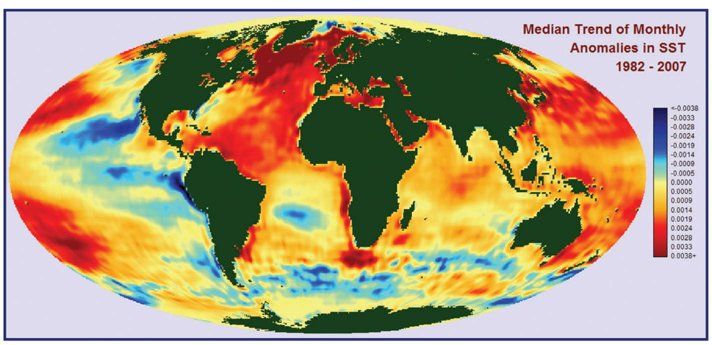
IDRISI Focus Paper

Exploring Image Time Series With Earth Trends Modeler

Environmental image series provide a critically important resource for understanding both the dynamics and evolution of environmental phenomena. Earth Trends Modeler, a vertical application within the IDRISI software system, provides a wealth of tools for the analysis of trends and the dynamic characteristics of these phenomena as evident in time series images. This paper focuses on several of the many data mining and exploration techniques that account for and disentangle various dynamics that may contribute to trends. For our image series example, we will be looking at monthly sea surface temperature data from 1982 to 2007 (from the Optimally Interpolated Version 2 Series available from NOAA) and the relationship to the Atlantic Multidecadal Oscillation (AMO).

THE MEDIAN TREND TECHNIQUE

The Median Trend procedure is one of several techniques offered in Earth Trends Modeler for the exploration of long-term trends. It is a robust non-parametric trend operator that is highly recommended for assessing the rate of change in short or noisy series. It is calculated by determining the slope between every pairwise combination of samples over time and then finding the median value. For example, with a 20-year sequence of monthly data, a total of 28,680 slopes would be evaluated at every pixel. For long series, the result is often identical to the Linear Trend (OLS) output, but for short or very noisy series, the result can be quite different and is more reliable.



The image above shows the median trend of anomalies in monthly sea surface temperature from 1982 to 2007 as determined by the Earth Trends Modeler. The units represent the rate of change per month in degrees Celsius. The image has been contrast stretched to a range between +/- 0.0038 degrees Celsius, which represents a change of approximately +/-1.2 degrees Celsius over the length of the series.

There are two very notable features of this trend image. First, most of the world's oceans show warming. Second, the warming is most intense in the Atlantic, particularly in the sub-polar gyre near Greenland, the North Sea and along the sea ice edge towards Svalbard. What is causing this warming in the Atlantic? To what extent is it a result of global warming versus the Atlantic Multidecadal Oscillation?

The Atlantic Multidecadal Oscillation (AMO) is a low frequency Atlantic SST oscillation hypothesized to be associated with the thermohaline circulation. It is thought to cycle within a 65-70 year timescale, causing sea surface temperature changes. The AMO is known as a climate teleconnection.

Teleconnections refer to a linkage between climate events over widely separated regions of the earth and are therefore a critical component for the study of trends in environmental image series. The best known of these is the quasi-oscillatory El Nino Southern Oscillation phenomenon (ENSO), where anomalous sea surface temperatures in the equatorial Pacific lead to widespread climate impacts with durations that can span from months to a year or more.

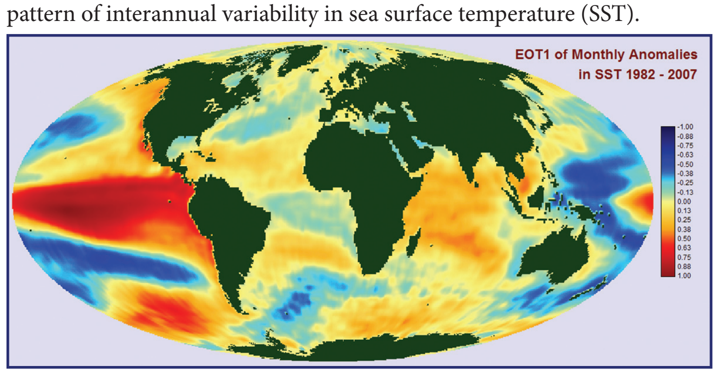
The Empirical Orthogonal Teleconnection technique within Earth Trends Modeler allows you to explore this relationship.

THE EMPIRICAL ORTHOGONAL TELECONNECTION (EOT) TECHNIQUE

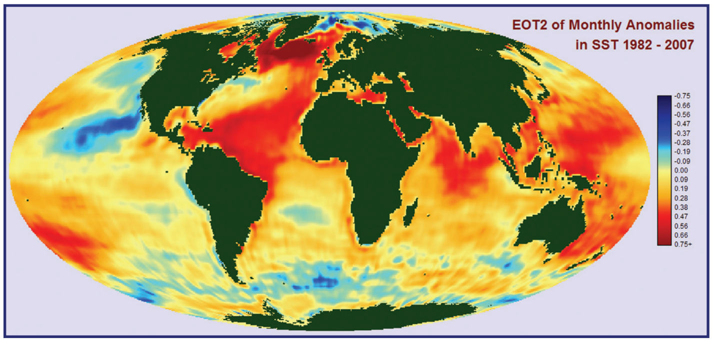
The intention of the Empirical Orthogonal Teleconnection (EOT) technique is to uncover teleconnections. It is a brute-force method that examines each pixel over time to find which one can explain the greatest amount of variability of all other pixels combined. That profile corresponds to the first EOT. Once the first EOT has been found, the effect of it is removed (by creating a residual series) and the process starts again.

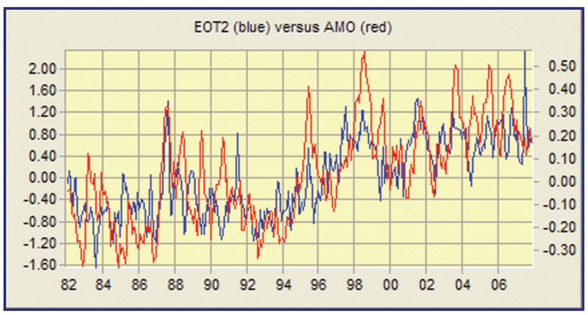
The EOT analysis provides both a temporal and a spatial portrait of each pattern. The EOT profiles provide the temporal portrait while the spatial pattern is created by correlating the EOT against the current residual series. EOTs are similar to obliquely rotated Principal Components. They are independent in time, but not necessarily in space. They have the advantage that they are easily understood, are associated with a specific location and are naturally rotated to correspond with the primary clusters of temporal patterns in the data.

In this case of monthly anomalies in sea surface temperature from 1982 to 2007, the first EOT, shown below, is the familiar El Nino / La Nina (ENSO) phenomenon – not surprising since it is unquestionably the dominant pattern of interannual variability in sea surface temperature (SST).



The second EOT below is the largest pattern of space-time variability in SST anomalies that the technique can find in the residuals from ENSO (i.e., after the effects of ENSO have been removed). The pattern is clearly similar to the exceptional warming in the Atlantic noted in the median trend. Of particular note is the dramatic warming in the Labrador Sea and adjacent areas southeast of Greenland, west of Iceland and to the northeast of Newfoundland. This is the North Atlantic Subpolar Gyre – a critical area for the production of deep water as part of the thermohaline circulation.





The temporal graph of EOT2 is shown here along with an index to the Atlantic Multidecadal Oscillation (AMO) superimposed (in red). Clearly the temporal evolution of EOT2 is a very close match to the AMO index (r = 0.71). Thus, it appears that the warming in the Atlantic may be related to the AMO. But might it also be related to global warming? To see if this can be untangled, we turn to Earth Trend Modeler's Linear Modeling procedure.

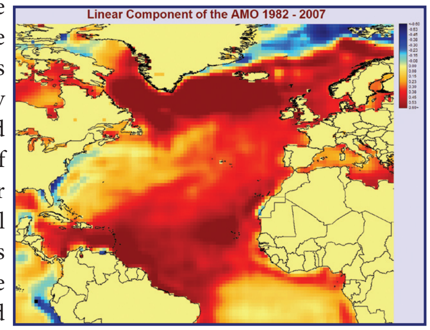
THE LINEAR MODELING TECHNIQUE

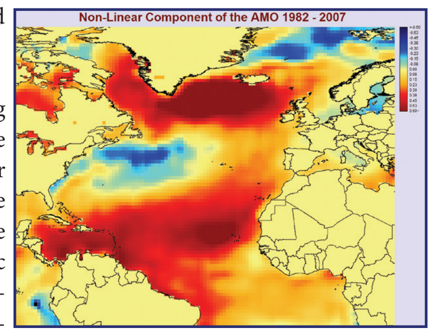
The Linear Modeling technique is a multiple regression procedure that allows one to examine relationships between a dependent image time series and one or more independent time series that can be either image time series or index series (non-image one-dimensional time series). One of the primary uses of the linear modeling tool is to map and explore the areas impacted by a particular phenomenon such as the AMO.

In this example, we will look at separating the linear and non-linear components of the Atlantic Multidecadal Oscillation (AMO) from 1982 to 2007. During this time frame, the AMO changed from its peak negative phase (in the late 1970s) to its peak positive phase. Thus, the linear component is ambiguous – it might represent global warming or it might represent the natural progression of the AMO. The non-linear phase is presumably more inherently related to the AMO.

The first step in creating this separation is to remove the effects of other climate teleconnections. In an analysis of sea surface temperature teleconnections using the Empirical Orthogonal Teleconnection procedure, the AMO was the second EOT. Thus, to remove the effects of other teleconnections, the Linear Modeling tool is used to create a residual series after removing the effects of EOT 1 and EOTs 3-10.

The next step is to run a linear model using this residual series as the dependent variable (which is presumably dominated by the AMO) and two unidimensional time series – one being a simple linear series (the Earth Trends Modeler provides a utility to create this) and a second being a detrended version of EOT2 (i.e., with the linear trend removed). The partial correlation option outputs images (on the right) of the spatial pattern associated with each of the linear and non-linear components.





There are several interesting characteristics about these results. First, the non-linear pattern shows a structure consistent with the negative phase of the North Atlantic Oscillation (NAO), an atmospheric pressure teleconnection, which causes changes in the position and strength of the westerlies that affect temperature and precipitation in both Europe and eastern North America. A 7-month mean filter used on both the NAO index and the non-linear component of the AMO (easily accomplished in Earth Trends Modeler) shows that they are negatively correlated (r = -0.46). This association suggests that the AMO may in some way be related to the NAO. Second, the pattern associated with the subpolar gyre is clearly associated with the linear component. Although there is likely a global warming component to this warming, the total increase (which exceeds 3 degrees Celsius in some parts of the gyre) is far greater than would be expected from global warming alone. It would appear then that this warming is likely associated with a combination of global warming and the low frequency component of the AMO.

Image time series data are a critical component in the study of climate change and ecosystem dynamics. The analytical tools included within Earth Trends Modeler, several of which have been discussed here, provide unique access to their rich information.

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