Geomorphometric analysis of morphoclimatic zones on the Earth

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Abstract— **The aim of the research was the comparison of selected geomorphometric parameters for the Earth morphoclimatic zones, which are classified differently by various authors. An attempt was made to assess the classification of the zones by Büdel [3], Tricart, Cailleux [11] and Poser, Hagedorn [9]. Selected primary and secondary parameters were calculated on the basis of SRTM V4. In the next step of the study the zones were also compared to the Köppen-Geiger climate classification map [10].**

I. INTRODUCTION

Supply of various amounts of solar radiation to the terrestrial Earth's surface from the North Pole to the South Pole causes diversified reactions of geomorphological processes shaping the morphological surface of the Earth. On a diverse supply of solar radiation shall be imposed in addition to its seasonal variability throughout the year. As a result of the repeated delivery of radiation in daily, seasonal, annual, multi-year and even longer cycles and the corresponding dominant, secondary and extreme processes produce on the globe a distinctive belt system matching separate morphoclimatic zones. In view of the permanent recurrence of the same or similar geomorphological processes in similar spatial and temporal scales, is indeed a relief type well enough formed to be grasped by geomorphometric parameterization? Can individual morphoclimatic zones be classified with geomorphometric parameters? Which of the primary or secondary geomorphometric parameters best reflect diversity of the morphoclimatic zones?

The present paper is attempted reply to the above-mentioned question. Selected geomorphometric characteristics will be presented according to different authors. Morphoclimatic zone classifications by Büdel [3], Tricart, Cailleux [11] and Hagedorn, Poser [9] were evaluated. Büdel [3] claims that at each point on the earth climate determines the fundamental combination of morphogenetic processes. His classification is based primarily on morphological criteria which correlate to climate. Tricart, Cailleux' [11] proposed classification is based on two types of criteria: large climatic and biogeographic zones that provide the principal divisions, and subdivisions based on the preceding criteria combined with paleoclimatic differences. Hagedorn and Poser [9] used a combination of geomorphological processes and factors indicating the spatial order of landforms. Zonal morphological and climatic variation of the Earth, therefore, reflects the spatial distribution of the nature and intensity of the ancient and modern processes of erosion, denudation and accumulation. This also includes extreme processes causing various geomorphological hazards corresponding to each zones.

II. DATA AND METHODS

A. Data

Morphoclimatic zone maps by three authors [3], [11] and [9] are obtained from rather low accuracy, literature-published analogue sources which have digitized to get polygon vector layers with consistent coverage for the whole world. Vector data were exported to the same coordinate system.

Elevation data obtained from the Shuttle Radar Topography Mission (SRTM Version 4) were used in the study [6]. For the downloaded tiles mosaic function was used to obtain a complete digital surface model. The disadvantage of the data was the lack

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of coverage for areas above 56°S and above 60°N. Consequently glacial zones (polar areas) are excluded from the comparison calculation. However, this was not considered an error, because most of the Earth surface area in the glacial zone included Antarctica, Greenland and the Arctic islands, so the areas covered by more than 90-95% of the continental or local ice sheets, do not capture the real nature of the surface topography.

We also analyzed Köppen-Geiger's climatic maps [10] according to the observed data for the period 1976-2000.

B. *Methodology*

Selected classifications of morphoclimatic zones are based primarily on morphological criteria, however, adopted arbitrarily by the authors, without confirming the results in the quantitative analysis. Currently available digital elevation models (DEM) datasets of global extent make it possible to verify and improve the classifications presented in the literature. In order to examine previously developed maps of morphoclimatic zones multiple parameters were calculated. Primary parameters consisted of relative heights, slope [2], plan and profile curvature [13]. We used in the analysis also the secondary parameters i.e. Topographic Wetness Index [1] and Convergence Index [8]. Within the analyzed zones we also compared automatic landform classification methods based on Topographic Position Index [12], Hammond's classification [4], unsupervised nested-means algorithm and a three part geometric signature; slope gradient, local convexity, and surface texture [5].

For the primary and secondary parameters descriptive statistics such as minimum, maximum, range, mean, standard deviation within each morphoclimatic zone were calculated. Then the parameter maps have been classified on the basis of the natural distribution of Jenks method [7]. Within each morphoclimatic zone, area percentage was calculated for the derived classes of parameters, as well as the percentage of surface forms generated on the basis of automatic classification methods [4, 5, 12].

C. *Hardware and software*

The data prepared for calculations constitute so called typical **big data**. Apart from input data for calculations, which take up a lot of space, any step calculation data and final results require enormous computing power as well. Therefore, the data pose a big performance challenge for computer hardware and software. The best solution is to use supercomputers with very big virtual memory and big disc space. In the study, ArcGIS v. 10.1 software was used.

III. RESULTS

Because of long-lasting and demanding calculation procedures, it is estimated that all calculations will be concluded in May 2015. The results obtained so far allow looking at the end-results of undertaken analysis with optimism.

Calculations according to unsupervised nested-means algorithm [5] using these authors' data should be considered as first. Iwahashi, Pike [5] obtained terrain class values, as well as terrain series values for the entire world (see last row in Table I). The table also contains newly calculated data for terrain classes and series, for individual morphoclimatic zones according to the classifications of Büdel [3], Tricart, Cailleux [11] and Hagedorn, Poser [9]. Differences for the entire world data between the original Iwahashi, Pike [5] data and the three classifications are relatively small and fall in the range of -3.1 to 2.4%. This means that at the scale of the entire world — regardless of the morphoclimatic zone classification method — the results are similar, despite the fact that glacial zones are not allowed for in the calculations. Extremely interesting information is provided by the analysis of data for the 16-fold terrain classes, which indicate significant differences in individual morphoclimatic zones according to different classifications (Table I, Fig. 1). They show obvious differences in the morphological development of morphoclimatic zones, regardless of classification.

Maps prepared for the primary and secondary geomorphometric parameters constitute the next series of results. Not all of the parameters have proven to be fully useful for the characteristics and differentiation of morphoclimatic zones. However, in many cases the analysis of the special layout of these parameters allows to discover interesting morphogenetic observations. The unquestionable benefit of many geomorphometric parameters is the possibility to indicate the morphometric relief circumstances fostering the presence of geomorphological hazards such as flooding or landslides.

The analysis of other results, including maps resulting from automatic landform classification, is still under way. The preliminary results at the scale of individual continents indicate big interpretation possibilities.

TABLE I. Terrain classes and series according to Iwahashi and Pike (2007) for three morphoclimatic classifications of the Earth [%]

Author	**Morphoclimatic zones**	**16-fold terrain classes**																**4-fold terrain series***			
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**I**	**II**	**III**	**IV**
		Percentage in zones																			
Büdel (1963)	Zone of pronounced valley formation	9.2	2.2	7.8	1.5	21.5	3.5	6.9	1.5	17.3	1.9	3.2	1.0	12.1	3.7	2.5	4.1	60.1	11.4	20.4	8.1
	Extratropical zone of valleys formation	16.1	1.1	8.7	1.9	17.9	2.2	7.3	2.8	12.7	2.0	3.3	1.8	8.5	4.1	2.4	7.3	55.2	9.3	21.7	13.8
	Subtropical zone of pediment and valley formation	18.1	1.0	11.4	4.2	7.7	2.0	8.6	6.2	5.8	1.7	4.8	4.2	3.7	3.4	2.9	14.4	35.3	8.1	27.6	29.0
	Tropical zone of planation surface formation	8.2	0.5	7.8	1.2	13.8	1.3	11.1	2.5	11.8	2.1	7.3	3.4	7.7	4.6	3.9	12.8	41.5	8.5	30.0	19.9
	Average	***12.9***	***1.2***	***8.9***	***2.2***	***15.2***	***2.3***	***8.5***	***3.3***	***11.9***	***1.9***	***4.7***	***2.6***	***8.0***	***4.0***	***2.9***	***9.7***	***48.0***	***9.3***	***24.9***	***17.7***
Tricart, Cailleux (1965)	Periglacial regions without permafrost	13.0	2.5	10.3	1.9	20.6	3.2	7.5	1.5	15.7	1.5	2.9	0.8	11.6	2.4	2.3	2.4	60.9	9.7	22.9	6.5
	Forest on Quaternary permafrost	7.6	3.1	5.9	1.6	25.1	3.0	8.0	1.9	21.8	0.9	3.9	0.7	12.6	0.9	2.1	0.9	67.2	7.8	19.9	5.1
	Maritime forest zone of mid-latitudes with mild winters	26.8	0.7	15.4	1.7	23.1	1.1	8.6	1.2	9.8	0.6	1.9	0.4	5.5	1.3	0.9	1.0	65.3	3.7	26.7	4.3
	Maritime forest zone of mid-latitudes with severe winters	21.4	0.2	12.1	0.5	17.2	0.3	10.4	0.9	11.3	0.4	5.0	0.8	6.1	1.4	3.6	8.4	56.1	2.3	31.1	10.5
	Mid-latitude forest zone of Mediterranean type	9.6	0.3	4.9	0.3	20.9	1.6	6.6	1.1	18.5	1.8	3.8	1.2	13.8	5.0	3.5	7.0	62.8	8.8	18.8	9.7
	Semi-desert steppes	29.2	0.9	19.2	3.9	14.6	0.9	11.2	3.6	3.7	0.5	2.6	1.8	1.0	0.8	1.1	4.9	48.5	3.1	34.2	14.1
	Semi-desert steppes with severe winters	4.6	0.7	5.3	2.5	10.0	3.2	8.4	5.7	8.5	4.3	4.9	5.6	5.1	7.6	2.6	21.1	28.2	15.8	21.2	34.8
	Deserts and degraded steppes without severe winters	3.8	0.7	4.0	2.3	6.2	2.4	8.3	5.9	9.3	3.7	8.7	7.1	7.7	6.7	5.4	17.6	27.0	13.5	26.5	33.0
	Deserts and degraded steppes with severe winters	8.6	1.9	8.6	7.8	4.8	4.5	7.8	12.0	4.4	2.6	3.8	5.6	4.7	4.4	3.0	15.7	22.5	13.4	23.1	40.9
	Savannas	5.4	0.3	5.0	0.6	21.4	1.4	12.1	1.7	13.0	2.0	7.4	2.5	4.9	4.2	3.1	15.0	44.7	7.8	27.6	19.9
	Intertropical forests	9.0	0.3	11.0	0.7	14.0	0.4	12.5	0.7	15.9	0.5	7.7	0.8	12.3	3.1	4.8	6.3	51.2	4.3	36.0	8.5
	Azonal mountain areas	39.4	2.3	18.1	5.1	7.7	1.5	6.9	4.2	2.7	0.7	2.1	1.9	1.4	0.8	1.0	4.2	51.2	5.4	28.0	15.4
	Average	***14.9***	***1.2***	***10.0***	***2.4***	***15.5***	***2.0***	***9.0***	***3.4***	***11.2***	***1.6***	***4.6***	***2.4***	***7.2***	***3.2***	***2.8***	***8.7***	***48.8***	***8.0***	***26.3***	***16.9***
Hagedorn, Poser (1974)	Most intense fluvial processes, very strong mass movements	11.0	0.4	11.3	0.8	14.0	0.3	11.5	0.6	17.2	0.4	6.9	0.5	14.3	2.3	4.6	3.9	56.5	3.4	34.3	5.7
	Fluvial processes and sheet wash	11.5	0.3	9.6	0.8	19.6	0.9	12.2	1.4	10.8	1.0	6.0	1.5	4.2	3.8	2.9	13.3	46.1	6.1	30.7	17.0
	Most intense sheet wash	5.1	0.4	6.4	1.3	13.9	1.8	12.5	3.2	9.7	2.4	8.4	4.2	4.6	4.5	3.6	18.0	33.3	9.1	30.9	26.7
	Most intense eolian processes, episodically strong sheet wash and episodic fluvial processes	3.0	0.9	4.1	3.2	5.5	3.0	7.5	7.2	7.9	4.1	7.1	7.2	6.6	7.5	4.5	20.8	22.9	15.5	23.1	38.5
	Intense slope wash and periodic strong fluvial processes	22.0	1.4	11.5	4.8	10.7	2.3	9.6	6.5	5.6	1.8	4.1	3.6	2.9	2.3	2.1	8.8	41.3	7.7	27.3	23.7
	Moderate fluvial processes, other processes especially weak	12.2	0.5	6.1	0.7	19.5	1.9	6.7	1.5	16.5	2.1	3.7	1.5	11.2	4.9	3.2	7.9	59.4	9.4	19.6	11.6
	Cryo-dynamic processes, including thermoerosion, intense slope wash and fluvial processes	25.1	1.7	13.9	2.9	18.0	1.9	7.5	2.1	10.6	0.9	2.3	0.9	7.0	1.5	1.5	2.1	60.7	6.1	25.2	8.0
	Average	***12.8***	***0.8***	***9.0***	***2.1***	***14.5***	***1.7***	***9.6***	***3.2***	***11.2***	***1.8***	***5.5***	***2.8***	***7.3***	***3.8***	***3.2***	***10.7***	***45.7***	***8.2***	***27.3***	***18.7***
Iwahashi, Pike (2007)		*13.2*	*0.9*	*9.0*	*2.1*	*14.3*	*1.8*	*9.1*	*3.3*	*10.9*	*1.9*	*5.2*	*3.0*	*7.2*	*4.0*	*3.2*	*10.9*	***45.7***	***8.7***	***26.4***	***19.3***

* Explanation of Terrain series: I - 1+5+9+13: fine texture, high convexity; II - 2+6+10+14: coarse texture, high convexity; III - 3+7+11+15: fine texture, low convexity; IV - 4+8+12+16: coarse texture, low convexity

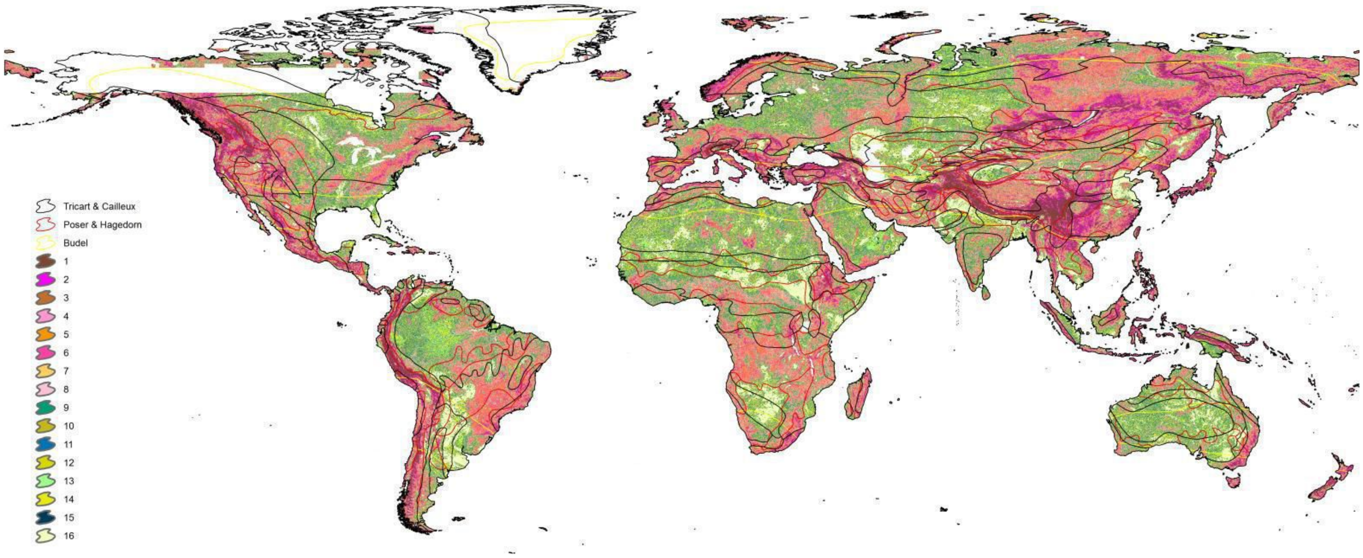

Figure 1. Spatial distribution of the terrain classes according to Iwahashi and Pike (2007) for three morphoclimatic classifications of the Earth.

IV. CONCLUSIONS

The obtained preliminary data confirm the sense of the undertaken research problem. The possibility to use big data in the calculation of geomorphometric characteristics for selected classifications of morphoclimatic zones at the scale of the entire world opens new ways of interpreting the landforms. Budel's proposal [3] should be considered the least useful of the three morphoclimatic classifications analysed. Generally, it may be assumed that the more complex the morphoclimatic classification, the better it adjusts to the spatial geomorphometric diversification of the topographic surface of the world.

Today, automatization of the digital elevation model calculation procedures constitutes one of the more important challenges of geomorphometry. The increase in the number and quality of elevation data through the creation of digital elevation models of higher and higher resolution guarantees such solutions.

REFERENCES

[1] Beven, K.J., Kirkby, M. J., Seibert, J., 1979. "A physically based, variable contributing area model of basin hydrology". Hydrolological Science Bulletin, 24:43–69.

[2] Burrough, P.A., McDonell, R.A., 1998. "Principles of Geographical Information Systems". Oxford University Press, New York, 190.

[3] Büdel, J., 1963. "Klima-genetische Geomorphologie". Geographische Rundschau, 15:269-285.

[4] Dikau, R., Brabb, E.E, Mark, R.M., 1991."Landform classification of New mexico by computer." Open File Report 91-634. U.S Geological Survey.

[5] Iwahashi, J., Pike, R., 2007. "Automated classification of topography from DEMs by an unsupervised nested-means algorithm and three-part geometric signature." Geomorphology 86, 409-440.

[6] Jarvis, A., Reuter, H.I., Nelson, A., Guevara, E., 2008. "Hole-filled seamless SRTM data V4". International Centre for Tropical Agriculture (CIAT). http://srtm.csi.cgiar.org.

[7] Jenks, G.F., 1967. "The Data Model Concept in Statistical Mapping. International Yearbook of Cartography". 7:186–190.

[8] Koethe, R., Lehmeier, F., 1996. "SARA - System zur Automatischen Relief-Analyse". User Manual, 2.

[9] Hagedorn, J., Poser, H., 1974. "Räumliche Ordnung der rezenten geomorphologischen Prozesse und Prozesskombinationen auf der Erde". Abh. Akad. Wiss. Göttingen, Math.-Physik. Kl. III/29, Göttingen: 426-439.

[10] Rubel, F., Kottek, M., 2010. "Observed and projected climate shifts 1901-2100 depicted by world maps of the Köppen-Geiger climate classification". Meteorol. Z., 19, 135-141.

[11] Tricart, J., Cailleux, A., 1965. "Introduction à la géomorphologie climatique". Traité de géomorphologie, tome I, SEDES, París, 306 p.

[12] Weiss, A., 2001. "Topographic position and landforms analysis". Poster Presentation, ESRI User Conference, San Diego, CA.

[13] Zeverbergen, L.W., C.R. Thorne. 1987. "Quantitative Analysis of Land Surface Topography". Earth Surface Processes and Landforms, 12:47–56.