SUPPLEMENTAL INFORMATION:

Great Houses, Shrines, and High Places: Intervisibility in the Chacoan World

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This document provides technical details on the intervisibility analyses reported in the main text. All analyses were performed using open source tools—the GRASS GIS (version 7.0.1; GRASS 2015), GDAL (version 2.1.0, GDAL 2015), and R (version 3.2.0; R 2015) software suites. In R, we used the *FedData* (Bocinsky and Beaudette 2015), sp (Pebesma and Bivand 2005), *raster* (Hijmans 2015), *rgdal* (Bivand et al. 2015), *igraph* (Csardi and Nepusz 2006), and *rgrass7* (Bivand 2015) packages; in GRASS, we calculated viewsheds using the *r.viewshed* (Haverkort et al. 2009) function. We also relied heavily on the *GNU parallel* software package (Tange 2011) for accelerating analyses. All analyses detailed here were scripted so as to be reproducible, and scripts should have been included as a zipped archive with this document; if not, they are available from Kyle Bocinsky (bocinsky@wsu.edu), and are archived on tDAR.

Study area

We chose a square study area that fully enclosed all the sites in our database, plus a small buffer. The study area is 400 x 400 km, and extends from 460000 m east to 860000 m east, and 3780000 m north to 4180000 m north in NAD 1983, UTM Zone 12 coordinates. This region contains a majority of the San Juan and Little Colorado river basins, and extends roughly from just east of the city of Flagstaff, Arizona to the Jemez Mountains in northern New Mexico, and from the Mogollon rim in the central Arizona to the Abajo Mountains in southern Utah. The study area includes prominent landforms such as the Chuska and Carrizo Mountains, Ute Mountain, Navajo Mountain, Shiprock, Monument Valley, Huerfano Mountain, Hosta Butte, Mount Taylor, Cedar Mesa, Black Mesa, and Mesa Verde.

Preparation of the digital elevation model

This study uses a 50-meter digital elevation model (DEM) derived from the 1 arc-second (approximately 30 m) National Elevation Dataset, available from the USGS (Gesch et al. 2002, 2009). Fifty meter DEMs have become the *de facto* resolution for regional GIS visibility studies and represent a good balance between spatial definition and computational viability (cf. Lake et al. 1998; Lake and Ortega 2013; Llobera et al. 2010), although rapidly improving computational power will undoubtedly drive regional visibility studies towards higher resolution DEMs in the future. In this study, we trade high-resolution for a very large study area; our study area encompasses 160,000 km², or 64 million 50 x 50 m pixels. Figures presented in this paper truncate the western part of the study area (including Wupatki), as visual connections did not extend that direction.

We prepared the DEM by re-projecting the NED from its native geographic (latitude/longitude) coordinate system to the UTM coordinate reference system (using the "projectRaster" function in the *raster* package for R), and resampling it at a 50-meter resolution using bilinear interpolation (via the "resample" function in *raster*). Finally, the resulting DEM was cropped to the study area using the "crop" function in *raster*.

Robust viewshed analysis

Viewshed analysis was performed using the *r.viewshed* tool in GRASS, using the parameters reported below. Viewsheds were calculated from the grid location (pixel) of each great house and shrine. Additionally, because many great houses are larger than the 50-meter resolution of our DEM, we calculated viewsheds from the eight pixels surrounding the primary

coordinate of great houses (this is known as the "Moore neighborhood" of the primary pixel). The nine viewsheds—the primary pixel plus its eight neighbors—were then combined to generate a "robust" viewshed from each great house. In doing this, we hope to capture the *effective* viewshed from the great house, though we acknowledge the day-to-day range of great house occupants likely extended beyond the bounds of the building itself.

The *r.viewshed* function accepts many parameters, allowing the user to tune the analysis to their particular purpose. We calculated viewsheds from an observer height and target height of 5 m above the observer and target elevation on the DEM. Thus, we assume intentional signaling by individuals in elevated places such as a tower or roof of a great house, as opposed to a casual, ground-situated signaler or receiver. We calculated viewsheds for an infinite distance away from the observer, although by default the *r.viewshed* function corrects for the curvature of the Earth, which limited viewsheds at the horizon.

Cumulative viewshed analysis

Cumulative viewshed analysis (CVS; Wheatley 1995) was developed as a way to assess covisibility shared between multiple places: What places on a landscape are covisible to one or more Chacoan great house or shrine? We calculated cumulative viewsheds (1) for all great houses and (2) for all shrines in our database by summing each site's robust viewshed using the *gral_calc.py* python tool from GDAL, parallelized for rapid processing on multiple processing cores (figure 5 in the main text). In the source code included in this supplemental information, the *calc.cvs.R* file details the function for calculating cumulative viewsheds.

Viewnet analysis

A *viewnet* is a way of representing intervisibility—visibility between places—as a network. Nodes of the network represent sites or other important places (the locations in our site

database), and an edge exists between two nodes if they are intervisible. Visibility in this case is assumed to be reciprocal. Viewnets not only allow one to graphically represent intervisibility, but enable researchers to quantify characteristics of intervisibility in a system (through various network statistics) and estimate the significance or likelihood of a particular viewnet given a landscape (Swanson 2003).

To calculate the viewnet between all sites in our database, we wrote a function that builds an edge list between intervisible sites, and exports it as an etwork (graph) object using the *iGraph* library in *R*. In the source code included in this supplemental information, the *calc.viewnet.robust.R* file details the function for calculating viewnets from individual site viewsheds.

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