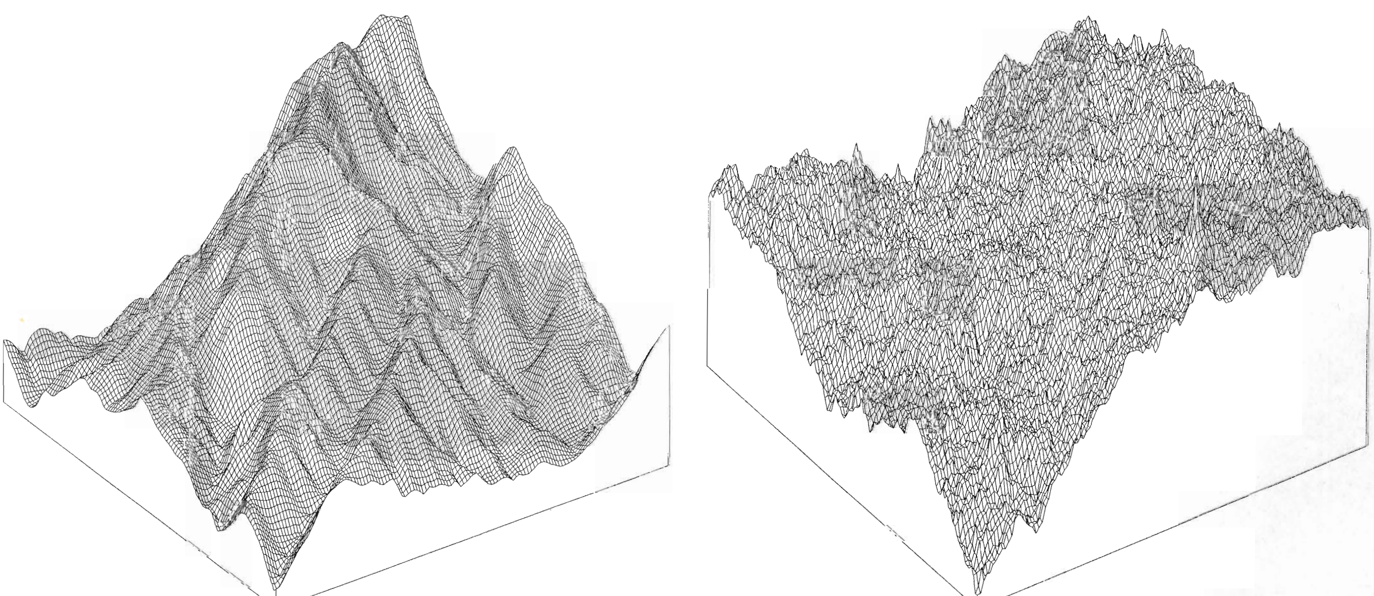
Geography

Viewed from a distance, a mountain range can be seen to be composed of individual peaks. From a closer vantage point, ridges are revealed on those peaks, and from an even nearer point, those ridges are revealed as being broken into crags and outcroppings. As more detail is exposed at closer views, it becomes evident that the smaller features appear similar to the larger features viewed at a greater distance. Geographers and geologists have long known that photographs of landforms need to include an object of known size—a coin, a person—or else it is difficult to determine the scale of the landforms. That many geographic features, such as mountain ranges, coastlines, and river networks, exhibit this phenomenon of similarity over a range of scales is intuitive to many people.

Fractals. In the mid-1970s, B. B. Mandelbrot coined the term fractal to define that class of objects with noninteger dimensions. A linear fractal function would have a dimension greater than 1 but less than 2, while a fractal surface would have a dimension between 2 and 3. A fractal dimension close to the euclidean dimension (that is, close to 1 for a linear fractal) would represent a relatively smoothly varying function, while a higher fractal dimension would represent a highly irregular function. For example, a sheet of paper can be used to represent a two-dimensional surface. If crumpled into a ball, this highly irregular surface nearly fills space and approximates a three-dimensional object. Thus, its fractal dimension would be nearer to 3 than to its euclidean dimension of 2. Even if the paper were uncrumpled, folds and creases would remain and its fractal dimension would still be greater than its euclidean dimension. Since Mandelbrot's introduction of fractals, techniques have been developed to generate computer images of landscapes, oceanscapes, clouds, and even planets whose fractal dimensions yield scenes that are more realistic than those based on the more traditional euclidean geometry. These techniques combine a set of rules with an element of randomness to create scenes that are nearly independent of scale. When the scaling processes are the same in all euclidean dimensions, the resulting fractal is said to be self-similar. Such is the case, for example, with coastlines and river networks, since the horizontal dimensions have the same scaling, limited by the circumference of the Earth. If the vertical dimension is included (for example, topographic profiles and surfaces), the scaling processes will no longer be the same; scaling in the vertical is controlled by



(a) (b)

Fig. 1. Landscape simulation generated through use of fractals. (*a*) Portion of a U.S. Geological Survey digital elevation model—128 × 128 grid points (3.84 × 3.84 km or 2.38 × 2.38 mi)—for the Fort Douglas (Utah) quadrangle. The fractal dimension of this topographic surface is approximately 2.39, and its elevation range is from 1633 to 2441 m (5358 to 8008 ft). (*b*) Fractal surface having the same dimension as for *a* but generated by using a midpoint displacement method with successive random additions. The mean elevation and standard deviation are also the same as for *a*.

gravity, which limits the maximum relief. Fractals with different scalings are termed self-affine.

Many of the earliest applications of fractals were for the creation of simulated geographies, which remain a subject of continuing effort by geographers, computer scientists, and film makers. However, the processes controlling landscape evolution in nature certainly are not random, and the underlying geologic structure can strongly influence the resulting surface features. Therefore, physical geographers, cartographers, and geologists have little difficulty differentiating between real and simulated landscapes. As a result, scientific applications of fractals to physical geography have been slow to develop and are somewhat limited in number.

Applications of fractals. Fractals have potential for providing information valuable in the fields of geomorphology, climatology, soil science, and remote sensing.

Geomorphology. As might be expected in light of the use of fractals to generate images of more realistic landscapes, most of the geographic applications of fractals have been in the field of geomorphology—the study of landforms and their evolution. While images of landscapes provide sometimes compelling visual evidence that topography is fractal, scientific investigation often reveals the greater complexity of natural landforms. For example, one frequent criticism made by geomorphologists and geologists is the failure of simulated landscapes to properly incorporate stream networks and their effect on the landscape (**Fig. 1**). Even though the geographic surface and the fractal surface have the same fractal dimension, mean elevation, and standard deviation, it is not difficult to identify which is which. Because no physical constraints (for example, rock strength or gravitational force) have been imposed on the generated surface and because erosional processes have not been taken into account, the generated surface appears much rougher and more jagged than the natural surface. Furthermore, no drainage network can be discerned on the generated surface, while valleys and ridges are clearly seen on the natural surface. Investigation of the differences between simulated landscapes derived from statistically self-affine fractal generators and natural landscapes might lead to a better understanding of the proceses at work sculpting the Earth's surface. Moreover, many natural landscapes exhibit more than one fractal dimension over a range of scales and are more properly termed multifractal. This multiplicity may be indicative of different geomorphic processes acting at these various scales. If such is indeed the case, measurement and classification of the fractal dimensions of geomorphic features such as coastlines, mountain ranges, and river networks may allow them to be characterized by the processes controlling their development.

The modeling of geomorphic processes offers another possible use of fractals. Models of stream erosion, for example, often have started with a flat surface, either horizontal or slightly tilted, and allowed erosion to shape the landscape. Because the initial surface is regular, some degree of randomness must be incorporated into the geomorphic processes being modeled to allow erosion to occur at different rates across the landscape. Fractal surfaces, which often are characterized as raw or unmodified by geomorphologists, could be

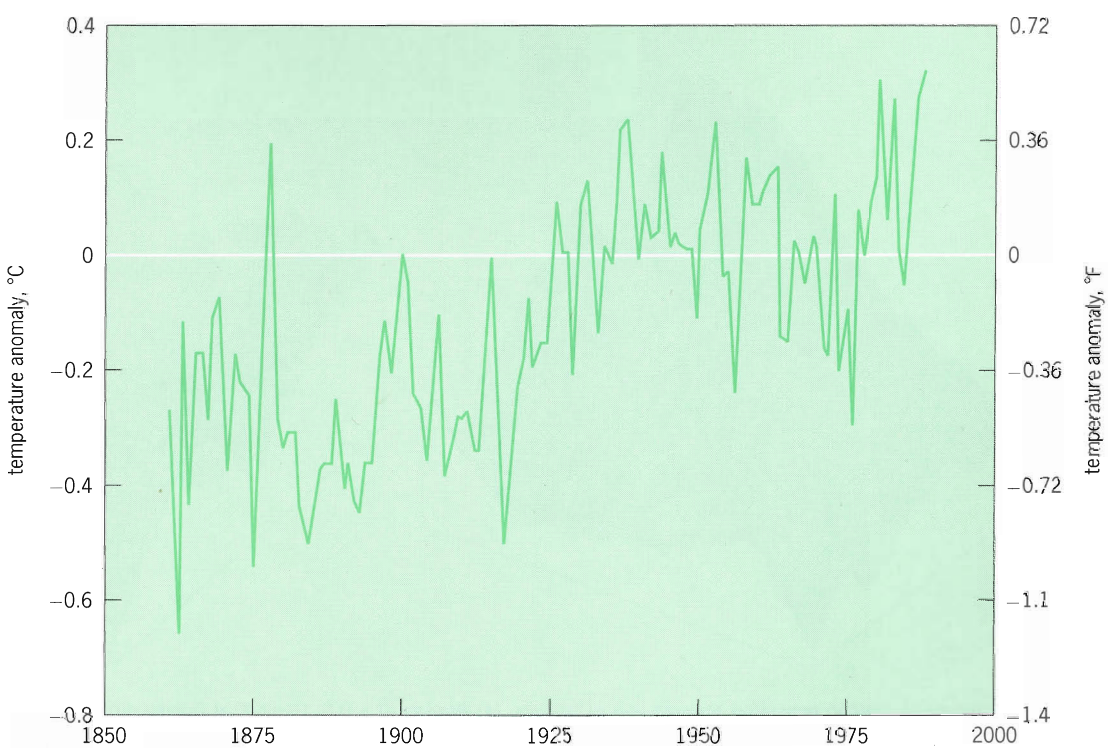


Fig. 2. Time series of Northern Hemisphere temperature anomalies from 1861 to 1988 in terms of departure from the 1951–1980 mean, indicated by the white horizontal line. The fractal dimension of this series is approximately 1.83.

used as the initial, preerosion surface in these models. Thus, the initial surface, not the processes, would contribute the spatial variation necessary to allow erosion, transportation, and deposition to take place at different rates across the landscape. *SEE STREAM SYSTEMS.*

Climatology. Applications of fractals in climatology have been more limited than those in geomorphology. S. Lovejoy studied clouds and rain areas and found a relationship between the perimeter and area of clouds and rain areas that is fractal. Moreover, he found that the fractal dimension was invariant over several orders of magnitude. This finding indicates that there is no well-defined length scale for clouds and rain areas, since the fractal dimension would differ at scales less than and greater than that length.

Time series of a number of climatic and hydrologic parameters such as temperature, precipitation, and streamflow have been found to exhibit fractal properties. A time series of annual temperature anomalies in the Northern Hemisphere from 1861 to 1988 (**Fig. 2**) exhibits a fractal dimension of 1.83, which is indicative of the highly irregular nature of climatic data. This series also demonstrates why it is difficult to discern evidence of climate change, whether natural or human-induced, from the climate record. Even though inspection of the time series appears to reveal a positive trend in the data, the variation makes it uncertain as to whether this increase is real or is only part of the noise. Fractals also offer a method for analyzing climate that could be used to enhance understanding of both the spatial and the temporal characteristics of climate variability. *SEE CLIMATOLOGY.*

Soils. Various soil properties such as texture, pH, moisture capacity, and density have been shown to display spatial variation that is fractal, although not necessarily self-similar. This finding has important implications for mapping of soil data, since spatial interpolation of soil properties may not always be appropriate because of sudden changes across boundaries. The same may also be true for studies of vegetation cover, although this possibility has not yet been demonstrated. For example, fractals may be useful in biogeographical studies of landscape patchiness and its effects on wildlife habitat or as a measure of disturbance of ecosystems by humans.

Remote sensing. In remote sensing, fractals may offer a method for classifying images of the Earth's surface. Landforms, vegetation covers, and other surface features may display distinct fractal dimensions that could be used to assist geographers and other users of remotely sensed data in their interpretation of aerial photographs and satellite images. For example, since human-built structures are generally not fractal, techniques might be developed to distinguish those portions of images where humans have influenced the landscape from regions that have not been modified.

Prospects. The use of fractals in geographic research is still in its early stages and has yet to find its full potential. This brief discussion can only hint at the possibilities offered by the study of geographic fractals and the impact they will have on theory and analysis in physical geography.

For background information *SEE CLIMATE MODELING; FRACTALS; GEOMORPHOLOGY; REMOTE SENSING* in the McGraw-Hill Encyclopedia of Science & Technology.

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