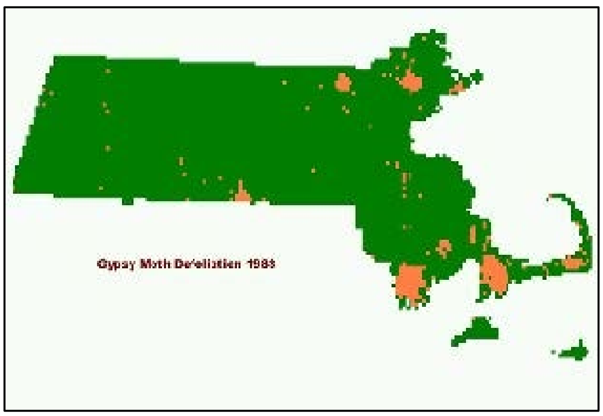
Environmental Modeling: Analyzing Motion with Trend Surface Analysis

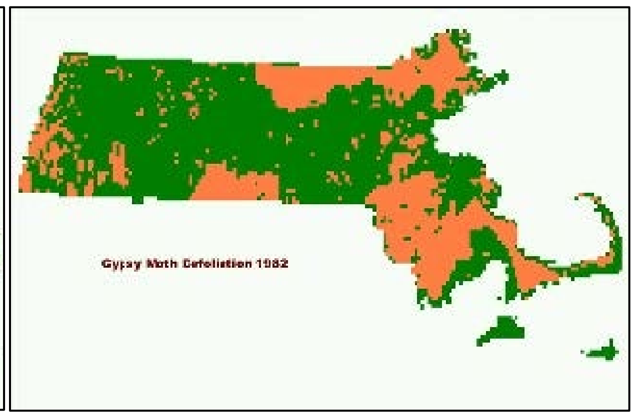
Analyzing Motion with Trend Surface Analysis

by J. Ronald Eastman

TREND

Generally speaking, GIS is not well suited to the analysis of phenomena that move. Analytical operations in GIS tend to focus on vertical relationships between layers. Further, it is sometimes very difficult to detect spatial movements. Figures 1 and 2, for example, illustrate areas of Gypsy Moth defoliation in 1982 and 1983 respectively. This insect was accidentally released in the late 1860's by an amateur entomologist, and has since spread over much of northeastern North America. However, it is hard to detect any spread with this much variability on a year-to-year basis. It is possible to describe such phenomena though with the TREND module (possibly with the assistance of the MDCHOICE module).





The TREND module can be found in the Statistics menu subgroup of the GIS Analysis menu. TREND calculates the coefficients of a best-fit polynomial surface to fit a set of spatially distributed data points. For those familiar with linear regression, a linear trend surface fits a plane through the values of a dependent variable using the X and Y coordinates as independent variables. Generally, the intent with trend surface analysis is to develop a generalized understanding of the spatial distribution of a phenomenon. As a consequence, only the simplest of polynomial surfaces are typically used: linear, quadratic, and sometimes cubic. Linear trends describe only the major direction and rate of change. Quadratic and cubic surfaces provide progressively more complex descriptions of spatial patterns. For those who are interested, here are the equations of these polynomial surfaces:

Linear : $z = b0 + b1X + b2Y$
Quadratic : $z = b0 + b1X + b2Y + b3X2 + b4XY + b5Y2$
Cubic : $z = b0 + b1X + b2Y + b3X2 + b4XY + b5Y2 + b6X3 + b7X2Y + b8XY2 + b9Y3$

where *bx* are parameters and *X* and *Y* are positional coordinates in a plane georeferencing system (such as UTM).

The key to working with moving phenomena is that the dependent variable (z) needs to be expressed in continuous units of time. For the Gypsy Moth defoliation data, one possibility would be to create a single image that expresses the number of years that have passed since initial infestation. This is illustrated in Figure 3, but for the larger area of the Eastern US and Canada (minus Michigan, which is the source of a second outbreak) [1].

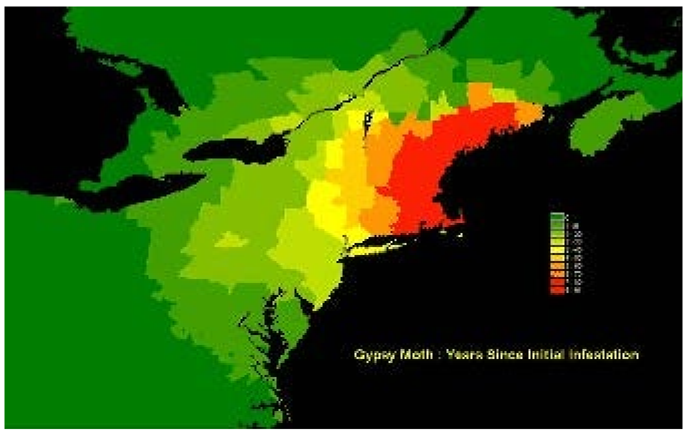


Figure 3

These data can then be submitted to the TREND module. Figures 4, 5 and 6 illustrate the linear, quadratic and cubic polynomial trends over time. These trends clearly show the progressive spread of the Gypsy Moth from an initial release in Medford Massachusetts (a town in the Boston metropolitan area).

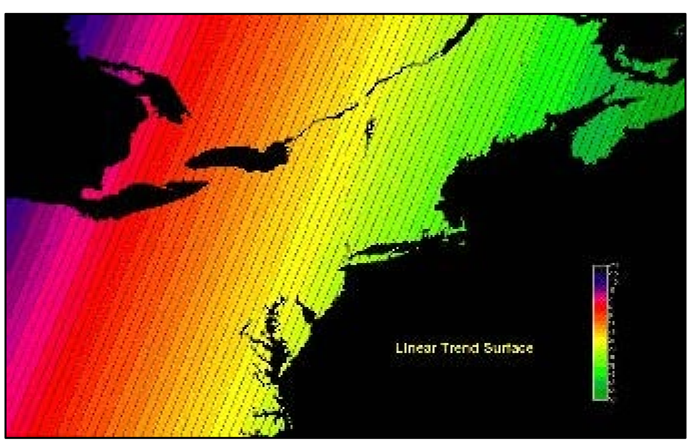


Figure 4

The linear is the most basic description and clearly shows older ages in the northeast and younger ages in the northwest. However, we do not see the true point of origin.

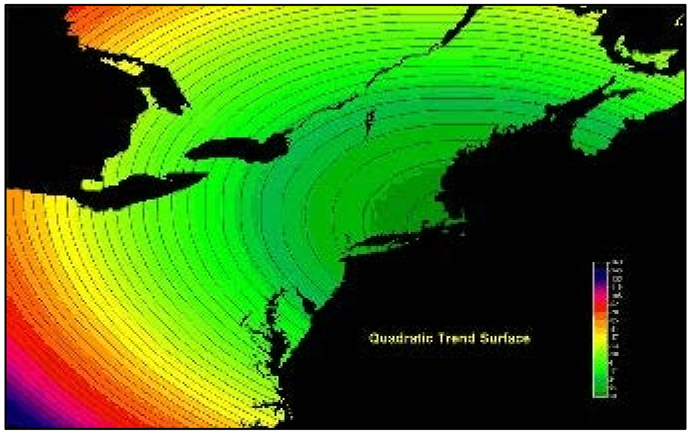


Figure 5

The quadratic trend (Figure 5), however, shows the point of origin to be Massachusetts, although it would appear to suggest that the release was near Cape Cod.

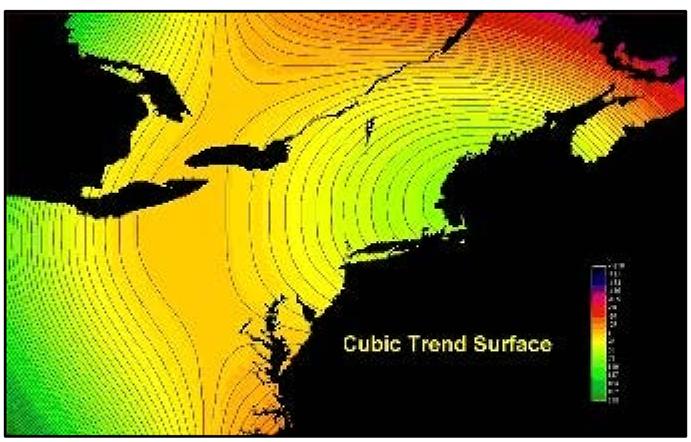


Figure 6

With the cubic trend, we now correctly see the point of origin being near Boston. We also are seeing evidence of a second point of release in Michigan. It would therefore seem that utilizing the cubic trend analysis is more advantageous. However, examination of Figure 3 would suggest that this is based on very little evidence. This underscores the point that as the order of the polynomial increases, extrapolations become exponentially riskier since the polynomials are unconstrained beyond the spatial range of data.

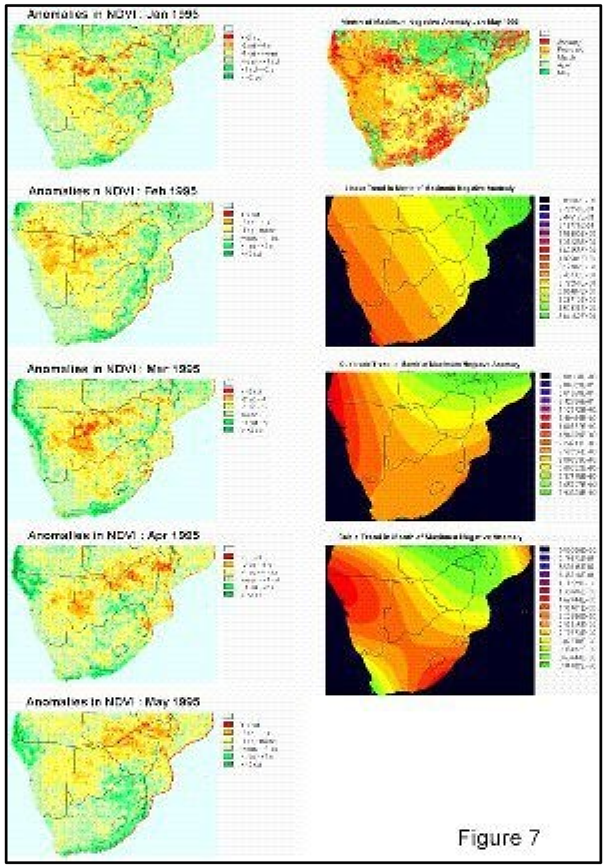


Figure 7

MDCHOICE is a procedure for multi-objective decision making and is found in the Decision Support menu subgroup of the GIS Analysis menu. Normally it is used to evaluate a set of suitability maps (one for each objective) to produce a single output designating, at each pixel location, the objective that had the highest suitability at each location. It can also prove to be useful in the context of trend surface mapping. The five maps on the left of Figure 7 illustrate anomalies in NDVI (normalized difference vegetation index) for Southern Africa during the austral summer of 1995. Using these five maps as inputs to MDCHOICE, along with the option to determine the output map with the minimum value (the lowest NDVI) over the five months yields the map in the upper-right corner of Figure 7. This map has integer values from 1-5 (background areas were masked to become 0), representing the five months considered. Thus a pixel with a value of 4 would indicate that it experienced the lowest NDVI readings in April. This was then used as input to the TREND module, which yielded the linear, quadratic and cubic trends shown below it on the right. As can be seen, this procedure was able to isolate trends that were much more difficult to detect than in the case of the Gypsy Moth data.

Footnote:

[1] Gypsy Moth data are courtesy of Dr. Andrew Liebhold. Details can be found in Liebhold, A.M. and Elkinton, J.S., (1989) “Characterizing spatial patterns of gypsy moth regional defoliation” Forest Science, 35, 557-568; Liebhold, A., Halverson, J., and Elmes, G., (1992) “Gypsy Moth Invasion in North America, A Quantitative Analysis,” Journal of Biogeography, 19, 513-520; Liebhold, A., Elmes G., Halverson J., and Quimby, J. (1994) “Landscape characterization of forest susceptibility to gypsy moth defoliation”, Forest Science, 40, 1, 18-29. This case study is explored in depth in McKendry, J., Eastman, J.R., St. Martin, K., and Fulk, M., (1991) “Applications in Forestry, Explorations in Geographic Information Systems Technology, Vol. 2. (Geneva: UNITAR).