THE HILLINESS OF U.S. CITIES

JOSEPH PIERCE and CRYSTAL A. KOLDEN

ABSTRACT. What is a hilly city, and which cities are hilliest? This study outlines a basket of methods for quantifying the differential hilliness of U.S. cities. We rank the 100 largest cities in the contiguous United States, using a selection of eight methods to evaluate their comparative hilliness. We then reflect on how four key "modes of encounter" with terrain shape human perceptions of urban hilliness: visual, pedestrian, automotive, and imagined/conceptual. Varying priorities among these different modes of encounter shape which of our indices may best correlate with lay understandings of urban hilliness or particular policy problems. We conclude with implications of this work for contemporary geographic scholarship and suggestions for further research, particularly with regard to the political and economic effects of hilliness. *Keywords: hilliness, ruggedness, U.S. cities, slope, urban geography.*

This paper examines comparative hilliness among large U.S. cities. Hilliness, or ruggedness of terrain, is an important geographical dimension that impacts urban development and socio-spatial patterns, with broad policy implications, including infrastructure development, social segregation, the land market, and potential economic uses of the urban landscape. Related scholarship by geographers on urban contexts has typically been more focused on urban differentiation or stratification by altitude than on the impacts of ruggedness. We ask here which cities are hilliest, and if there are different kinds of hilliness that should be analytically differentiated from one another. We offer a working definition of urban hilliness and a comparative analysis of the largest 100 cities by population in the contiguous United States.

This article begins with a literature review of previous work in the area of hilliness within American urban geography, and on ruggedness in geography more generally. We then introduce methods for calculating the hilliness of different cities, building conceptually on previous work by William Meyer (1994, 2012), Jeff Ueland and Barney Warf (2006), and Jerome Dobson and Joshua Campbell (2014). We analyze differences in these indices, and conclude with some implications for further work on hilliness in urban geography. In particular, we argue that geographers are uniquely positioned to analytically integrate how physical and social terrains interact in urban environments to produce varying political and development outcomes. The conclusion identifies several potential opportunities for more closely coupled physical and social research in urban geography.

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Literature Review: Urban Terrain in Geography

Mid-twentieth century scholarship in economic and regional geography articulated a variety of spatial typologies and conceptual urban hierarchies (Harris and Ullman 1945; Shevky and Bell 1955; Bell, 1958; Berry 1971; Janson 1980). During this period, limits to computational capacity constrained geographers in their ability to model large and complex three-dimensional social and economic landscapes, shaping the level of abstraction in geographical typologies, which were often limited to two-dimensional representations of a few highlighted spatial dimensions (Openshaw and Turton 2005). Transportation geographers and demographers, among others, have continued to extend and refine this spatial tradition in the context of contemporary GIS methods and data (Horner 2004; Harris and others 2007). Simultaneously, scholars in the remote sensing community have revolutionized the kinds of observations available for analysis in urban contexts (Zhou and Troy 2008).

Recent scholarship on the social or political impacts of urban topography has largely been focused on the impact of flooding; this work is most often positioned in the literature on environmental vulnerability and resilience (Adger, 2000; Chakraborty and others 2014). In the aftermaths of recent American coastal disasters—Hurricanes Katrina and Sandy, in particular—urban geographers and political ecologists have begun to bring a more environmental justice-oriented perspective to flood risk (Maantay and Maroko 2009). More generally, geographers' disciplinary interests in global climate change are also driving climate-justice analyses of low-lying coastal inundation (Walker and Burningham 2011).

Relatedly—though altitudinally opposite—urban planners and some geographers have shown interest in the impact of landslide risk on both vulnerable populations (as in Oso, Washington in 2014 [Haugerud 2014]) and the potential for economic growth (Smyth and Royle 2000; Cascini and others 2005). Sites from Rio de Janeiro's favelas to Los Angeles' steep ridges offer clear, differentiated possibilities of development in landslide-prone landscapes, with differential social and economic impacts. Similarly, scholars focused on walking- and bicycle-oriented development feasibility point to the utility of flatness, although sometimes without much specific empirical evidence (Jones 2006; Middleton 2011; Dill and Voros 2015). Urban-located topological research, such as road-network impact analyses, may be affected by hilliness inasmuch as urban road networks respond to terrain, though the specific impacts of hilliness are often implicit in the network topology (Nowell and others 2014).

Some geographers have done research on urban topography, particularly with regard to the impacts of altitude (Willie 1961; Montz and Gruntfest 1986). Cohen and Small stratify demography by altitude (1998). Ueland and Warf provide evidence of residential segregation in southern cities based on altitude, where they find that African-American residents are systematically restricted to less desirable low-lying areas in many cases (2006). In a more cultural vein, Bernard Debarbieux examines an urban mountain as a site of social import

(1998). Most notable here, however, is the career-long effort of Meyer, who has insisted on the importance of hypsography (the mapping of relative elevation) in understanding the urban landscape (1994, 2008, 2012). Meyer (2000) reexamines and complicates Ernest Burgess' (1929) "other" urban model of altitudinal zonation, critiquing geographers' inattention to urban altitude. His empirical work is principally historical in nature, examining how elevation in different sites and moments is related to residential desirability, particularly in various historical epochs. Most recently, he explores how the desirability (or, inversely, undesirability) of hilltops in Syracuse, New York has waxed and waned with shifting technological regimes of mobility (2012). In eras when walking was the most common form of transport, hilltops were anathema; the rise of motorized transport transformed the residential and commercial desirability of relative altitude. Yet rather than representing altitude as now safely "good," he emphasizes the ongoing contingency of its value in urban processes.

Meyer calls for more attention to topography as it impacts social and political dimensions of urbanism, noting that: "foremost among the topics neglected . . . [are] the ways in which such physical features as climate, terrain, soils, and natural resources can be said to affect human life and activities" (2012, 1). We take up Meyer's call for more attention to the impacts of physical topography on the social and political, and attempt to extend it into a systematic study of American cities. Where Meyer has examined the impact of elevation, however, we highlight the differential potential impact of hilliness, or variegation in the ruggedness of terrain, on U.S. cities.

Elevation and hilliness, of course, are not precisely the same thing. Elevation is a property of particular location, but hilliness is a property of a set of locations—that is, it is a description of the relationships between multiple sites' elevations. Yet we argue that it is the property of hilliness that more broadly shapes urban development than elevation. There are flat cities at both low and high elevations, including low-lying costal cities like New Orleans and plains cities such as Wichita; while the proximity of the looming Rocky Mountains certainly shapes the experience of Denver, the fact of its high base altitude does not inherently make it hilly. More subtly, though, are differences between cities with only a few dominant, defining bluff formations (such as Kansas City) and cities that are strongly variegated throughout (for instance, Pittsburgh or San Francisco). These urban physical realities shape cities' development histories, and they can also be instrumental in shaping contemporary political-economic landscapes of urban use and connectivity.

In the text that follows, we echo Dobson and Campbell's recent explication of the comparative flatness of U.S. states in fomenting a disciplinary discussion of the social and political impacts of urban hilliness (2014). We adopt a basket of measures to assess the relative hilliness of the most populous 100 cities in the contiguous United States. This analysis is an exploratory one: the goal is to offer an initial framework for identifying cities as differentially hilly and articulate some important questions that are exposed by attempting to evaluate hilliness, rather than to offer a definitive, final statement about what examinations of hilliness can contribute to the urban literature. We argue that relative hilliness is an essential component of urban form, and should be of interest to those who are concerned with social and political development processes in contemporary urban geographic research.

Data and Methods

We analyzed the 100 most populous cities in the continental U.S. for their relative hilliness. Hilliness has multiple dimensions and plays out at multiple scales, none of which can be said a priori to be empirically most correct: different kinds of urban practices are impacted by hilliness as it emerges at a variety of scales. As a result, we avoid choosing a single, ultimate ranking of cities by hilliness. However, in comparing different rankings, we highlight how different measures of hilliness may be more useful in measuring its impact on different urban issues, and note which rankings might conform more closely to public mental models of, and affective experiences regarding, urban hilliness.

In order to develop a set of cities for analysis, we used U.S. census-derived, urban places rank-ordered by city population (Census 2013; ESRI 2010). Where polygon rather than point locations were applied, legal city boundaries that delineate the formal incorporated area of the city, not specifically urbanized areas, were used to bound the study area. Where point data were used, we adopted the location of a municipality's downtown center (ESRI 2010). To analyze terrain, we utilized the National Elevation Dataset (Gesch and others, 2002) Digital Elevation Model (DEM) and resampled the thirty meters raster cell size to ninety meters; this smoothed the surface of human-made features such as roadways and bridges, but remained sufficiently high resolution to capture the contours of major geologic features. We examined the 100 largest cities in the contiguous U.S. by census population in 2010.

Dobson and Campbell (2014), focusing more on the experience of flatness at the scale of U.S. regional states than on the experience of hills at the scale of the city, define flatness based on topographic features exceeding a line-of-sight slope that approximates the curvature of the earth; this is meant to capture visual disruption to the line of sight (that is, are there visual obstructions between the viewer and the horizon?). In an urban context, however, standing visual observation is only one of a number of ways in which people "encounter" terrain. In addition to this kind of visual encounter, U.S. urban residents experience hilliness through various modes of mobility, principally via walking and automobile. They also engage with terrain conceptually, in imagining boundaries either around the city or in distinguishing areas within it, as in the case of the separation between east and west Baltimore, or the western edge of "Chicagoland." These four engagements with terrain—visual, pedestrian, automotive, and conceptual—are likely to have quite varied implications for a holistic understanding of when a hill (or a hilly region) is steep or shallow in character.[1] For example, Dennis Proffit and others find that pedestrians systematically overestimate the steepness of the sidewalks they climb; furthermore, their analysis of steepness is (perhaps expectedly) fatigue-dependent, estimating slopes to be more severe when they are tired (1995). However, the human visual perceptual system is more attentive to visual signals about speed than those of distance or perceived angle (Gordon 1965); therefore, one might find that automobile drivers are less sensitive to the experience of hill steepness both because of their reduced physical effort and because they experience hills at higher average speeds. This parallels Dobson and Campbell's (2014) speculation about drivers' perceptions of states' flatness based both on speed and the axial direction of interstate highways.

Rather than privilege one particular mode of engagement in order to develop a single index of hilliness, we examined a collection of eight different measures of hilliness. Our approach to defining and measuring hilliness is more multidimensional than that of Dobson and Campbell (2014); they initially determine solely whether a viewing direction from a cell was flat (no visual interruptions to the horizon) or not, while we wished to quantify relief in a way that captured the scale-dependent spatial heterogeneity of both the topography and the city population density. The latter contributing factor was evident in assessing initial topographic relief calculations by polygon city boundaries; many newer western U.S. cities (for example, in southern California and Arizona) are centered in flat valleys but have annexed surrounding mountainous areas—that are usually rural and less populated, if at all—either to protect urban watersheds or in anticipation of future suburban development. Unfortunately, the only higher-resolution population dataset that is consistently available across the U.S. is census data, but we found that census tracts have the same annexation boundary issues as the legal city boundaries, thus we chose to utilize the latter.

Attempts to characterize terrain variability have fallen generally into two camps: those who seek to assess and improve DEM accuracy as a function of relief (Zhou and others 2006) and those who seek to understand how terrain variability contributes to physical process (Stambaugh and Guyette 2008). There has been no focused tradition or effort to systematically produce a set of "best" indices for representing topographic roughness, however, nor is there consensus on best practices or indices. The physical and environmental sciences have independently and disparately developed a diverse array of indices to try and capture terrain ruggedness and topographic complexity; these indices are regularly utilized to understand the contributions of solar insolation and hydrologic function to ecological process (Parker 1982; Kumar and others 1997), soil-erosion tendencies (Mitasova and others 1996), animal ranges (Beasom and others 1983), and patterns of natural hazards such as wildfires (Kolden and Weisberg 2007). In geography and cognate disciplines, these kinds of indices have not, to our knowledge, been systematically applied in urban landscapes in the service of research on typically urban-geographical analytical problems such as social segregation or uneven economic development.

We calculated three indices capturing topographic relief independent of scale: the Melton Ruggedness number (Melton 1958) describing basin relief, raw elevation range (max-min) relief, and the standard deviation of elevation (that is, aggregated and localized relief) were calculated across all DEM cells within a city's formal incorporated area. Four indices address different scales of spatial population density by calculating standard deviation of elevation for all of the DEM cells within increasing circular radii from the city center: 0.5 km, 1 km, 2 km, and 5 km, respectively. The last index is a synthetic calculation of the slope of the standard deviations of the four buffer calculations, which is intended to estimate the degree to which cities change in their hilliness—becoming either more or less variegated in their terrain relief—as one moves outward from the city center (see Table 1 for summary). For example, a higher slope value indicates that a city becomes more hilly or has greater relief the further from city center, as is typically seen when cities are founded in relatively flat valleys between mountain ranges (but also, for example, where a city center is situated upon a flat-topped bluff or butte). Hilliness does not mean that an area is somehow inhospitable to urban activities: after all, a number of the hilliest large U.S. cities are nationally or internationally prominent. However, it is difficult to know how hills impact social, political, or economic activities differentially without some tools for differentiating them. Our eight indices offer divergent rank-orderings of cities, although there are certainly commonalities, particularly among those that are flattest: New Orleans, Louisiana, Baton Rouge, Louisiana, and Rochester, New York, for example, are the flattest among the cities evaluated across all measures. However, at the hilliest end of the spectrum, different indices suggest differently "maximum" rankings.

TABLE 1—INDICES OF HILLINESS CALCULATED FOR 100 MOST POPULOUS CITIES IN CONTIGUOUS US.

INDEX	METRIC	DESCRIPTION/EQUATION	CALCULATION AREA
A	Relief	Elevation Range [max-min]	City Boundaries
B	Melton Ruggedness Number	Scale-independent basin-wide relative relief [Relief / SQRT(area)]	City Boundaries
C	Standard Deviation (SD)	Variability [SQRT(variance)]	City Boundaries
D	SD 0.5 km	Standard deviation of area within a 0.5 km radius of city center	0.25n km^2 circle around city centers
E	SD 1 km	Standard deviation of area within a 1 km radius of city center	π km^2 circle around city centers
F	SD 2 km	Standard deviation of area within a 2 km radius of city center	4π km^2 circle around city centers
G	SD 5 km	Standard deviation of area within a 5 km radius of city center	25π km^2 circle around city centers
H	Slope of expanding radii	Slope [rise / run] of the four increasing-radii SD metrics	From city centers

Rankings and Analysis

Paralleling Dobson and Campbell's (2014) study of the flatness of states, we notice that many of the calculated indices of hilliness do not (as a group) reflect especially closely the authors' understanding of popular perception of the most hilly cities in the United States, a group likely be led by places such as San Francisco, Seattle, or Pittsburgh (Hartwell 2011). The index that most closely approximated these pre-existing expectations about hilliness is the Index F: the standard deviation of DEM cells within a 2 km buffer around the city center (see Table 2 for comparison).

Each of the three city boundary-limited indices (A, B, and C) showed a strong bias toward western U.S. cities as the hilliest (see Figure 1). This is in part because the delineation of the legal bounds of cities have been constrained very differently across various parts of the country and over time. In the East, where large cities are often surrounded by other incorporated entities, urban regional growth often spills out of a core city without a formal change in its geography. In western states, however, annexation for potential future growth (as well as in order to protect vulnerable upstream or uphill runoff zones) has been a common tactic (Rusk 2003). Western state city boundaries are also somewhat influenced by the processes of historical expansion; many of them reflect the grids of the Public Lands Survey System, particularly where transcontinental railroads were part of the establishment narrative. As a result, western city limits are both more likely to encompass undeveloped land reserved for future planning, and to incorporate lands which are hillier than the urban core, but which are intended as buffers rather than as part of the urban grid.

As these first three indices (A, B, and C) reflect the physical attributes of the bounded terrain of municipalities, the degree to which they are useful proxies in social or political urban research may depend on the degree to which those social and political processes engage with hilliness across the entire legal urban area. This might include issues such as the politics of urban watershed protection, or municipal policy responses to runoff pollution.

Indices D through G measure the hilliness (via standard deviation of elevation) of various (expanding) radii from the downtown center; each of these might best reflect the experienced hilliness of different classes of cities (or uses). For example, the smallest area (a 0.5 km radius circle, for index D) might best represent experiences of hilliness in a smaller, heavily walked cities with compact downtowns. The largest radius (5 km, for index G) might better reflect cities whose core urban areas are larger, or those cities where the transit-use mix skews more toward the automotive. Because they are not influenced by spatio-historical differences in municipal boundary drawing, indices (D through G) are much less biased toward western states; they also show a substantial cluster in the Appalachian region and are less biased than the first three measures toward the annexation-friendly landscapes of the southwest (compare

TABLE 2—RANKING OF HILLIEST CITIES BY INDEX; ORDERED BY BENCHMARK RANKING (INDEX F).

		AREA INSIDE CITY BOUNDARIES			AREA INSIDE RADIUS FROM CITY CENTER				FOUR PREV.
CITY	STATE	ELEVATION RANGE	STANDARD DEV. (M)	MELTON RUGGED. INDEX	STANDARD DEV. (M) (0.5KM RADIUS)	STANDARD DEV. (M) (1KM RADIUS)	STANDARD DEV. (M) (2KM RADIUS)	STANDARD DEV. (M) (5KM RADIUS)	SLOPE (INCREASING RADII)
Pittsburgh	Pennsylvania	31	27	26	25	1	1	9	11
Seattle	Washington	39	29	45	18	6	2	13	16
Spokane	Washington	24	23	19	8	2	3	6	9
Lexington	Kentucky	36	54	59	3	3	4	19	25
San Diego	California	17	16	24	9	9	5	16	19
San Francisco	California	27	36	29	36	14	6	7	7
Henderson	Nevada	8	9	6	14	12	7	1	1
Saint Paul	Minnesota	51	40	37	2	4	8	21	34
Albuquerque	New Mexico	10	11	17	22	15	9	11	12
El Paso	Texas	4	4	9	5	8	10	2	3
Omaha	Nebraska	56	47	60	1	7	11	22	30
Kansas City	Missouri	49	41	71	12	10	12	23	23
Cincinnati	Ohio	41	30	30	11	22	13	12	14
Riverside	California	19	13	15	10	5	14	33	61
North Las Vegas	Nevada	26	25	21	40	39	15	17	15
Los Angeles	California	1	3	8	17	11	16	18	20
Long Beach	California	72	80	67	6	13	17	63	97
Reno	Nevada	15	12	12	56	26	18	5	5
Winston-Salem	North Carolina	38	52	33	24	21	19	34	41
Montgomery	Alabama	73	71	77	20	19	20	40	56
Oakland	California	14	8	11	58	33	21	4	4
Nashville	Tennessee	30	33	54	15	20	22	30	40

(continued)

TABLE 2—CONTINUED

		AREA INSIDE CITY BOUNDARIES			AREA INSIDE RADIUS FROM CITY CENTER				FOUR PREV.
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Aurora	Colorado	28	21	22	7	16	23	26	31
Portland	Oregon	20	18	23	49	35	24	3	2
Colorado Springs	Colorado	5	5	7	38	41	25	14	13
Newark	New Jersey	64	50	34	78	29	26	28	22
Baltimore	Maryland	42	28	35	4	18	27	25	26
San Bernardino	California	6	6	1	39	37	28	10	8
Tulsa	Oklahoma	55	60	65	29	28	29	38	42
Cleveland	Ohio	42	35	32	21	17	30	42	60
Fort Worth	Texas	45	43	66	51	32	31	50	55
Milwaukee	Wisconsin	67	62	70	62	45	32	45	44
Austin	Texas	32	31	43	19	24	33	37	46
St. Louis	Missouri	70	65	63	45	56	34	41	38
Irvine	California	23	22	16	68	68	35	15	10
Denver	Colorado	35	39	40	47	40	36	29	27
Raleigh	North Carolina	51	48	51	33	36	37	31	32
Durham	North Carolina	56	59	53	13	23	38	61	82
Charlotte	North Carolina	33	51	46	28	27	39	60	72
Memphis	Tennessee	71	66	85	30	34	40	56	63
Birmingham	Alabama	25	32	25	55	31	41	20	17
Oklahoma City	Oklahoma	37	45	64	34	51	42	57	57
Columbus	Ohio	39	46	55	23	42	43	55	64
Jersey City	New Jersey	79	75	50	16	25	44	67	84

(continued)

TABLE 2—CONTINUED

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Atlanta	Georgia	46	49	44	32	38	45	43	49
Chula Vista	California	11	17	4	54	47	46	27	21
Dallas	Texas	48	42	74	35	50	47	49	53
Minneapolis	Minnesota	61	76	48	48	30	48	66	70
Washington	D. C.	47	34	36	61	61	49	32	24
Greensboro	North Carolina	61	58	62	43	44	50	62	62
Buffalo	New York	83	77	76	42	54	51	72	73
Tucson	Arizona	21	19	28	53	52	52	35	28
Las Vegas	Nevada	3	2	2	66	60	53	24	18
Garland	Texas	69	64	58	41	43	54	46	50
Madison	Wisconsin	50	44	42	44	69	55	47	43
Laredo	Texas	51	53	39	31	46	56	58	59
Santa Ana	California	76	68	47	65	62	57	44	36
New York	New York	65	69	41	50	57	58	36	29
St. Petersburg	Florida	92	89	92	46	55	63	77	81
Lincoln	Nebraska	59	55	52	71	63	64	59	51
Irving	Texas	75	72	69	60	64	65	54	48
Louisville	Kentucky	54	67	38	26	49	66	70	77
Detroit	Michigan	87	83	87	59	59	67	80	80
Philadelphia	Pennsylvania	44	37	49	86	81	68	64	47
San Antonio	Texas	22	24	31	70	71	69	51	39
Glendale	Arizona	29	38	20	76	73	70	65	52

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TABLE 2—CONTINUED

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Boston	Massachusetts	58	61	57	27	48	71	81	94
Indianapolis	Indiana	34	57	61	77	80	72	71	58
Anaheim	California	18	14	10	80	76	73	69	54
Tampa	Florida	88	87	90	74	77	74	82	75
Orlando	Florida	86	90	84	75	74	75	87	85
San Jose	California	9	10	14	83	82	76	53	37
Corpus Christi	Texas	90	88	94	79	70	77	85	83
Gilbert	Arizona	82	73	73	84	84	78	73	66
Houston	Texas	60	82	82	64	67	79	90	96
Chicago	Illinois	73	85	83	73	72	80	88	88
Jacksonville	Florida	77	78	91	63	75	81	89	91
Lubbock	Texas	68	70	72	91	86	82	74	65
Toledo	Ohio	85	86	81	87	91	83	84	76
Fremont	California	7	7	5	89	83	84	8	6
Phoenix	Arizona	13	15	27	90	85	85	79	71
Bakersfield	California	12	20	13	95	92	86	48	35
Virginia Beach	Virginia	91	93	97	69	79	87	91	92
Chesapeake	Virginia	93	94	96	72	78	88	92	93
Chandler	Arizona	83	81	75	85	89	89	83	74
Sacramento	California	89	91	88	92	94	90	94	87
Fresno	California	80	79	78	82	90	91	86	79
Miami	Florida	95	95	93	81	87	92	95	89

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Table 2—continued

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Mesa	Arizona	16	26	18	97	96	93	78	67
Norfolk	Virginia	97	96	95	93	93	94	96	90
Wichita	Kansas	77	74	80	88	88	95	75	68
Stockton	California	94	92	89	94	95	96	93	86
Hialeah	Florida	95	97	86	96	97	97	97	95
Baton Rouge	Louisiana	98	98	98	97	98	98	98	98
New Orleans	Louisiana	98	98	98	97	98	98	98	98
Rochester	New York	98	98	98	97	98	98	98	98

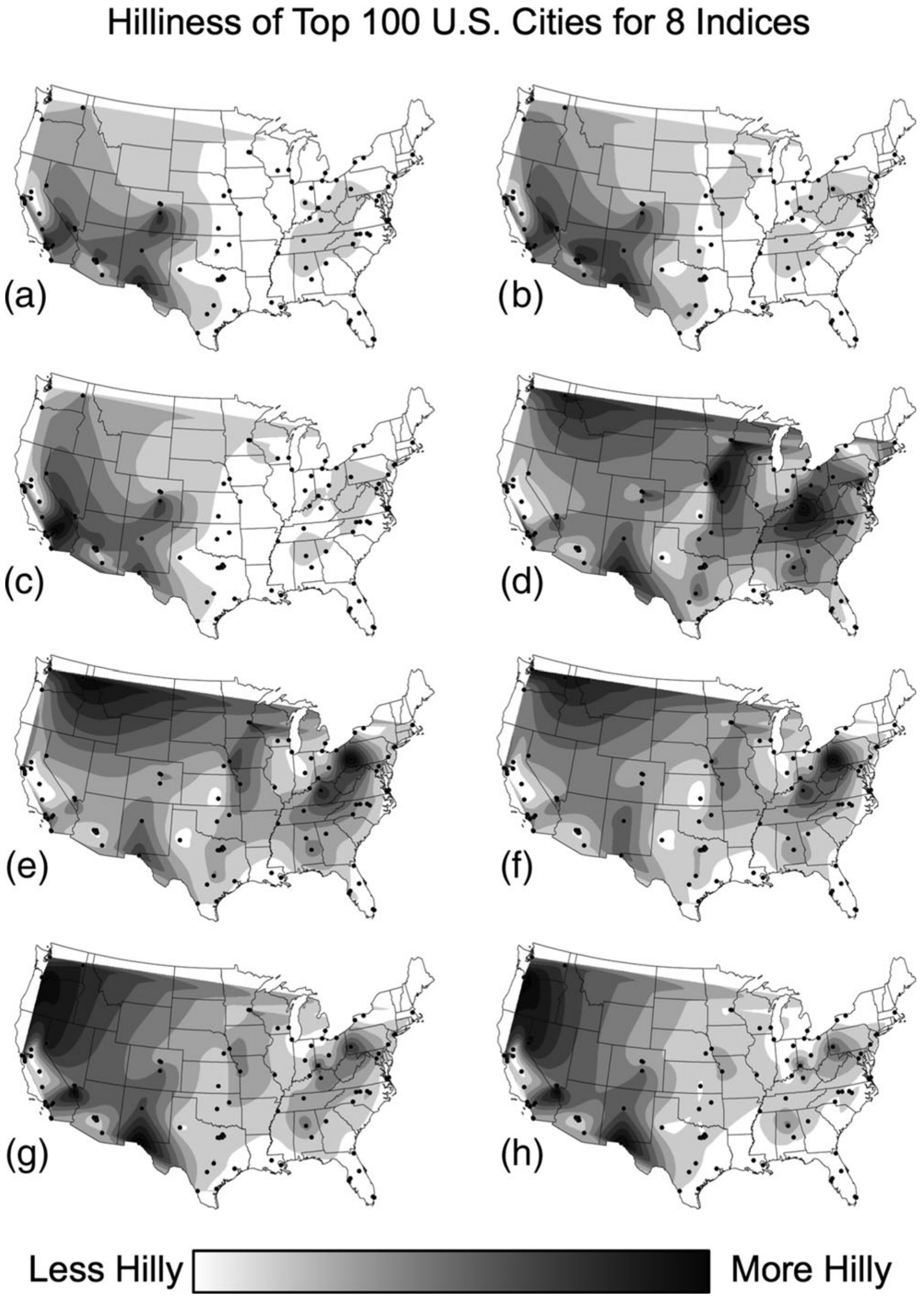

FIG. 1—Interpolated hilliness across the U.S. utilizing eight different metrics: a) elevation range, b) standard deviation of city area, c) Melton Ruggedness, d) standard deviation of a 0.5 km radius from city center, e) same as previous with a 1 km radius, f) same as previous with a 2 km radius, g) same as previous with a 5 km radius, h) slope of metrics (d) through (g). Black indicates greatest hilliness for a metric, white is least.

Rusk 2003). Index H, the synthetic slope of these previous four, was calculated to see if experiences of hilliness might be usefully captured by the change in hilliness from the center to edges of an urban area, giving an experience of being "surrounded" by rugged terrain.

While, as noted above, we find only anecdotal prior references to which U.S. cities can be defined as hilliest (compare Hartwell 2011), such anecdotal references (and the authors' personal experiences) seem to conform most closely to Index F, the standard deviation of elevation over a 2 km radius from the city center, including a top-ten set of cities that include oft-labeled hilly cities such as Pittsburgh, Seattle, San Diego, and San Francisco. As a result, we tentatively identify Index F as our benchmark index for further, future research. This is not to say that Index F is "more correct" than others in our basket, but it may serve as a closer proxy for everyday or "lay" experiences of urban hilliness across U.S. cities.

There is substantial differentiation in rankings for individual cities across the indices, and particularly so for some of the western cities discussed above (see Figure 2). We note that this is not an indication of a failure of certain indices, but rather their potential applicability to differing urban problem domains. Cities ranked high on Index F may offer more of a character of "scenic hilliness," while those that are highly ranked on index A or B (such as Scottsdale, Las Vegas, or San Jose) may face distinctive policy challenges regarding urban-regional management or intraurban migration. We are interested in exploring in more detail the ways that these different indices serve as proxies for different kinds of urban social/political experiences, and detail potential further research directions below.

Directions for Further Research and Policy Implications

We see a number of ways in which hilliness may impact social, political, and economic processes, and trace three "low hanging" examples of future research directions for urban geographers. First, cities with higher levels of hilliness have a larger "ease of use" gradient between walking and driving for urban-scale mobility. While this gradient is not constant across a region—indeed, the utility of Index H is predicated on its variation—areas of the city that are hillier will be more resistant to pedestrians than drivers. This could well have differential impacts on access to jobs, services, and networking opportunities: lower income residents with less access to automobiles will likely experience these areas of the city as more costly to traverse. Urban geographers who examine geographically differentiated development patterns, or social segregation, could use analyses of hilliness to explore how terrain impacts neighborhood formation and identity, how it reinforces or undermines divisions by race and/or class, and the degree to which terrain is wielded consciously toward self-interested political actors. Additionally, urban actors, both government and otherwise, are likely to be see different financial costs (and opportunities) in hillier contexts. Services such as street construction and snow removal are likely to be

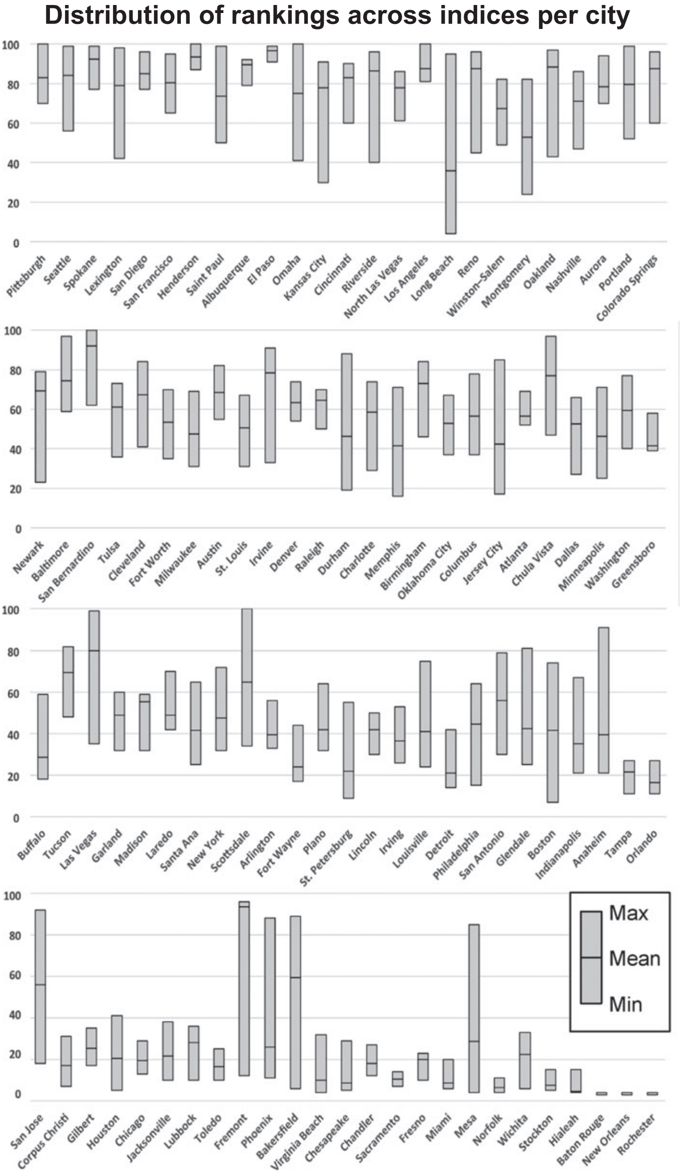

FIG. 2—Maximum, average, and minimum rank of each city across the eight indices, ordered by Index F.

more costly, all else being equal, than in flatter environments. Concomitantly, highly variegated terrain may change the financial trade-offs among various approaches to providing urban-area services such as policing or fire protection, affecting municipal decision making.

Second, the role of landscape aesthetics in urban politics and development is not well established. While urban land markets clearly value a “room with a view," the impact of neighborhood viewsheds or visibility from without may shape political decision making (Bond and others 2002). For example, while Ueland and Warf take note of altitudinal segregation in southern U.S. cities, the dynamics of aesthetics in more vs. less variegated terrains is unclear (2006). Are urban hillsides aesthetically desirable or not? And to what degree is this a function of specific proximity, historical associations, technological regimes (for example Meyer 2012), or other causal factors? Further, how are these aesthetics deployed by those who have power to reinforce their own political goals? While some of these questions have been tentatively explored in the context of rural wild lands—see Terry Daniel and Ron Boster (1976)—in urban political analyses they represent largely open areas of study.

Finally, and perhaps most provocatively, what are the impacts of different kinds of hilliness on social, political, and economic processes? We noted above that cities built around a single major geologic feature—a bluff, ridge, or promontory—are likely to have different dynamics than those whose hilliness is more continuously variable. Baltimore, with one major delineating gorge—the Jones Falls—and several minor associated ones, was slow to develop a unified sewer system: the Falls provided both a substantive, though noxious, substitute option and an obstacle to an integrated system (Boone 2003). The sharp east/west divide in Baltimore extends beyond infrastructure provision to the social, where largely separate gang structures control drug markets in eastern and western neighborhoods (Simon and Burns 1997). The impact of the east/west divide even impacts the genetic divergence of east-side and west-side rat populations (Gardner-Santana and others 2009). How do these dynamics compare with those of cities like San Francisco or Pittsburgh, which are heavily differentiated throughout? Martin Aurand argues that Pittsburgh has three key conceptual "rooms" defined by an interaction of elevation and hills, but these are noncontiguous conceptual spaces: do they mirror the ecological dynamics or service-provision politics of a dominant-gorge city like Baltimore (2006)? What about a city like Portland, Oregon, which possesses large flat areas sharply punctuated by steep features? We know that transportation choices in Portland are shaped by trip terrain (Rodriguez and Joo 2004; Dill and Voros 2015), but not as clearly how such choices made in the hills impact economic or political processes in the flats, or—crucially—how these choices are different from those in a city like Baltimore or one like Pittsburgh. Such comparisons serve as a rich domain for future analyses that explore the functional dynamics of different kinds of physical urban landscapes.

These questions are not only of scholarly interest, but bring into focus the ways in which a more topographically attuned urban geography can be relevant to policy conversations as well. Urban policy is clearly impacted if hilliness impedes amelioration of economic inequality differently across communities, or drives land markets in ways that two-dimensional spatial demographic analyses fail to capture. Geography as a discipline is uniquely suited to contribute to these policy conversations about hilliness; yet, as discussed above, scholars have focused more on altitudinal differentiation than hilliness as a causal factor. This paper's initial exploration suggests that there is a need for further analyses of the impact of hilliness in urban contexts in order to explicate both the community effects and policy challenges that differential hilliness imposes on urban populations.

Additionally, we believe that these kinds of bridging analyses—bringing geography's human and physical wings into analytical engagement—emphasize the flexibility and utility of integrative geographical approaches to urban scholarship. We hope that this project helps to spur urban geographical work that bridges methodological and historical divides (Wyly 2014) and contributes to urban geographic research that is more synthetically geographic. Our aim is that the indices developed here serve as an initial effort to frame and contribute to such future research programs.

NOTE

[1] This list is meant to be illustrative rather than exhaustive; additional dimensions of engagement with hilliness in urban contexts are likely.

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