Fractals and Catastrophic Bifurcation: Exploring Treeline Structure Using Drones and Mathematical Models in R

Kummel, Kathryn (School: William J. Palmer High School)

This investigation presents a novel approach of characterizing the alpine treeline as a phase transition from one phase (forest) to another (tundra). Phase transition research in other systems shows that the structure of transitions often displays fractal geometry, which is a hallmark of catastrophic bifurcations. Catastrophic bifurcations are characterized by abrupt shifts between two phases that are hard to reverse and coexistence of both phases within the same environmental conditions. This project investigates how theories on phase transitions could explain the creation and maintenance of spatial structures in the treeline. Mathematical models of treelines were created, followed by analyses of a drone-derived map of an actual treeline to examine which of the mathematical models best fit the empirical data. Using R (programming language), a mathematical model was created with adjustable parameters to examine how competition and facilitation between trees affected treeline elevation and spatial patterns. All of the models produced fractal structures. The models differed in the elevation and spatial pattern of the treeline. Only one model, where trees facilitated survivorship and inhibited recruitment, showed catastrophic bifurcation. The analysis of a real treeline showed that it has a fractal structure and is most like the treeline model with catastrophic bifurcation, but it was not possible to determine if it is a result of a catastrophic bifurcation. The presence of fractals cannot predict the reversibility of a phase change but can predict when a system nears a tipping point; this is applicable to climate change and medicine, as well as societal phenomena.

Awards Won:

Second Award of $1,500