Trend(Sat)^2: Trend analysis for Satellite data that accounts for spatial and temporal autocorrelation

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Introduction

Our world is defined by its impermanence. Change, whether fostered by plate tectonics over eons or in wildfires ignited by mundane moments of negligence, is a fundamental characteristic of all natural and human systems. Identifying and adapting to environmental change is an ability essential to the survival of a species. Complex human society only flourished after the Mesopotamians learned to read seasons and sow their fields accordingly. As with the agricultural planners of antiquity, change detection and description serves as an indispensable tool used by the scientific community to quantify environmental processes. Current and future volatility in environmental systems perturbed by human activity represents one of the greatest threats ever confronted. Its perils are manifold as we must not only conceptualize them, but also determine their region and extent of impact, persistence, and frequency of occurrence.

Fortunately, our repertoire of analytical tools has grown enormously over the past several decades. In particular, the widespread acceptance of remotely sensed datasets has been a major windfall for the climate and ecological science communities. These datasets have enabled analyses of previously infeasible geographic and temporal scales and provide a vital multi-decade global archive for use in detecting anomalous environmental trends. However, not all trends that are detected are significant, and many that are identified are misunderstood. This is because commonly employed analytical methods largely ignore the spatial and temporal autocorrelation intrinsic to geographic datasets and thus do not control for their impacts.

This dissertation will rectify these issues through the application of a time series methodology (Ives et. al. In Prep) that controls for spatio-temporal autocorrelation in geographic datasets. This methodology will be used to evaluate multiple commonly observed trend types including a) long-term, incremental change in Arctic sea ice, b) wildfire induced infrequent, abrupt transitions in Russian boreal forests, and c) a combination of abrupt and long term trends in Amazonian deforestation. The results of these analyses will provide robustly generated descriptions of these ecological processes and potential repercussions. Additionally, they will highlight the impact of uncontrolled autocorrelation within datasets and the need for robust analytical methods.

Chapter 1: Ice

The Arctic is experiencing faster changes in climate than the global average due to atmospheric and oceanic circulation patterns and an overall reduction in surface albedo (Strove et al., 2007; Pistone et al., 2014; Letterly et al., 2018). This has dramatically reduced summertime sea ice volume, extent, and persistence (Onarheim et al., 2018), and rapidly altered Arctic ecosystems (Pistone et al., 2014; Sévellec et al., 2017). It is vital that patterns in Arctic sea ice loss are correctly identified and described to allow for accurate future climate predictions. This need motivates our primary research question; what are the spatially explicit trends in Arctic sea ice loss?

To answer this, we will use our time series methodology to evaluate patterns in Arctic sea ice extent quantified as the number of days of ice coverage per month in each 25-km pixel from 1978 to 2018 according to the NOAA-DoD SSM-I/SMMR dataset. This knowledge will be useful for understanding current and predicting future patterns of ice coverage of ice loss within the region.

Chapter 2: Fire

Climate change is predicted to increase the frequency of large-scale and high-severity wildfires in Siberian boreal forests (Malevsky-Malevich, 2008). This will have severe ecological consequences, including increased greenhouse gas emissions resulting from both deforestation and permafrost degradation (Kukavskaya, 2013; Fedorov, 2006). Due to the enormous implications of these processes for the global carbon budget it is critical that wildfires which facilitate them be documented. Accurate mapping of wildfires within Siberian boreal forests has historically been difficult due to their expansive and remote nature (Soja et al., 2006). To overcome these limitations remotely sensed datasets are used with varying degrees of success (Achard et al., 2008, Bondur et al., 2017, Valendik et al., 2011). These mixed results prompt our primary research question; can remotely-sensed time series be used be accurately detected destructive wildfires within the boreal forests of eastern Siberia?

To answer this we will use EVI data from the Landsat archive (1984-2020) in conjunction with our time series methodology (Ives in prep) to map wildfires within the boreal forests of Sakha, Russia's largest sub-national body. This dataset will then be used to evaluate for regions of intense fire occurance.

Chapter 3: Human

Deforestation of the Amazon Rainforest represents an enormous ecological threat due to the region's importance for biodiversity maintenance, carbon storage, and water cycling (Capobianco et al. 2001, Salati & Vose 1984, Lean et al. 1996). The immense and inaccessible nature of the Amazon makes ground-based mapping of deforestation infeasible, requiring that remotely sensed datasets instead be used (Milodowski et al. 2017). The location and extent of Amazonian deforestation is well mapped (Hansen et al. 2013). However, geographic patterns in deforestation rate are not described in detail (Lu et al. 2007). Mapping patterns in deforestation rate is important because it provides greater contextual knowledge than its extent alone. Discerning whether deforestation occurred randomly, in discrete "waves", or at a generalized consistent rate is useful for estimating its current and future ecological impacts. This utility prompts our primary research question; what are the geographic patterns in Amazonian deforestation rate?

To answer this we will use the Hansen Global Forest Change dataset (Hansen et al. 2013) in conjunction with our time series methodology (Ives in prep.) to identify geographic trends in deforestation rates. This analysis will span the years 2000-2019 and quantify deforestation rate as annual % forest loss at a resolution of 1 kilometer. Its results will identify regions within the Amazon whose deforestation rates are spatially and temporally correlated, suggesting that their degradation and post-conversion successional pathways are similar.

Significance

Global change will affect nearly every ecosystem on earth within the coming century (IPCC, 2001). Quantifying these changes in the Arctic, Siberian Taiga, and Amazonian Rainforests, each of which maintain vital climatological feedbacks, provides a holistic view of the current and potential scale, rapidity, and intensity of this global process. Now more than ever, it is critical that tools be developed and disseminated that allow for the robust detection and description of these effects. The time series methodology employed in each of these analyses fills this role and will allow future predictions. In turn, this information will allow for ecologists, land managers, and policymakers to make better informed decisions when navigating future climate uncertainty.

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