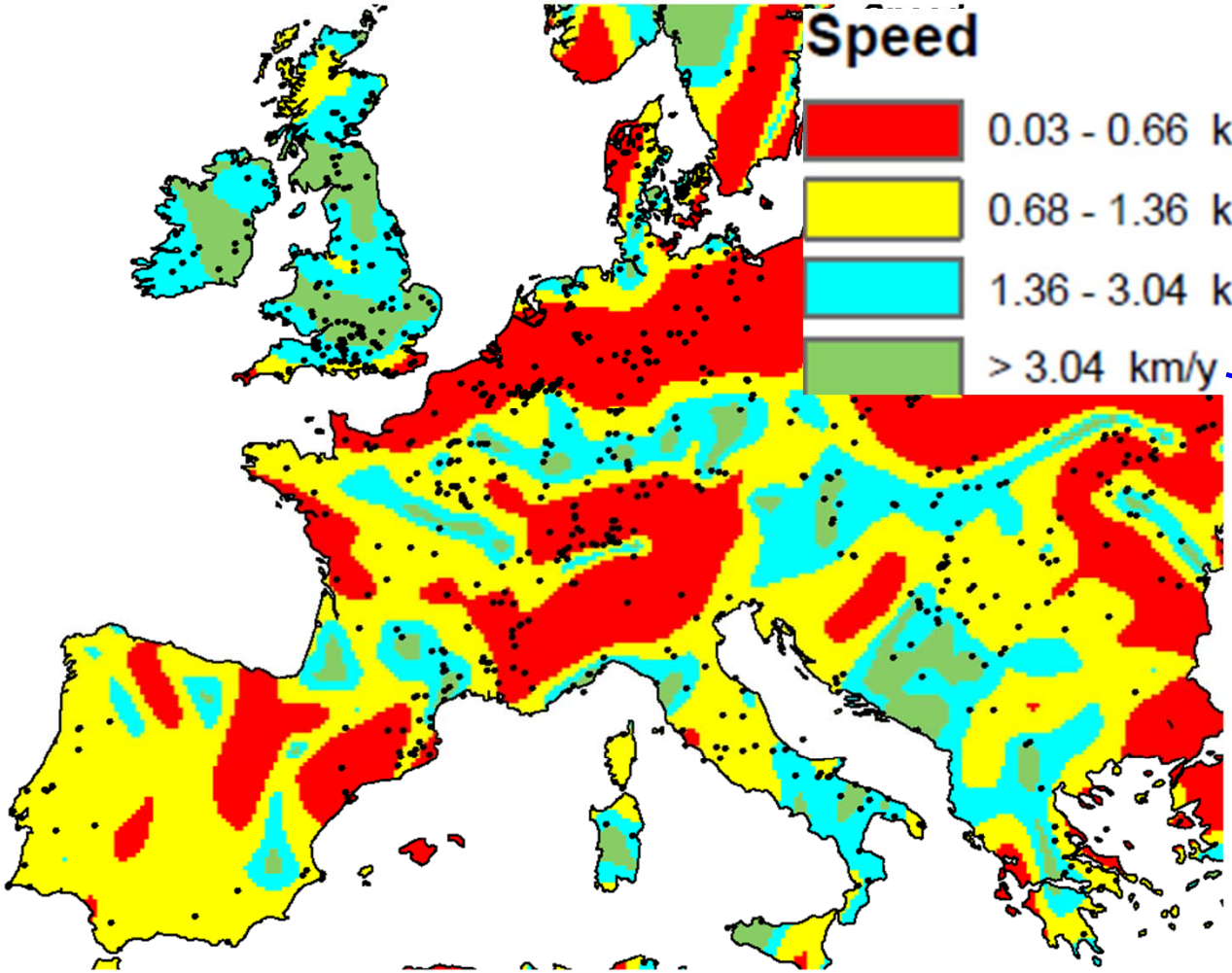
· The fastest demic kernel (population C or D),

· The highest observed value of the reproduction rate a_N ($0.033\ y^{-1}$), and

· The lowest observed value of the generation time T ($29\ y$).

Using these data we find **3.04 km/y.**

Interpretation of the observed speeds



→ cultural

→ mainly demic

→ either m. demic or m. cultural

→ **too fast**

Fig. 3

Fort, *J. R. Soc. Interface* (2015)

Interpretation of the observed speeds

· Mainly demic diffusion (yellow) was fast (speeds above 0.68 km/y). Areas: Greece, Italy, the Balkans, Hungary, Slovakia, Czechia and central Germany.
This includes a substantial part of the Linearbandkermic (LBK) culture in Central Europe*.
It agrees with Bogucki (2003) and Shennan & Edinborough (2007).

·Cultural diffusion (red) was slow (speeds below 0.66 km/y). Areas: Northern Europe, the Alps and West of the Black Sea (red color). This agrees, respectively, with Bogucki (1996), Clark (1990) and Anthony (2007).

*Kaczanowska M, Kozlowski JK, 2003, Fig. 12.7

Open problem

These results use parameter values which
are not fitted but estimated from independent data.
But are the parameter values used realistic?

It would help a lot to measure prehistoric
dispersal kernels, if possible:

· Strontium isotope: not accurate distances
· Genetics: identification of parent-child pairs?

Until we have accurate parameter values,
the models can be useful but the
conclusions are preliminary.