Urban Physics: City Texture Matters

PROBLEM

Cities cover a mere 2% of the world's land, but they are home to over 50% of the population and contribute to over 70% of greenhouse gas emissions. They also intensify air and surface temperatures when compared to their rural surroundings. This effect, known as urban heat island (UHI), amplifies air pollution and increases cooling energy usage while imperiling human health and comfort, and therefore poses one of the major societal climate challenges. Although city managers are aware of these issues when devising mitigation strategies for UHI, a limiting factor remains how to quantitatively address the complexity of cities—here defined by a network of hundreds of thousands of buildings—under operational and extreme conditions when evaluating mitigation strategies. Consequently, there is a need to quantify city complexity without compromising the relevant texture information that makes each city distinct, or reducing the city to a single density parameter (population or building), as does the current state-of-the-art UHI and urban planning.

APPROACH

The striking resemblance between urban environments and molecular structure of materials (fig.1a) allows us to leverage common methods from statistical physics to reduce the complexity of urban systems to a universal set of dimensionless measures. We employ radial distribution function to capture the variation between local and average building density. We can then derive short-range texture characteristics in the form of an ordering parameter to characterize the average angular distortion of buildings when compared to a perfect order. With order parameter, we utilize the traditional norms of density to study the UHI normalized by the local rural temperature adjusted for Earth's average albedo effect. We expect that greater local order of buildings, which goes along with an increased order of its complement dominated by pavements that typically have lower radiation reflectivity than buildings, will magnify such albedo effects and hence UHI.

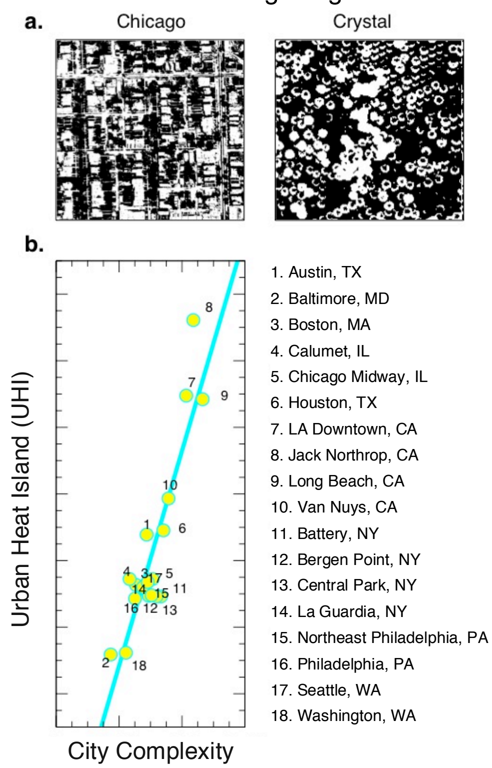

Fig.1. a) In 2D, cities at building scale and materials at nano level present visually comparable structures. b) Such analogy when further explored enables us to apply tools from statistical physics to quantify dimensionless city complexity, a function of density and order parameter, which we find to be related to dimensionless UHI (b).

FINDINGS

We establish a novel means of classification of cities based on ordering of buildings. Crystals (i.e. Chicago, New York) present distinct periodic geometries, while liquids (i.e. Boston, Los Angeles) offer more sporadic and chaotic distributions. We find that such expedients enrich the traditional texture measures and ameliorate the appraisement of physical responses of cities. While non-urban climatic influences cannot be excluded, we herein suggest that a polynomial form considering order parameter can significantly improve the current urban equation, which puts the city density as the antecedent of UHI (fig.1b). Moreover, we conclude that for a constant density, a highly ordered city experiences UHI twice as great as a city with highly disordered structure of local buildings. To exemplify, our findings suggest that for the county of Los Angeles, the Jack Northrop area or Downtown Los Angeles should be prioritized over Van Nuys for implementing UHI mitigation policies.

IMPACT

Our multi-disciplinary approach is a rudiment that can help shift cities toward the realm of quantitative predictions based on the emerging field of urban physics. Incorporation of ordering parameter into urban planning will allow developers to simplify city complexity to reliable measures—crucial for prioritizing cities or their neighborhoods for mitigating UHI—without the need of detailed temperature data.

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