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Orbis: the Stanford geospatial network model of the Roman world

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Abstract: ORBIS allows us to express ancient Roman communication costs in terms of both time and expense. By simulating movement along the principal routes of the Roman road network, the main navigable rivers, and hundreds of sea routes in the Mediterranean, Black Sea and coastal Atlantic, this interactive model reconstructs the duration and financial cost of travel in antiquity. Taking account of seasonal variation and accommodating a wide range of modes and means of transport, ORBIS reveals the true shape of the Roman world and provides a unique resource for our understanding of premodern history.

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Introducing ORBIS

Spanning one-ninth of the earth's circumference across three continents, the Roman Empire ruled a quarter of humanity through complex networks of political power, military domination and economic exchange. These extensive connections were sustained by premodern transportation and communication technologies that relied on energy generated by human and animal bodies, winds, and currents. Conventional maps that represent this world as it appears from space signally fail to capture the severe environmental constraints that governed the flows of people, goods and information. Cost, rather than distance, is the principal determinant of connectivity. For the first time, ORBIS allows us to express Roman communication costs in terms of both time and expense. By simulating movement along the principal routes of the Roman road network, the main navigable rivers, and hundreds of sea routes in the Mediterranean, Black Sea and coastal Atlantic, this interactive model reconstructs the duration and financial cost of travel in antiquity. Taking account of seasonal variation and accommodating a wide range of modes and means of transport, ORBIS reveals the true shape of the Roman world and provides a unique resource for our understanding of premodern history.

ORBIS is the result of collaboration between historians and information technology specialists at Stanford University. The project was designed and led by the Roman historian Walter Scheidel and the Digital Humanities specialist Elijah Meeks, and completed with the assistance of a number of graduate students and IT staff. Its implementation was made possible by two Stanford Digital Humanities Grants in 2011/1 and 2013/14.

How ORBIS works

ORBIS reconstructs the time cost and financial expense associated with a wide range of different types of travel in antiquity. The model is based on a simplified version of the giant network of cities, roads, rivers and sea lanes that framed movement across the Roman Empire. It broadly reflects conditions around 200 CE but also covers a few sites and roads created in late antiquity. The primary model consists of 632 visible sites, most of them urban settlements but also including important promontories and mountain passes, and covers close to 10 million square kilometers (~4 million square miles) of terrestrial and maritime space. 301 sites serve as sea ports. The baseline road network encompasses some 85,000 kilometers kilometers (53,000 miles) of road or desert tracks, complemented by some 28,000 kilometers (17,500 miles) of navigable rivers and canals (Figure 1).

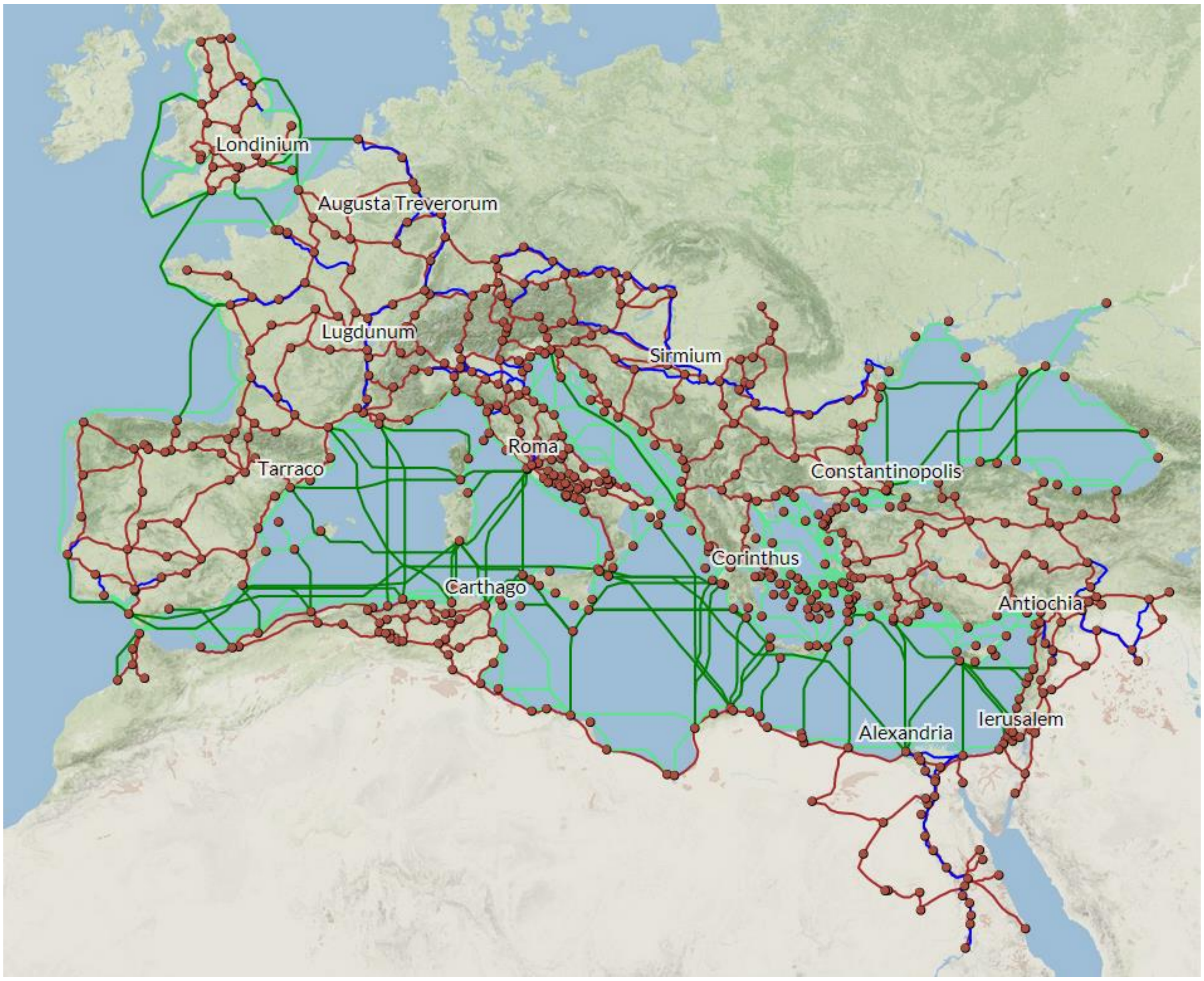

Figure 1
The ORBIS routes (red: road, blue: river, dark green: overseas, light green: coastal)

Sea travel moves across a cost surface that simulates monthly wind conditions and takes account of strong currents and wave height. The model's maritime network consists of 1,026 sea routes (linking 513 pairs of sites in both directions), many of them documented in historical sources and supplemented by coastal short-range connections between all ports and a few mid-range routes that fill gaps in ancient coverage. Their total length, which varies monthly, averages 193,000 kilometers (120,000 miles). Sea travel is possible at two sailing speeds that reflect the likely range of navigational capabilities in the Roman period. Maritime travel is constrained by rough weather conditions (using wave height as proxy). 158 of the sea lanes are classified as open sea connections and can be disabled to restrict movement to coastal and other short-haul routes, a process that simulates the practice of cabotage as well as sailing in unfavorable weather. For each route the model generates two discrete outcomes for time and four for expense in any given month.

The model allows for fourteen different modes of road travel (ox cart, porter, fully loaded mule, foot traveler, army on the march, pack animal with moderate loads, mule cart, camel caravan, rapid military march without baggage, horse with rider on routine travel, routine and accelerated private travel, fast carriage, and horse relay) that generate nine discrete outcomes in terms of speed and three in terms of expense for each road segment. Road travel is subject to restrictions of movement across mountainous terrain in the winter and travel speed is adjusted for substantial grade.

Fluvial travel is feasible on twenty-five rivers on two types of boat. Travel speed is determined by ancient and comparative data and information on the strength of river currents. Cost simulations are sensitive to the added cost imposed by movement upriver and, where appropriate, take account of local variation in current and the impact of wind. The river routes are supplemented by a small number of canals. For each route there are four discrete outcomes for time and four for expense.

Route-finding

Overall, the network consists of 2,973 base segments for which the model simulates a total of more than 363,000 discrete cost outcomes. The model allows users to generate time and expense simulations for connections between any two sites across different media and for specific means and mode of transport and months of the year. As an example, Figure 2 shows the fastest connection between London and Alexandria in July, using a donkey, river boat and sail ship where applicable.

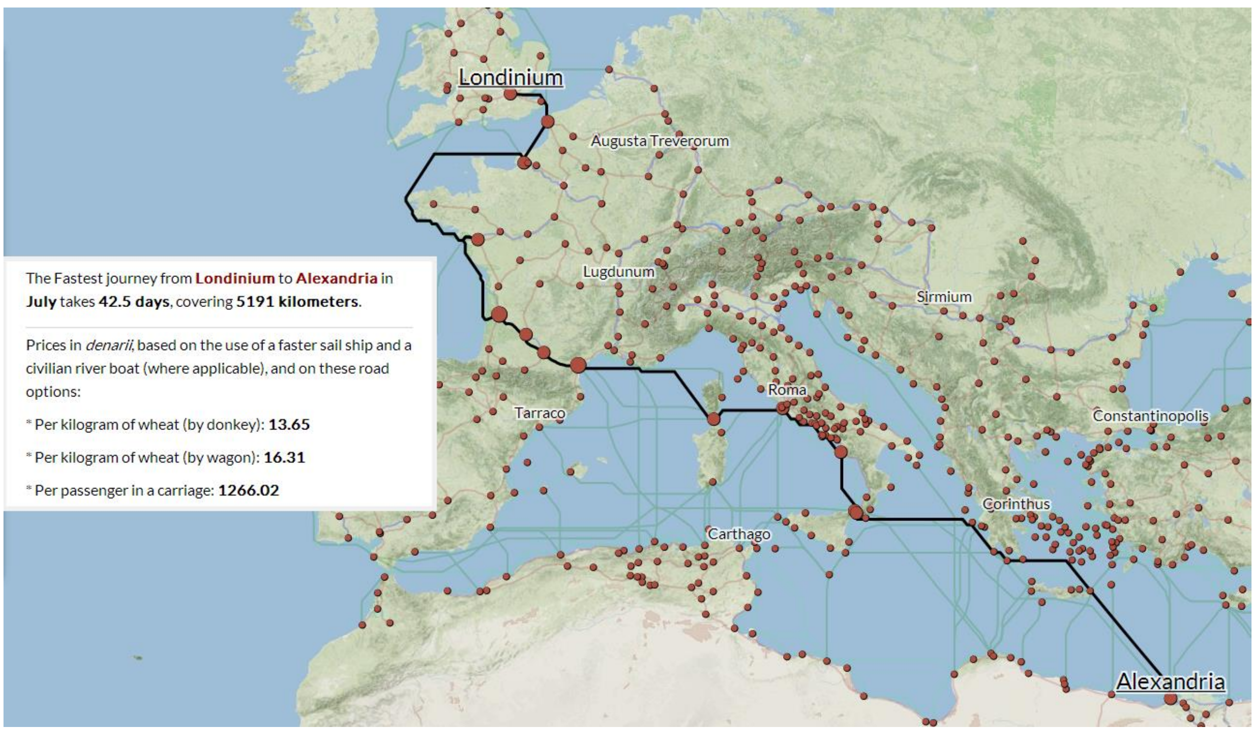

Figure 2
The fastest route from London to Alexandria

The first version of Orbis, launched in May 2012, was primarily a path-finding tool that enabled users to establish the least costly connection (in terms of distance, time or price) between any two sites within the network. The upgraded version, launched in July 2014, expands the simulation capabilities of the model. It seeks to make route simulations more realistic by allowing for the time cost of transfers between different modes of transportation (say, from road to ship). It also highlights the cost properties of all existing routes in a generic fashion: in Figure 3, blue routes are the cheapest and red ones the priciest.

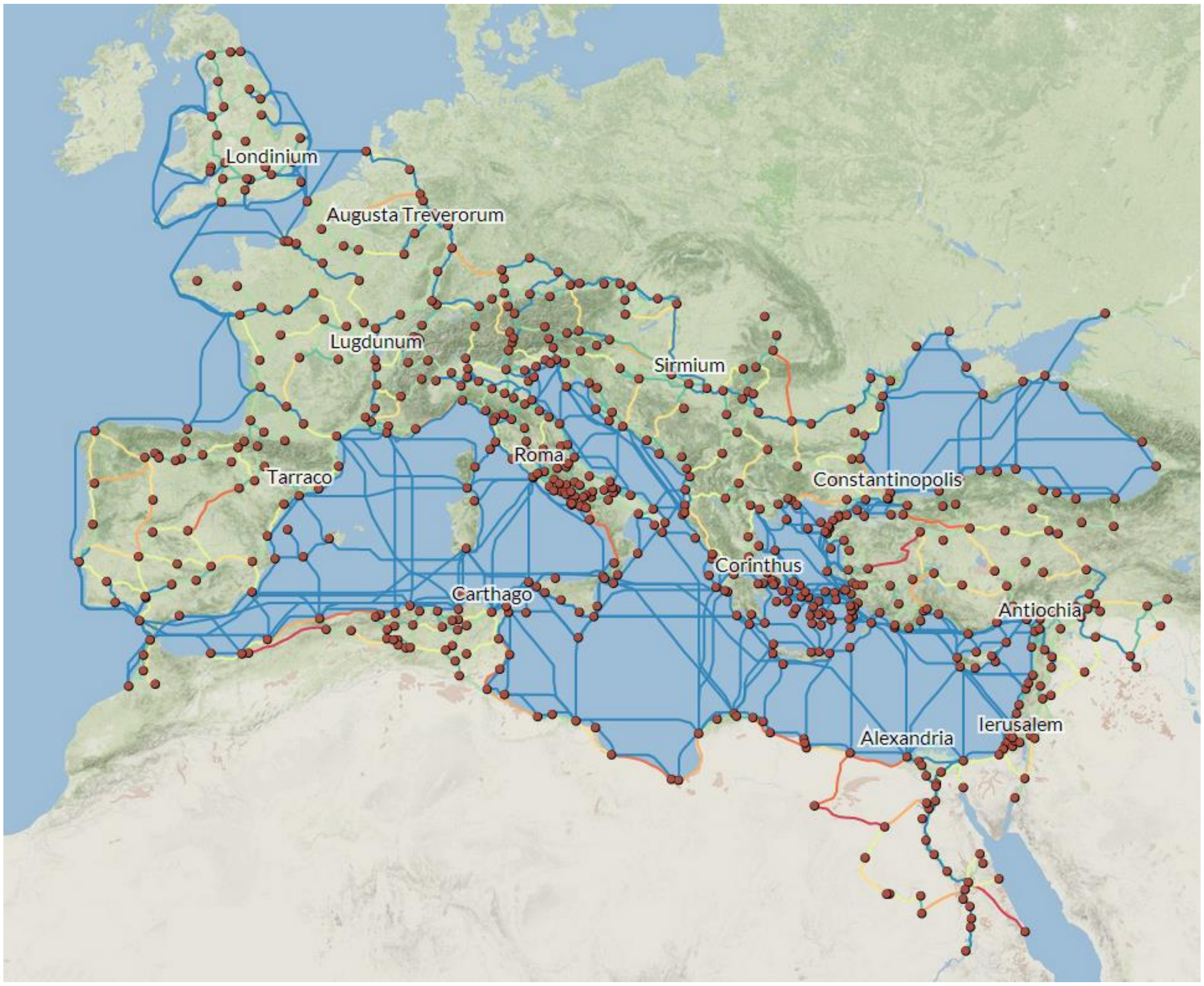

Figure 3
Routes colored according to transport price

A new function creates what is known as “Minard diagrams” by calculating all the most efficient routes from or to a selected site and aggregating them to show which paths were more or less frequently used overall (Figure 4).

Figure 4
Minard diagram centered on Rome

Network properties

Most importantly, users are now also able to generate distance cartograms of all or parts of the network that visualize cost (in time or price) as distance from or to a central point, which can be any site in the network. Every unit of radial distance between the center and a given site in the network corresponds to a unit of cost: the farther away a site appears to be from the center, the costlier is the connection between them. Figure 5 illustrates this by distorting the location of all sites in the network based on how much it would have cost to ship grain from the sites to the city of Rome in the month of July, using donkeys, river boats and fast sail ships.

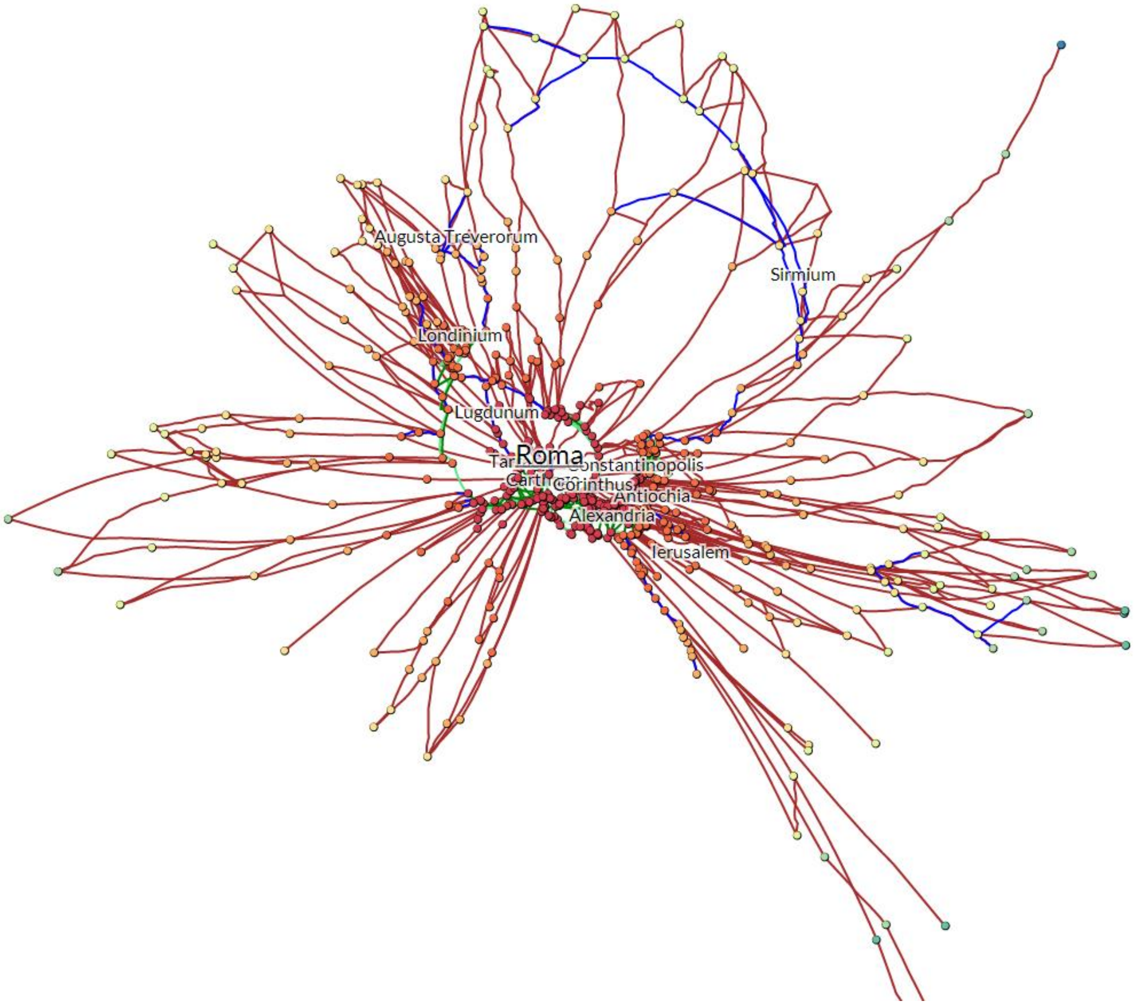

Figure 5
Price distances to Rome

This application allows users to simulate the structural properties of the network, which are of particular value for our understanding of the historical significance of cost in mediating connectivity within the Roman Empire. Cartograms can be converted ("georectified") into cost contour maps that reveal the connectivity cost between a central point and different segments of the network. This can be achieved by coloring sites according to their cost distance from the center (as in Figure 6, a conversion of Figure 5), or by grouping all sites within a particular cost range into discrete regions to highlight the "cost contours" associated with the selected modes of transportation (Figure 7, derived from Figure 6).

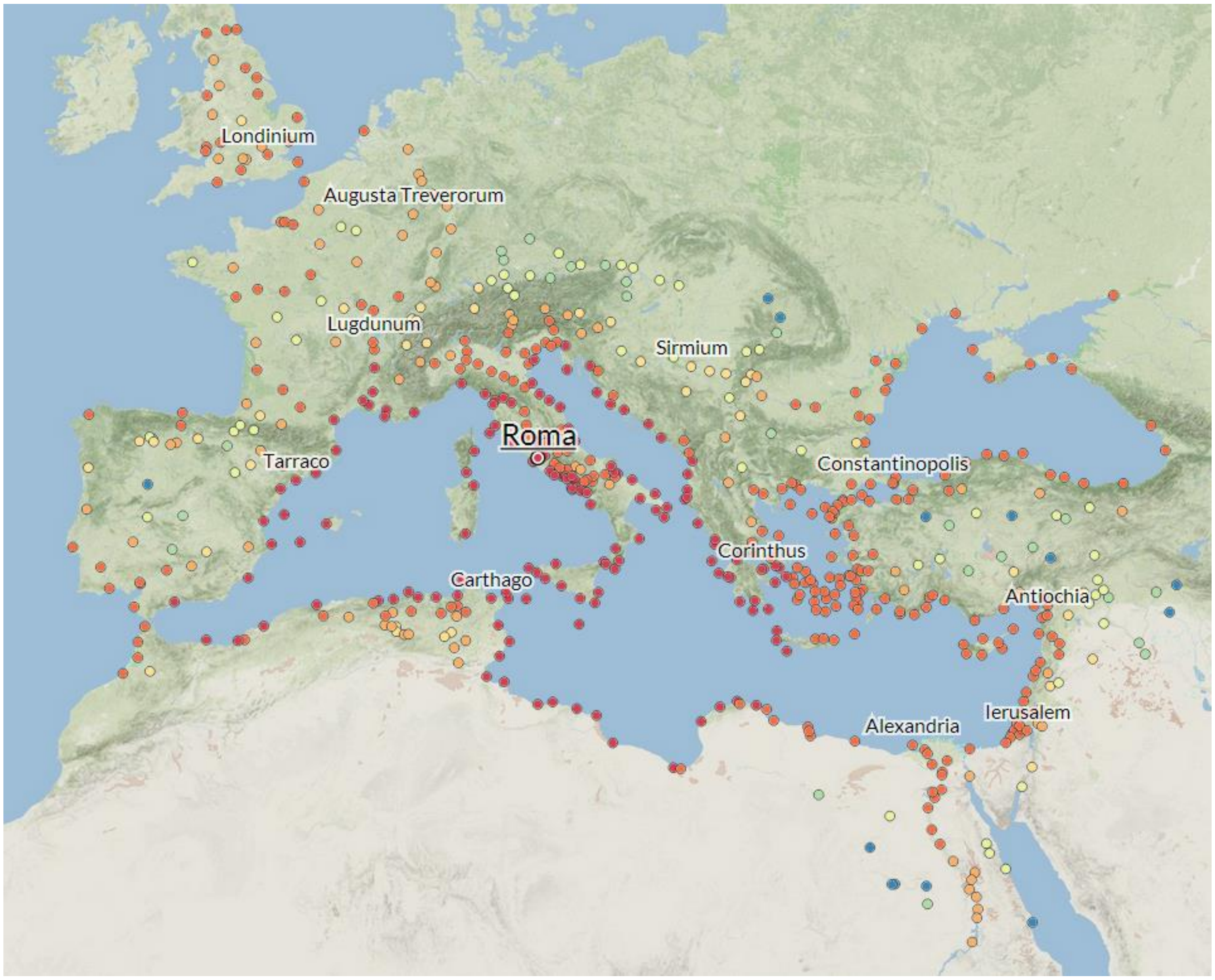

Figure 6
Price distances to Rome (red: lowest, blue: highest)

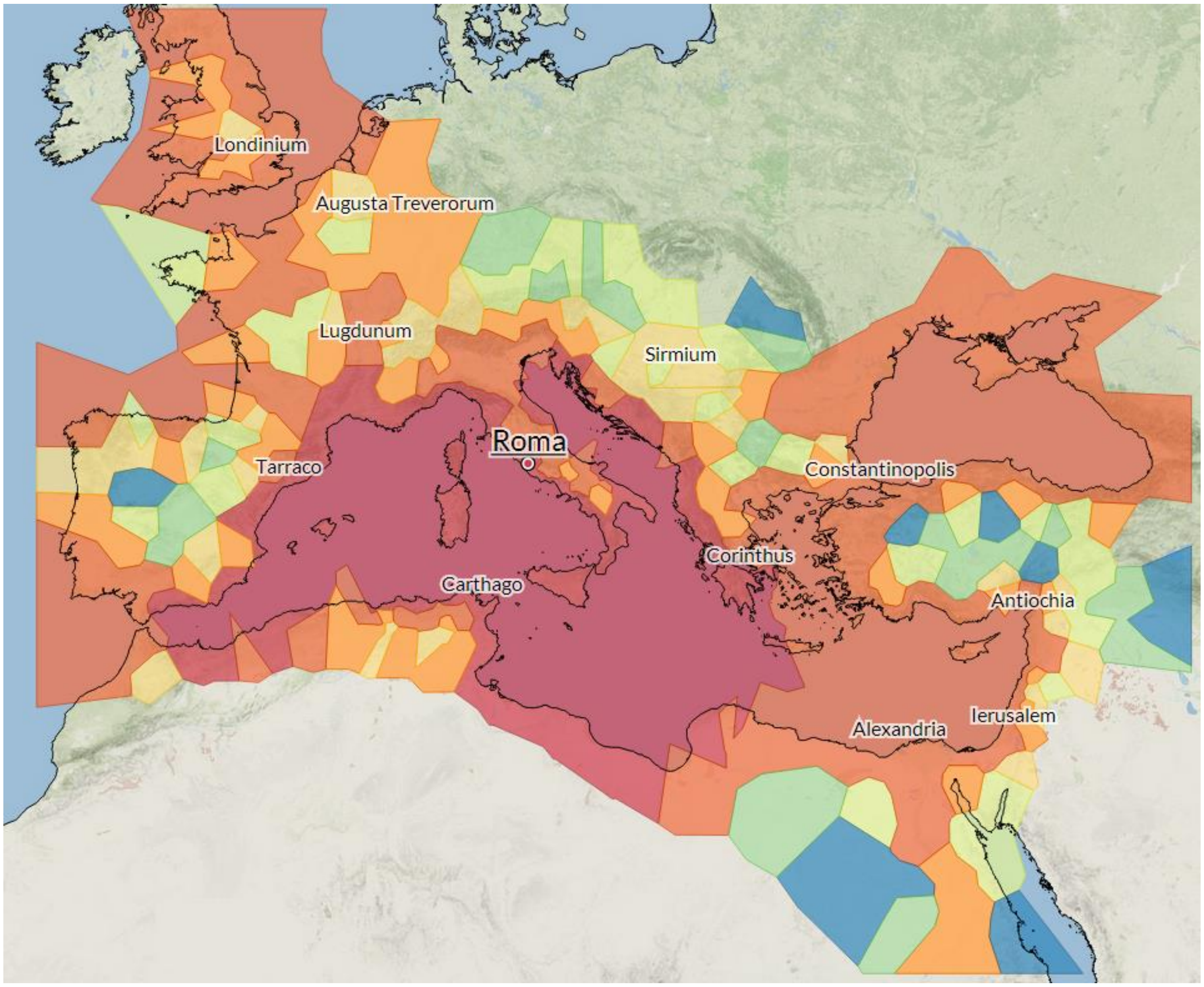

Figure 7
Price distances to Rome (red: lowest, blue: highest)

The model now also supports simultaneous cost distance simulation for multiple centers within the overall network. For example, Figure 8 shows which sites closer to Rome or to Constantinople in terms of travel time for a given set of parameters.

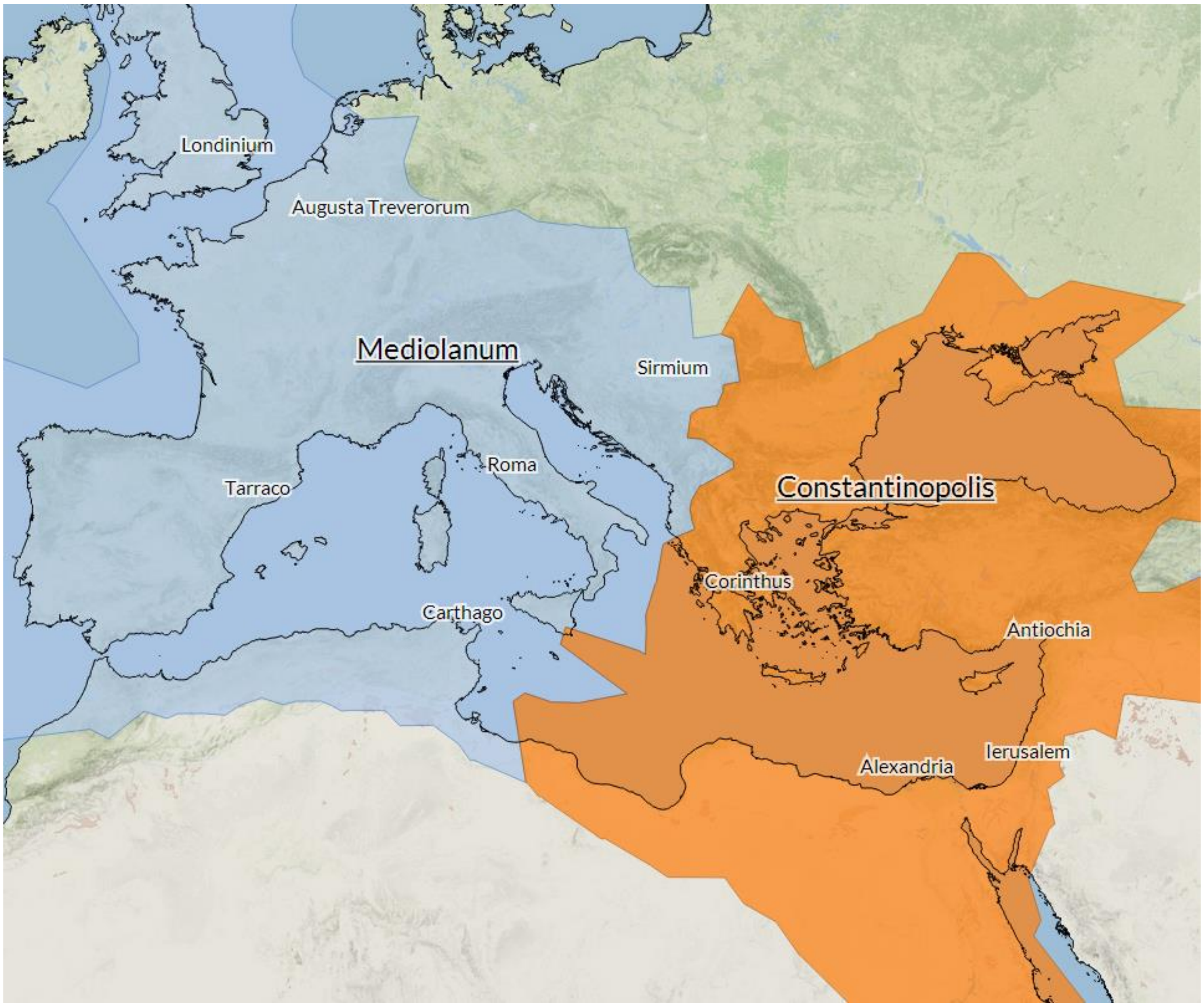

Figure 8
The catchment areas of Mediolanum and Constantinople, by time distance

This function can be fine-tuned by identifying areas that are almost as close to one center as to another. Figure 9 shows an intermediate "frontier" zone comprised of sites whose connectivity cost to Rome and Constantinople varies by not more than 20 percent.

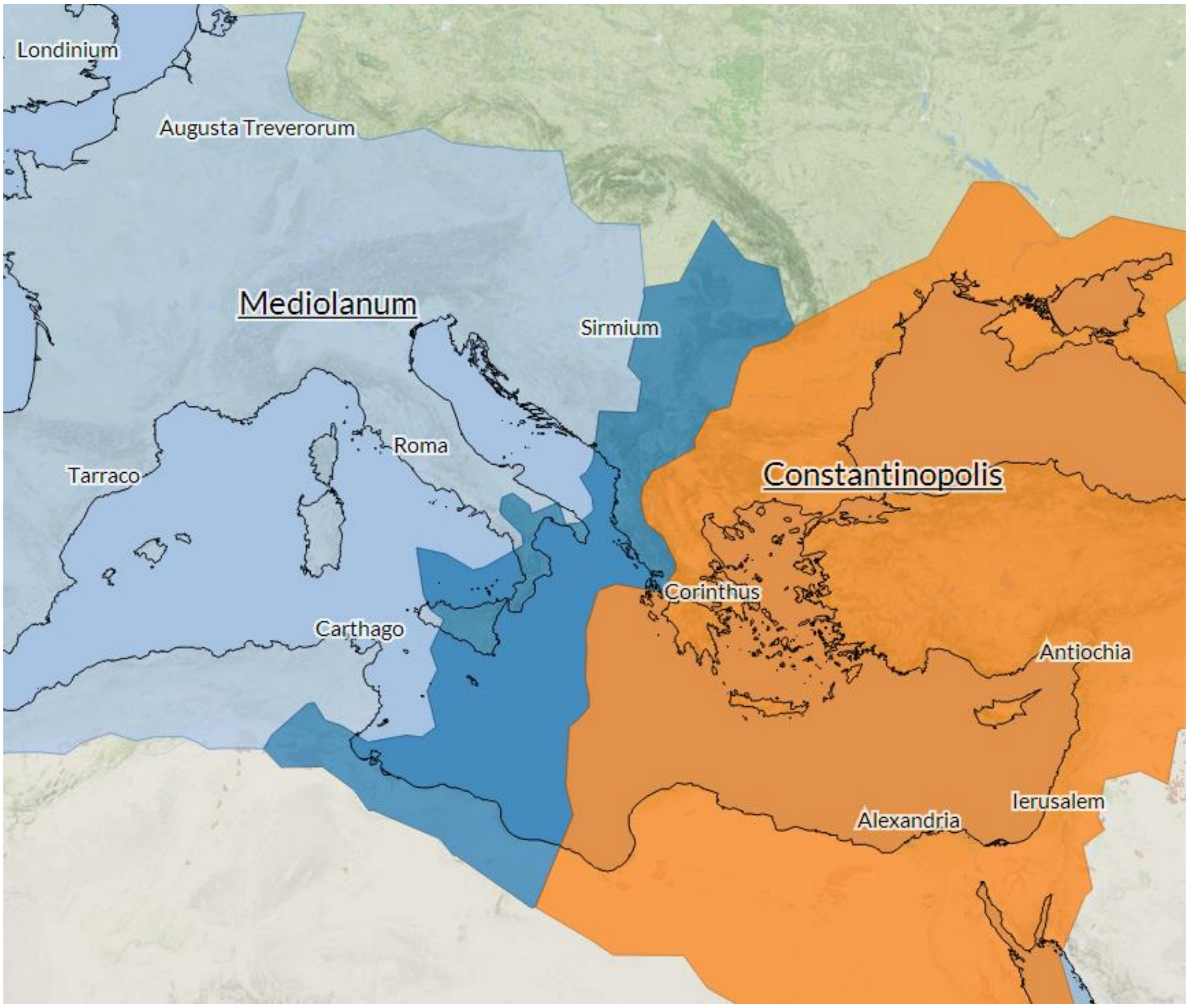

Figure 9
The catchment areas of Mediolanum and Constantinople with intermediate "frontier zone", by time distance

Research applications

ORBIS seeks to reconstruct the physical constraints on different types of connectivity in the Roman world, such as military movements, communication, and trade. It helps historians assess historical developments within the context of these constraints. In an exploratory paper,[1] I try to develop this perspective by focusing on two issues that are fundamental to our understanding of the Roman world. I revisit the trajectory of imperial expansion and decline, demonstrating that Roman expansion proceeded in accordance with connectivity cost constraints and that the eventual segmentation and separation of the empire was likewise shaped by the same factor. And I argue that the model allows us to address key questions about the nature of the Roman economy, namely the relative significance of market forces and state intervention and the degree of economic integration. In an earlier and more technical note, I related the price ceilings for maritime freight in Diocletian's Price Edict of 301 CE to the projected duration of specific sea voyages in an attempt to show that the former had largely been determined by the latter.[2] ORBIS has also been used to test the reliability of Roman itineraries, and provides infrastructure for ongoing work on Roman trade networks and the Virtual Water trade in the Roman world.[3] In the future, the connectivity cost simulations pioneered by ORBIS can be expected to play a role in more ambitious models of historical development.[4]

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[1] Walter Scheidel, "The Shape of the Roman World: Modeling Imperial Connectivity," *Journal of Roman Archaeology* 27 (2014), 7-32.
[2] Walter Scheidel, "Explaining the Maritime Freight Charges in Diocletian's Prices Edict," *Journal of Roman Archaeology* 26 (2013) 464-8.
[3] Nicholas W. Dugdale, "Modeling Trade Networks in Late Antiquity: A Case Study of Marble Architectural Elements from Proconnesus," Paper Delivered at "The City & the Cities: From Constantinople to the Frontier," The Oxford University Byzantine Society's XVI International Graduate Conference (March 1, 2014); Brian J. Dermody et al., "A Virtual Water Network of the Roman World," *Hydrology and Earth System Sciences* 18 (2014): 5025-5040.
[4] Cf., e.g., Peter Turchin et al., "War, Space, and the Evolution of Old World Complex Societies," *Proceedings of the National Academy of Sciences* 110 (2013) 16384-9.