An Interdisciplinary Site Suitability Analysis for Cosmic Explorer

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Abstract. This investigation focused on a suitability analysis conducted by the Cosmic Explorer geographic information systems (GIS) team at the University of Arizona. Cosmic Explorer (CE) is the next generation gravitational wave observatory that will be constructed in the US. CE is based on the LIGO Livingston and Hanford concept but scaled up by a factor of 10. Existing LIGOs in the U.S. are about four kilometers in length for each arm. CE is planned to be 40 kilometers in length for each arm. GIS is a platform that integrates geospatial data for analysis and management. GIS is extremely well suited for site suitability analysis because it focuses on spatial data. CE is currently in the process of selecting promising sites across the US. This analysis set acceptable thresholds across 91 interdisciplinary factors to search for promising areas that CE can fit in the contiguous United States.

1 Site Search Overview

The site suitability analysis used a land-and-people approach to ensure any site is promising for scientific observations, suited to maintain a talented workforce, and is situated in a region that is generally conducive to relationship building with CE. Suitable locations need to be able to support CE's scientific goals while also retaining a talented workforce in these areas [1]. This GIS National Suitability Analysis (NSA) integrates 91 different social, cultural, and scientific considerations. It works in concert with efforts to characterize costs, known as Cosmic Explorer Location Search (CELS), gathering information from location visits, and relationship building. CELS is a Python package designed to score potential detector configurations based on United States Dollars (USD) and science costs incurred by the topography, geology and geography of the land. CE's National Suitability Analysis uses GIS to identify locations based on thresholds from multiple data sets [2, 3, 4]. It draws on research in sociology, geography, geology, and physics to find acceptable thresholds for the observatory and its workers. NSA integrates all considerations simultaneously inside a geometric algorithm to find sites where CE can potentially fit. This analysis is a land-and-people integrated approach (see Figure 1). Some of the issues NSA attempts to provide information on include whether an area makes a good home for staff, determines if local communities would be amenable to host an observatory, and whether the land can support the scientific needs of CE. Not only is NSA considering the scientific facility itself and the physical parameters for it, but it also considers where the staff is going to live and if they'll feel welcomed in the community that they're situated in while commuting to work. The CE GIS team is currently finalizing NSA.

2 Crafting An Interdisciplinary Approach

The NSA integrates three key indexes: science, quality-of-life, and social landscape; each index is equally weighted (see Figure 1). The science index includes a Topographic Position Index, Anselin's Local Moran's I statistic on elevation data, earthquake risk, 5 second seismic noise, 1 second seismic noise, land use, wind speed estimations, and wilderness preserves. Wilderness preserves also include a series of no-go areas such as national monuments, national parks, specific land use categories, and wilderness areas. The quality-of-life index examines amenities for staff that are living in a proximate community but commuting to the observatory. The quality-of-life index considers factors such as food access, educational opportunities, and environmental burden. The social landscape index broadly addresses matters of inclusion. The social landscape index considers LGBTQ inclusion, segregation, ethno-racial inclusion, and women inclusion. These factors come from census-derived geometries, such as census tracts and public use microdata areas, and each area is scored according to how inclusive they are based on these variables. Many of the social landscape index comes from work done in concert with the National Opinion Research Center (NORC). NSA selects the top 75th percentile of these data and approximates a 2.5 hour drive time from those areas outwards. What is being considered in the social landscape index are areas that one can commute to from a locale offering a high quality-of-life.

From each spatial dataset within the NSA, a Boolean mask, or a binary raster data set is created. A raster data set is an image of pixels that is georectified to the Earth. Thresholds are established by considering what is not acceptable for CE, and these data are reclassified into a binary (acceptable/not acceptable) in geographic space. For instance, in Figure 2 areas in red are considered less promising because we don't want any portion of CE to spatially intersect with high earthquake hazards. A threshold is set on that dataset based on whether an area will produce excessive amounts of downtime or damage the instruments in CE. Using thresholds in this manner, it is possible to set Boolean masks for all 91 factors that can then be aggregated based on spatial coincidence, where all factors occupy the same space. From this Boolean mask, for the science considerations in particular, CE is planned to take the form of an 'L' of 40km on each arm. Minor variations in opening angle around 90 degrees, and any orientation, are considered. This defines an observatory 'footprint'. This binary surface, then undergoes a moving window operation that looks at the way in which the observatory is going to be oriented with an opening angle between 75 degrees and 110 degrees. A 40km arm is rotated by 360 degrees for all possible combinations by increments of 5 degrees. This allows for the analysis to see if orientations at every point in the contiguous U.S. intersect with an area that is promising or not for CE.

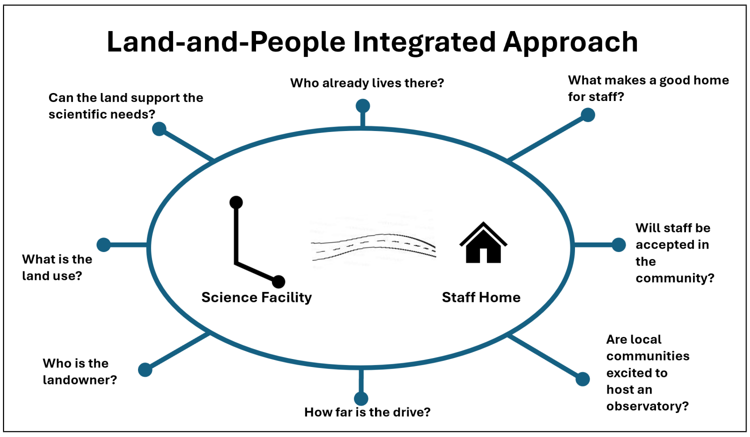

Figure 1: Motivating questions for NSA.

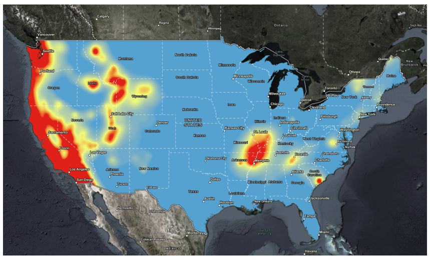

Figure 2: Earthquake hazard estimation for the contiguous U.S.

3 National Level Data Limitations and Future Work

Results from the NSA produce clusters of observatories where it is possible to define convex hulls or minimum bounding geometries (see Figure 3). These convex hulls are promising areas that need to be further studied through regional and site level analysis. There are some limitations to a national scale suitability analysis because it is not possible to aggregate all types of data sets together and there is a non-negligible margin of error in national data. For instance, local land ownership or infrastructure data needs to be used at regional and local scales to obtain more precise results. For example, Figure 4 shows Midland, Texas, which looks very promising from a scientific perspective. However, Texas is about 95% privatized land. More landowners equate to more negotiating. Further, in Midlands there are lots of oil wells, pipelines, and railroads that make it quite difficult to build an observatory of this size. Regional and site level analysis is required before finalizing a recommend CE site list.

To conclude, suitability analysis is a common form of GIS analysis and well suited to determine the best locations for CE. The CE GIS analysis includes social, cultural, and scientific factors. The results of the NSA are the convex hulls, or areas of interest for further analysis. In the future, CE is considering further technical documentation and metadata for all the GIS analysis conducted, creating a data architecture and repository and then following up with regional and site-level analysis on the areas of interest.

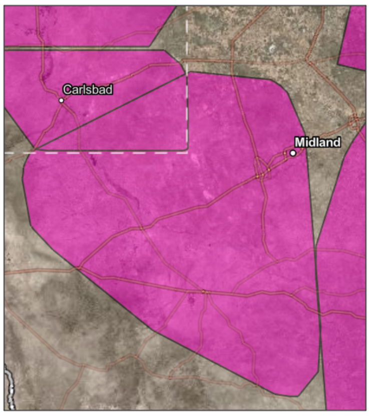

Figure 3: An area of interest in West Texas.

Figure 4: Oil wells and infrastructure in West Texas (Product name is a trademark of Google Maps).

References

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