CAUTION DUST STORMS DO EXIST (and so do mountains): Modeling dust source suitability within an object-oriented geoecology

Charles P. Jackson
Department of Geography
New Mexico State University
Las Cruces, USA
charliej@nmsu.edu

Abstract—**GIScience has long been dominated by the naturalistic and scientistic ontological constraints championed by Willard Van Orman Quine. This has relegated dust storms and even mountains to the so-called slum of possibles that Quine had sought to clear in favor of a more aesthetic desert landscape. Paradoxically, mountains and dust storms often are real constituents of Earth's deserts and semi-arid regions. The New Mexico Department of Health (NMDOH) is studying air quality and its impact on human health in the U.S.-Mexico border region. Emissions of fine particulate matter (PM_{10}) from the Pleistocene pluvial Lake Palomas basin in the Chihuahuan Desert are a primary concern. Through Graham Harman's object-oriented philosophy and rejection of the abiotic and biotic as ontologically distinct realms, "species" distribution models (SDMs) generated in Maxent become possible with just a small number of dust source presences located in MODIS visible band imagery. The first models from 2013 used multiple geoecologically relevant terrain objects to replace the geographically uncertain point sources. Although the terrain objects had been segmented with eCognition® from only two of the three ASTER GDEM parameters used, the early SDMs nevertheless suggested that dust storms are accessible on geomorphometric terms alone. Wind directions were derived in 2014 using dust plume image objects segmented from the MODIS thermal band translations of three dust storms. Three 'wind-related terrain attributes' were then generated for each storm in Whitebox GAT from the SRTM DEM to complement the new SRTM terrain objects. When comparably biased multi-object "background data" also replace the 10,000 pixel-level background samples in Maxent, the model AUCs decrease expectedly but still remain high enough for the SDMs to be potentially useful. The probability distributions are now "projected" over the same extents to the successively lower object and pixel levels in this novel and geographically scalar approach.**

I. INTRODUCTION AND BACKGROUND

Dust storms and the emissions of fine particulate matter (PM_{10}), airborne particles with aerodynamic diameters less than 10.0 µm, have been studied across many of Earth's endorheic basins and dry plains. Most of the studies oriented towards the sources of PM_{10} have typically focused on geomorphological settings, soil types, anthropogenic factors, land cover, climatic and meteorological drivers of atmospheric dust loading or, in some cases, the discernment of dust plumes in satellite imagery. In addition, some recent studies have turned to the sub-basin scale and even include attempts at locating individual dust sources in MODIS imagery [1], [2]. However, until now, none has approached dust storms as unified and ephemeral objects with component parts in a geomorphometric and geoecological context.

The development of an object-oriented maximum entropy approach for modeling dust source suitability distributions began in 2013 as an attempt to utilize what was previously done by [1] and [3]. [1] located close to 150 individual dust sources from the distinct plumes visible in the U.S.-Mexico border region and on the U.S. southern High Plains in a "true color" enhancement of the MODIS translation of the 15 December 2003 dust storm. [3] developed a method for locating dust sources in NOAA GOES and POES satellite imagery that translated five synoptically-forced dust storms in the border region during 2002 and 2003. Of the five dust storms in [3], only three have samples with at least 15 presences located in the higher spatial resolution NOAA POES AVHRR imagery to take advantage of the 'hinge features' in the presence-only maximum entropy modeling software known as Maxent [4]. As was expected, the preliminary model that used the MODIS presences from the border region in [1] outperformed those using the far more geographically uncertain AVHRR presences from [3].

Species distribution models (SDMs) are important for determining the distribution of suitable conditions for a species or, in this case, objects. Geographic bias in sampling can be especially problematic for presence-only or presence-background

In: Geomorphometry for Geosciences, Jasiewicz J., Zwoliński Zb., Mitasova H., Hengl T. (eds), 2015. Adam Mickiewicz University in Poznań - Institute of Geoecology and Geoinformation, International Society for Geomorphometry, Poznań

models [4], [5]. Sampling satellite imagery for dust source occurrences has its own peculiar forms of bias associated with it. First, because discovery is constrained by the spatial resolutions of the imagery, we cannot say that there are, in fact, any true absences. Second, the dust plumes can sometimes obscure additional underlying sources and plumes [1] resulting in an upwind concentration at or near the 'plume head' [2]. Third, the object-oriented ontology used here for replacing the geographically uncertain point sources introduces a new bias and its own subsequently novel and geographically scalar solution.

One consequence of the *anti*-object-oriented naturalism and ontological scientism established by [6] and endorsed by [7] is the reduction of geomorphometric data to "ancillary" status in service to a more primary optical remote sensing. Despite the many object-based and object-oriented approaches and some noteworthy attempts to unify them with field-based models, none have been object-oriented in the ontological sense. That is, entities, objects and fields are typically either reduced downward to supposedly more fundamental elements or processes or reduced upward to events, appearances, aggregates, bundles of qualities, effects or relations [8], [9]. Contra anthropocentric philosophy, all forms of access are indirect and take place on the interior of a containing relation-object [10]. Not even mountains are reducible to mere conceptualizations or specific aggregates of molecules, as they are for [11], but are indeterminate and real objects in their own right that remain susceptible to translation by humans, glaciers, air parcels and the asthenosphere.

II. Methods and Materials

A. *Terrain attributes*

A 3-arc-second CGIAR-CSI post-processed Shuttle Radar Topography Mission (SRTM) DEM mosaic was projected in the UTM projection with a 90 meter spatial resolution and filtered in Whitebox GAT. Two geoecologically relevant terrain attributes were generated in Whitebox GAT for use in Maxent along with elevation. The first is the statistical parameter measuring local vertical complexity in the DEM generated with a three by three neighborhood application of the 'standard deviation filter' [12], [13]. It is referred to here as 'local variability' (LV). [14] used 'local variance' (also LV) to refer to a statistical procedure for describing the variability over an entire image, and [15] were correct in later renaming it as 'average local variance' (ALV). Because the local variability of any parameter can be a quality of objects at any spatiotemporal scale including the image as a whole, the use of LV as local variability is retained here for the sake of simplicity.

The second terrain parameter approximates the asymmetrical heating of the land surface in the northern hemisphere [16]. This simple estimation of the anisotropic diurnal heat (H_α) distribution (referred to here as ADHD) is generated through a seven-step process involving the local slope aspect and angle of the DEM as they appear in the following formula:

$$H_\alpha = \cos(\alpha_{max} - \alpha) \cdot \arctan(\beta)$$

where α_{max} is the slope aspect of maximum total heat surplus in the northern hemisphere (202.5°), α is slope aspect and β is the slope angle [16]. The ADHD index effectively approximates relative available soil moisture, possible changes in soil type and even possible changes in ecological community structure and function, especially when it is coupled with vertical complexity and elevation in terrain segmentations within an object-oriented ontology. Use of the biophysically and geoecologically relevant ADHD parameter also circumvents the problem encountered by [17] when attempting to segment terrain objects from surrogates like slope aspect [5].

B. *Wind-related terrain attributes*

Due to the absence of surface meteorological observations, surface wind azimuths were approximated using the directions of long and narrow 'microplume' objects. The reprojected 1 km spatial resolution MODIS thermal infrared (TIR) surface/cloud temperature bands (23, 32 and 31) were segmented and classified in eCognition® after a histogram equalization was applied to highlight and intensify the dust plumes (Fig. 1). The 'main direction' of the microplumes were averaged and reversed by 180° for the wind azimuths. The 'directional relief', 'fetch analysis' and 'relative aspect' were then generated in Whitebox GAT using the hypothetical azimuths for each storm [18].

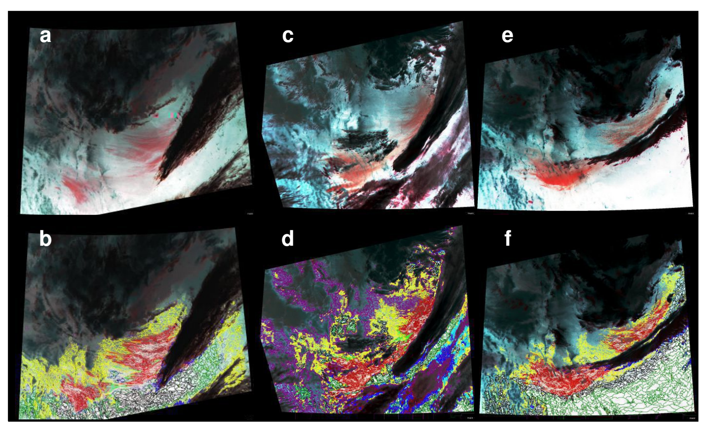

Fig. 1. The 1 km spatial resolution MODIS thermal infrared (TIR) surface/cloud temperature bands 23, 32 and 31 (red, green and blue (RGB), respectively) after reprojection and histogram equalization (top row). Border region (left) and High Plains region (right) dust plumes appear red in these TIR translations of the 15 December 2003 (a&b), 19 February 2004 (c&d) and 27 November 2005 (e&f) dust storms. The classified objects appear in the bottom row. Wind azimuths were derived from the white microplume objects within the red 'macroplumes'.

C. Terrain segmentations

Multiresolution terrain segmentations were completed for three subsets in the U.S.-Mexico border region containing the dust source presences so as to minimize presence-background bias [4], [5], [19]. A 'scale parameter' of four was used and the 'shape' and 'compactness' homogeneity criteria were set at 0.1 and 0.7, respectively. Only the LV and ADHD attributes were used and a double weight was applied to the ADHD layer to ensure a higher degree of geoecological relevance. This results in terrain objects locally determined by both the variability in elevation and the estimated topo-climatic heating of the terrain. The 39,590.2 km^2 subset containing the 15 December 2003 dust storm presences in the Lake Palomas basin yielded 46,887 objects with a mean of 104.2 pixels (SD: 97.5) or mean area of 84.4 hectares. The smaller but more topographically complex 14,290.6 km^2 subset for the 19 February 2004 dust storm is located on the eastern slope of the Sierra Madre Occidental in Mexico where a total of 33,886 terrain objects with a mean of 52.1 pixels (SD: 53.4) or mean area of 42.2 hectares were segmented. The 73,429.5 km^2 subset of the 27 November 2005 model area in the Lake Palomas basin yielded 128,511 objects with a mean of 70.5 pixels (SD: 77.7) or mean area of 57.1 hectares. Each of the presences and 10,000 background points was given a 1 km radius uncertainty buffer following the stated confidence that the points were within one or two kilometers of the actual dust source [20]. The means for each of the six parameters were then calculated from the objects intersecting the uncertainty buffers and compiled as 'samples with data' (SWD) for use in Maxent.

III. Results

The Maxent models used cross-validation with 10 replicates for each of the four presence-only samples from the three dust storms. The logistic outputs of the Maxent distributions (Fig. 2)

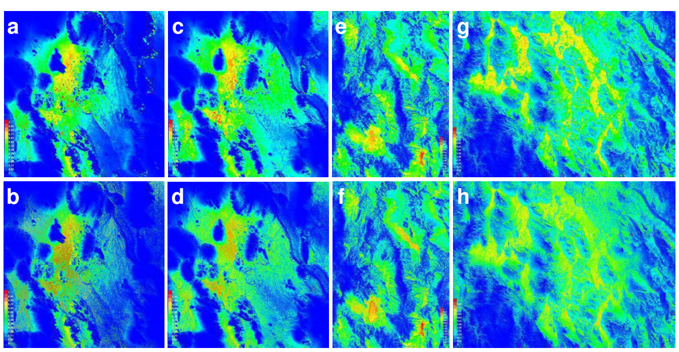

Fig. 2. The logistic outputs of the Maxent 10-replicate average suitability distributions "projected" to the successively lower object level (top row) and pixel level (bottom row) for the 15 December 2003 (a-d; a&b come from the [1] sample), 19 February 2004 (e&f) and 27 November 2005 (g&h) dust storms. Typical presences have values near 0.5 (green) [4].

were "projected" to the successively lower terrain object and pixel levels within the presence subsets. The [1] sample of the 15 December 2003 dust storm had the highest test and training AUCs (areas under the receiver operating characteristic [ROC] curves) (Table 1). Furthermore, each of the four presence samples produced potentially useful models with average test AUCs above 0.75 [4]. However, the 10-replicate cross-validation model runs that are well-suited for small sample sizes also exhibit considerable variability (Fig. 3).

TABLE I. RESULTS OF THE 10- REPLICATE MODEL RUNS IN MAXENT USING CROSS-VALIDATION.

Dust Storm Day (DSD)	**Presences (*n*) and average area under the ROC curves (AUC)**		
	# of dust source presences: Training n (Test n)	***Training AUC***	***Test AUC***
15 Dec 2003 [1]	29 or 30 (4 or 3)	0.9142	0.8804
15 Dec 2003	62 or 63 (7 or 6)	0.8717	0.8315
19 Feb 2004	53 or 54 (6 or 5)	0.8624	0.7920
27 Nov 2005	56 or 57 (7 or 6)	0.8315	0.7976

IV. Discussions

A novel and geographically scalar approach for modeling suitability distributions for dust sources during major dust storms has been introduced. This object-oriented geoecological strategy provides a necessary and coherent foundation that uses geomorphometric terms alone. The early SDMs generated in Maxent in 2013 demonstrated that the obscuration of downwind dust sources by the dust plume(s) might be overcome in this way. The addition of three Whitebox GAT wind-related terrain attributes has resulted in improved models with AUCs high enough to consider them as being potentially useful. More importantly, by properly accounting for geographically uncertain, and therefore biased, presence samples, the Maxent suitability

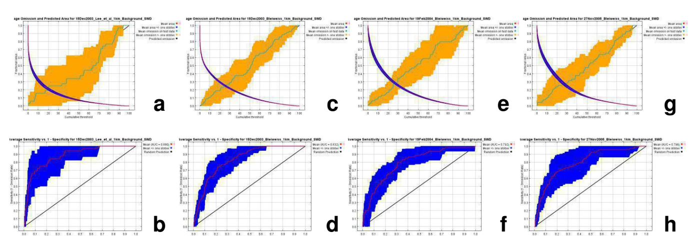

Fig. 3. Average omission and predicted area (top row) and test ROC curves (bottom row) for the four 10-replicate model runs for the 15 December 2003 (a-d; a&b come from the [1] sample), 19 February 2004 (e&f) and 27 November 2005 (g&h) dust storms. One SD of omission is shown in orange and one SD of variability in the ROC curves is shown in blue.

distributions are now able to be projected to the successively lower object and pixel levels.

In doing so, we effectively go below the MODIS spatial resolutions through "displacement" to the spatial resolution of the geomorphometric terms while simultaneously retaining pixels as objects. That is to say, the suitability distributions have more or less been "transferred" to the lower scalar levels over the same spatial extents without privileging spectral remote sensing over and above geomorphometry. Not only does an object-oriented geoecology put the abiotic and biotic on equal ontological footing, it has also allowed, through a geographically scalar application of the maximum entropy principle, for dust sources to be either vagile or non-vagile objects.

This approach can now be further improved with additional land-surface parameters and a more thorough investigation of the wind-related terrain attributes used here, and others including the 'channelling/deflection index' (CDI) [18]. Analysis of specific dust storm characteristics is also required. For instance, the lower AUCs for the 19 February 2004 and 27 November 2005 dust storm models might be explained by the greater variability in the orientations and morphologies of the microplume objects and estimated wind directions. The 15 December 2003 dust storm models benefit from the many distinct microplumes of relatively uniform direction and shape. Additional geomorphometric analyses are also required for the region as a whole, especially with respect to the hydrology of the many playas and their associated agricultural uses. Finally, terrain objects like these can now be "encrusted" with the appropriate spectral data and further segmented for more comprehensive analyses.

ACKNOWLEDGMENTS

This project was initially funded by the New Mexico Department of Health (NMDOH) and made possible by atmospheric scientist and New Mexico State Climatologist, David W. DuBois, PhD. I would like to thank Max P. Bleiweiss for kindly providing dust source samples of these and many more dust storms. The segmentations were all completed through the use of the eCognition® software license which the Jornada Experimental Range, and Jim Lenz in particular, thankfully made possible. Thank you, Janet Greenlee, Andrew Martinez, Shelby Van Arnam and Curtis Atherton, for your support and insights while employed at the Spatial Applications and Research Center (SpARC). Finally, this application of a non-holistic geography is entirely the author's own and in no way does it reflect the views held by anyone in either the NMSU Department of Geography or the Jornada Experimental Range.

REFERENCES

[1] Lee, J.A., Gill, T.E., Mulligan, K.R., Dominguez Acosta, M., Perez, A.E., 2009. "Land use/land cover and point sources of the 15 December 2003 dust storm in southwestern North America". Geomorphology 105: 18-27.

[2] Baddock, M.C., Bullard, J.E., Bryant, R.G., 2009. "Dust source identification using MODIS: A comparison of techniques applied to the Lake Eyre Basin, Australia". Remote Sensing of Environment 113: 1511-1528.

[3] Rivera Rivera, N.I., Gill, T.E., Bleiweiss, M.P., Hand, J.L., 2010. "Source characteristics of hazardous Chihuahuan Desert dust outbreaks". Atmospheric Environment 44: 2457-2468.

[4] Phillips, S.J. and Dudík, M., 2008. "Modeling of species distributions with Maxent: New extensions and a comprehensive evaluation". Ecography 31: 161-175.

[5] Phillips, S.J., 2008. "Transferability, sample selection bias and background data in presence-only modeling: A response to Peterson et al. (2007)". Ecography 31: 272-278.

[6] Quine, W.V.O., 1964. "From a Logical Point of View: 9 Logico-Philosophical Essays". 2nd ed., rev., Harvard University Press, 184 p.

[7] Zhang, J. and Goodchild, M.F., 2002. "Uncertainty in Geographical Information". CRC press, 266 p.

[8] Harman, G., 2011. "The road to objects". Continent 3(1): 171-179.

[9] Harman, G., 2011. "The Quadruple Object". Zero Books, 148 p.

[10] Harman, G., 2010. "Time, space, essence, and eidos: A new theory of causation". Cosmos and History: The Journal of Natural and Social Philosophy 6(1): 1-17.

[11] Smith, B. and Mark, D.M., 2003. "Do mountains exist? Towards an ontology of landforms". Environment and Planning B 30(3): 411-428.

[12] Lu, H., 2008. "Modelling terrain complexity". In: Zhou, Q., Lees, B., Tang, G. (Eds.), "Advances in Digital Terrain Analysis". Springer, 462 p.

[13] Olaya, V., 2009. "Basic land-surface parameters". In: Hengl, T. and Reuter, H.I. (Eds.), "Geomorphometry: Concepts, Software, Applications". Developments in Soil Science Vol. 33, Elsevier, 796 p.

[14] Woodcock, C.E. and Strahler, A.H., 1987. "The factor of scale in remote sensing". Remote Sensing of Environment 21: 311-332.

[15] Bøcher, P.K. and McCloy, K.R., 2006. "The fundamentals of average local variance—part I: Detecting regular patterns". IEEE Transactions on Image Processing 15(2): 300-310.

[16] Böhner, J. and Antonić, O., 2009. "Land-surface parameters specific to topo-climatology". In: Hengl, T. and Reuter, H.I. (Eds.), "Geomorphometry: Concepts, Software, Applications". Developments in Soil Science Vol. 33, Elsevier, 796 p.

[17] Drăguţ, L. and Blaschke, T., 2006. "Automated classification of landform elements using object-based image analysis". Geomorphology 81: 330-344.

[18] Lindsay, J.B. and Rothwell, J.J., 2008. "Modelling channelling and deflection of wind by topography". In: Zhou, Q., Lees, B., Tang, G. (Eds.), "Advances in Digital Terrain Analysis". Springer, 462 p.

[19] Phillips, S.J., Anderson, R.P., Schapire, R.E., 2006. "Maximum entropy modeling of species geographic distributions". Ecological Modelling 190: 231-259.

[20] Lee, J.A., Baddock, M.C., Mbuh, M.J., Gill, T.E., 2012. "Geomorphic and land cover characteristics of aeolian dust sources in West Texas and eastern New Mexico, USA". Aeolian Research 3: 459-466.