THE FLATNESS OF U. S. STATES

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Abstract. Does perception match reality when people judge the flatness of large areas, such as U. S. states? The authors conducted a geomorphometric analysis of the contiguous United States, employing publicly available geographic software, Shuttle Radar Topography Mission (SRTM) elevation data, and a new algorithm for measuring flatness. Each 90-m. cell was categorized as not flat, flat, flatter, or flattest, and each state was measured in terms of percentage flat, flatter, and flattest as well as absolute area in each category. Ultimately 48 states plus the District of Columbia were mapped and ranked according to these values.

Asked which U. S. state is the flattest, in a recent nationwide poll, 33% of respondents said Kansas and 23% said Florida (Kozak et al. 2013). Kansans know well this popular notion that Kansas is exceptionally flat, yet any mildly alert observer can see that most of the state is rolling to quite hilly. Indeed, the Great Plains Region as a whole is not as flat as most Americans think it ought to be.

What is the flattest state? Florida is the obvious answer, since its highest point is only 105 m. above sea level, but 77% of all respondents, including 62% of Florida residents, did not recognize its overwhelming flatness.

Which state is second and how do other famously flat states rank when measured geomorphometrically? How well does perception match reality? Landforms can now be measured rigorously over large areas and these questions can be tested empirically.

In the past century, at least three successful attempts have been made to map the physiography of U. S. terrain, and slope has been a key variable in each algorithm (Hammond 1954; Fenneman. 1928, 1931, 1938; Sayre et al. 2010). Areas of low slope are discernible in the final results, and some of the algorithms have been automated in recent years (Dikau 1989, Dikau et al. 1991, Thelin and Pike 1991). The results are suitable for synoptic characterization of large areas at coarse scale, but they do not relate directly to personal perception of topographic landforms at fine scale.

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We aimed for a specific measure of flatness that would mimic human perception *in situ* at close range. Our approach utilized only free and open source Geographic Information Systems (GIS) software, specifically GRASS GIS 6.4 (GRASS Development Team 2010) and Quantum GIS version 1.5 (QGIS Project 2013). Our definition of flatness utilizes a ray-tracing algorithm, r.horizon in GRASS (Huld et al. 2013, Neteler et al. 2008) performed along multiple directions and then combined to produce an index of flatness. Horizontally, the algorithm projects 16 radians from the center point of each 90-m. cell[1] at uniform intervals of 22.5 degrees of azimuth. Vertically, for each radian the algorithm constructs an angle of incidence between the earth tangent and the nearest intersection with a higher cell on the terrain. The ray continues outward to a distance of 5,310 m. with the output being the largest angle encountered along the ray. Determining the appropriate distance to extend the ray relied on a visibility-at-sea conceptual model of flatness. Using the appropriate equation from the *Annapolis Book of Seamanship* (Rousmanier and Smith 1999), it was determined that an observer who is 1.83 m. tall, focusing solely on the horizon, can see a distance of 5,310 m.

Once all 16 rays were computed for each cell, they were classified into binary "flat or not-flat" categories. This again required some estimation to determine at what angle of incidence a flat landscape changes into a not-flat landscape. Based on personal experience with Great Plains landscapes, the authors determined that an angle of 0.32^{o} was the appropriate cut-point for the classification. In practical terms, the visual effect is equivalent to observing a stand of trees 15 m. tall at 2,655 m. distance, or a 30m hill at 5,310 m. (This example serves purely as an illustration related to ordinary human experience; trees do not count in our elevation figures.) This directional approach may seem odd from the viewer's perspective at any given pixel, but it means conversely that any promontory (i.e., any cell more than 30 m. higher than its neighboring cells) exerts an influence over all cells occurring within 5,310 m. of it (Figure 1). This approach is not concerned with depressions (lower elevations) relative to the surrounding area, e.g. small canyons or arroyos, because observers often ignore such depressions in perceiving "flatness" and, in many cases, cannot see them anyway.

Figure 1. Schematic of vertical definition. In this illustration, a promontory (green) the height of a tree (yellow) is considered flat if it occurs at 5,310 m. distance (b) and not flat if it occurs at any closer distance (a).

To produce the flat index (Figure 2), each of the 16 rays was classified into either 0 or 1, with 1 being "flat" (under the 0.32^{o} angle) and then summed together. Therefore, a given cell can have a final flat index score from 0 through 16 where 0 would be not flat in all directions and 16 would be flat in all directions. The final index score was categorized into four classes based on the number of terrain intersections: not flat (0-4), flat (5-8), flatter (9-12), and flattest (13-16). A water mask[2] was

1 The objective is to make the data resolution fine enough to capture nearly all intervening landform features. Once that is achieved, no harm is done by using even finer resolutions. We therefore opted for the finest digital elevation data available worldwide.

2 "Masking" is a standard GIS function which identifies all features of a given type and assigns them to a "no data"

then used to remove any large lakes or reservoirs from the data, and the data were summarized within state boundaries (Table 1).

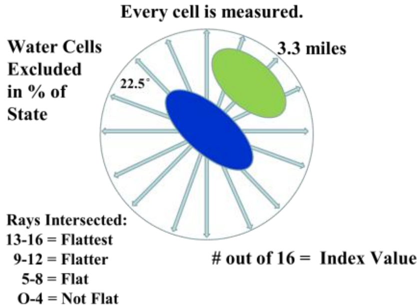

Figure 2. Schematic of the horizontal definition applied in sequence to each cell in the entire spatial array. In each case, 16 rays are projected azimuthally and intersections with higher terrain are counted . The green oval represents a promontory affecting three radians. The blue oval represents a water body, which would not be counted in the area calculations.

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category.

Rank Percentage of State Area in Flat, Flatter, and Flattest Categories	State or District	Rank Percentage of State Area in Flattest Category	Percentage of State Area in Flat, Flatter, & Flattest Categories	Percentage of State Area in Flattest Category	Percentage of State Area in Flatter Category	Percentage of State Area in Flat Category	Percentage of State Area Not Flat
1	Florida	1	52	16	15	21	48
2	Illinois	3	50	9	16	26	50
3	North Dakota	7	49	8	14	27	51
4	Louisiana	2	47	10	15	23	53
5	Minnesota	5	47	8	14	25	53
6	Delaware	6	44	8	13	23	56
7	Kansas	9	44	6	13	25	56
8	Texas	8	43	6	12	26	57
9	Nevada	38	43	1	5	37	57
10	Indiana	12	42	5	13	24	58
11	South Dakota	17	40	4	10	26	60
12	Michigan	22	40	3	10	26	61
13	New Mexico	29	38	2	7	29	62
14	Arizona	36	38	1	7	31	62
15	South Carolina	4	38	8	10	19	62
16	Oklahoma	23	37	3	10	25	63
17	New Jersey	14	37	5	10	23	63
18	Iowa	13	36	5	11	21	64
19	Nebraska	20	36	4	9	23	64
20	Ohio	19	36	4	10	22	64
21	Arkansas	10	35	5	10	20	65
22	Mississippi	15	35	4	10	21	65
23	Utah	32	35	2	4	29	65
24	California	24	35	2	5	27	65
25	Colorado	31	34	2	6	26	66
26	North Carolina	11	33	5	9	19	67
27	Rhode Island	26	32	2	6	24	68
28	Maryland	18	31	4	7	20	69
29	Wisconsin	25	31	2	8	21	69
30	Georgia	16	31	4	8	19	69
31	Missouri	21	30	3	8	18	70
32	Idaho	40	29	1	4	24	71
33	Wyoming	46	29	0	4	24	71
34	Montana	39	28	1	4	23	72
35	Oregon	44	28	1	3	24	72
36	Maine	43	26	1	3	22	74
37	Alabama	27	26	2	6	17	74
38	District of Columbia	35	25	1	4	20	75
39	New York	37	25	1	4	21	75
40	Massachusetts	34	25	1	5	19	75
41	Washington	41	25	1	3	21	75
42	Virginia	28	24	2	5	17	76
43	Tennessee	33	22	1	5	15	78
44	Connecticut	42	21	1	3	17	79
45	Vermont	49	20	0	2	18	80
46	New Hampshire	48	20	0	2	18	80
47	Kentucky	30	20	2	5	13	80
48	Pennsylvania	45	20	1	3	16	80
49	West Virginia	47	12	0	2	10	88

Table 1. Calculated percentages of not flat, flat, flatter, and flattest land ranked by state. Although applied here to U. S. states, this method is designed to be applied globally to all land surfaces covered by Shuttle Radar Topography Mission (SRTM) elevation data, i.e., all land areas between 60 degrees north latitude and 54 degrees south latitude.

We began with the following hypotheses, based on field observations over many years of field experience unrelated to the project:

1. Florida would be the flattest state.
2. Illinois would be the second flattest state.
3. Other extremely flat states would include coastal ones with only small portions (edges or corners) in uplands. South Carolina and Delaware are good examples.
4. Kansas would not rank among the top five flattest states.

All four null hypotheses are rejected (Table 1; Figures 3 and 4).

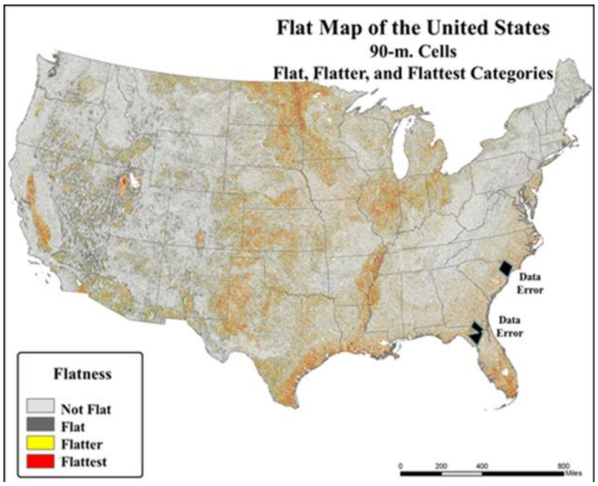

Figure 3. Flat map of the contiguous United States.

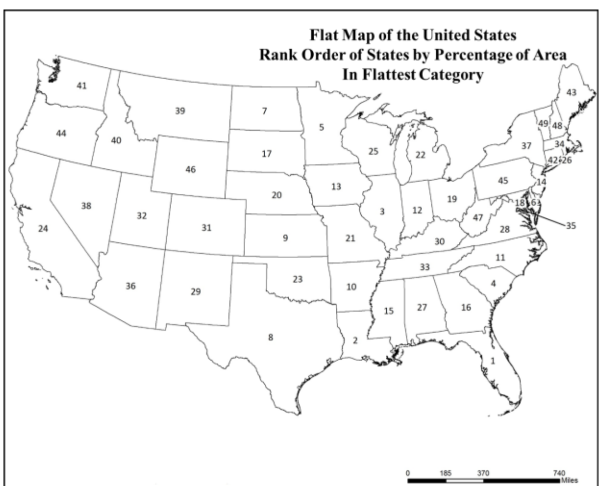

Figure 4. Numbers indicate rank order of 48 contiguous U. S. states plus the District of Columbia by percentage in flattest category.

In an article published as a spoof but based on actual data and legitimate algorithms, three geographers (Fonstad et al. 2003) cleverly proved that "Kansas is flatter than a pancake." Their conclusion was widely reported by news media and accepted as proof by many people. The argument played well in a public already inclined to believe that Kansas is flat, but Lee Atchison, then Director of the Kansas Geological Survey, retorted that, by that measure, any state, even mountainous Colorado, would be flatter than a pancake. His point is readily conceived if one imagines stretching a pancake to the size of a state. The pancake measured in the article was 130 mm, and its surface relief was 2 mm. Apply that ratio to the east-west dimension of Kansas, approximately 644 km., and the state would need a mountain 9,908 m. tall in order *not* to be flatter than a pancake. Since the highest mountain in the world is 8,848 m. tall, every state in the U. S. is flatter than a pancake.

2 / 130 X 644,000 m. = 9,908 m.

Clearly, popular notions do not match the measured flatness of U. S. states. Florida is a fascinating case because its land is so demonstrably flat, and yet so few people think of it as such. This, in turn, begs the question, "What drives human perceptions of flatness?" Do Florida's dense forests mask its flatness? Does standing water influence human perception of flatness?

The case of Kansas versus Illinois raises another compelling question. Does azimuthal orientation affect the perception of how much total area is flat? Drivers crossing the U. S. east-to-west or west-to-east traverse the short axis of Illinois and the long axis of Kansas. Does that mean travelers mentally tolerate the flat expanse in Illinois and yet grow weary of the flat expanse in Kansas? Eastern Colorado is just as flat as Kansas, both being in the High Plains Physiographic Section[3]; do drivers later reflecting on crossing the state mentally meld the High Plains of Kansas with the High Plains of Colorado and think of it all as flat Kansas? Answers to all these questions will be complicated by other factors, such as the preference of Interstate highway planners for long level stretches of interfluve compared to the general topography spanned by smaller roads.

These and other questions suggest fruitful avenues for future research. However, breakthroughs that will alter present perceptions are difficult to imagine.

Does it matter? Yes, aside from state pride, stereotypes have consequences. Business, academic, and other recruiting, for instance, are hampered by negative attitudes about the perceived flatness of "fly-over country" held by even the most qualified candidates[3].

Perception notwithstanding, measuring and mapping flatness are important. Significant economic implications are associated with distinctive combinations of promontories and flat land that, for instance, create scenic vistas, produce favorable sites for wind farms to generate electricity, or determine the need for and cost of snow removal in winter storms. These are real costs that demand serious attention over large areas.

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References

3 We are not aware of any empirical studies on these topics, but anecdotal evidence abounds.

Dikau, R. 1989. The application of a digital relief model to landform analysis. In *Three Dimensional Applications in Geographical Information Systems*, ed. J. F. Raper, 51-77. London: Taylor and Francis.

Dikau, R., E. E. Brabb, and R. M Mark. 1991. Landform classification of New Mexico by Computer. U.S. Geological Survey Open File Report 91-634.

Fenneman, N. M. 1928. Physiographic divisions of the United States, *Annals of the Association of American Geographers.* **18**:261-353.

Fenneman N. M. 1931. *Physiography of the Western United States*. New York: McGraw-Hill Book Co., 534 pp.

Fenneman, N. M. 1938. *Physiography of the Eastern United States*. New York: McGraw-Hill Book Co., 691 pp.

Fonstad, M., W. Pugatch, and B. Vogt. 2003. Kansas is flatter than a pancake. *Annals of Improbable Research* **9**(3):16-17.

GRASS Development Team, 2010. Geographic Resources Analysis Support System (GRASS) Software, Version 6.4.0. Open Source Geospatial Foundation. (http://grass.osgeo.org Accessed July 28, 2013).

Hammond, E. H. 1954. Small scale continental landform maps. *Annals of the Association of American Geographers.* **44**:33-42.

Huld, T., T. Cebecauer, J. Hofierka, and M. Suri. 2013. r.horizon (http://grass.osgeo.org/grass64/manuals/r.horizon.html) Accessed July 28, 2013.

Kozak, S. L., J. E. Dobson, J. S. Wood, et al. 2013. *The American Geographical Society's Geographic Knowledge and Values Survey: Report of Results for the United States*, Special Publication # 43, American Geographical Society, Brooklyn, NY, 78 pp. http://www.amergeog.org/geoknowledgesurvey13.pdf Accessed July 1, 2013.

Neteler, M., D. Beaudette, P. Cavallini, L. Lami, and J. Cepicky. 2008. "GRASS GIS," Chapter 9 in *Open Source Approaches in Spatial Data Handling*, ed. G. B. Hall and M. G. Leahy, 171-199. Berlin, Heidelberg: Springer Berlin Heidelberg.

QGIS Project. 2013. *QGIS User Guide* QuantumGIS software (http://download.osgeo.org/qgis/doc/manual/qgis-1.8.0_user_guide_en.pdf Accessed July 28, 2013).

Rousmaniere, J., and M. Smith. 1999. *The Annapolis Book of Seamanship*, Third Edition. New York: Simon & Schuster, 403 pp.

Sayre, R., P. Comer, J. Cress, and H. Warner. 2010. Terrestrial ecosystems of the conterminous United States: U.S. Geological Survey Scientific Investigations Map 3106, scale 1:5,000,000, 1 sheet.

Thelin, G. P. and R. J. Pike. 1991. Landforms of the conterminous United States: a digital shaded-relief portrayal, USGS IMAP: 2206.