

Exploring Climate Patterns Embedded in Global Climate Change Datasets

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Abstract

This paper aims to explore the analysis of climate patterns embedded in the Global Climate Data Sets generated by the Community Climate System Model (CCSM) for the 4th Assessment Report of the Intergovernmental Report for Climate Change (IPCC). A Geographic Information Systems (GIS) approach is taken to examine spatiotemporal correlates among climate processes and to draw insights into their relationships and responses to climate change scenarios. With foci on El Nino southern Oscillation (ENSO) events and precipitation anomalies, the research explores three CCSM cases from worst-case, average, and conservative CO₂ emission scenarios, respectively. The scenarios used are A2: continental economic regions dominate with an economic focus (representing a worst case scenario), B1: a global economy with environmental focus (representing an average scenario), CC: CO₂ levels are stable at the current level (representing the best case scenario). GIS methods were used to examine the spatial and temporal development of precipitation anomalies under these three scenarios. A GIS spatiotemporal object growth classification scheme is proposed and then developed further in this paper. Further research is proposed to further the development and use of the GIS spatiotemporal object growth classification scheme.

Introduction

Geographic Information Systems (GIS) offers a new methodological framework to study the interaction of atmospheric and oceanic processes. The El Nino Southern Oscillation (ENSO) event is one such event with a global impact on weather patterns. On the other hand, the increase in CO₂ can have significant influence on the ENSO patterns and intensity. The degree to which CO₂ scenarios affect ENSO patterns in space and time is critical to the understanding of possible long term effects of CO₂ driven climate change. GIS provides an integrated platform for spatial analysis of the range of future climates possible under the different Intergovernmental Report for Climate Change (IPCC) CO₂ emission scenarios (Nakicenovic and Swart 2000). The model runs of the different scenarios offer important information in isolation. The correlations between different model scenarios and time periods are also a rich source of information on the potential impact of CO₂ driven climate change (McCarthy, Canziani, Leary, Dokken and White 2001).

Central to the GIS methods being developed is a temporal GIS framework with abilities to represent and analyze geographic dynamics. The research expands upon the process-based GIS approach (Yuan 2001, McIntosh and Yuan 2004) that incorporates representational and analytical needs to characterize spatiotemporal behavior and relationships of ENSO Sea Surface Temperature (SST) and global precipitation anomalies. Precipitation anomalies from years classified as El Nino event years are modeled as GIS data objects with spatial and temporal dimensions. The shape, growth, movement, internal structure, lifecycle and other spatiotemporal characteristics of the anomaly data objects were examined (Hornsby and Egenhofer 2002). In addition to object characterization, these measures serve as the basis for similarity queries and correlation analysis. Similarity query facilitates retrieval of anomaly events that exhibit similar spatiotemporal behaviors, such as similar El Nino events or similar precipitation anomalies in the three scenarios. "An anomaly tree" based on similarity measures can

suggest the effects of CO₂ emission scenarios on the distributions of El Nino events and precipitation anomalies, respectively. Complementarily, correlation analysis relates El Nino events and precipitation anomalies to reveal their spatial and temporal correspondences in answering questions such as where, when and how precipitation anomalies echo El Nino events.

The life cycle classification of the spatiotemporal anomalies portrayed in GIS can be envisioned as tubes in a two-dimensional space (x,y) with a one-dimensional time (t). Three types of life cycle classifications were initially envisioned; oscillatory, emergence and dissipative. Oscillatory exist during the entire time being represented but change shape and/or location. Emergent spatiotemporal anomalies initially do not exist and then appear during the time interval under study. Dissipative spatiotemporal anomalies exist at the initial time but dissipate during the time period under study.

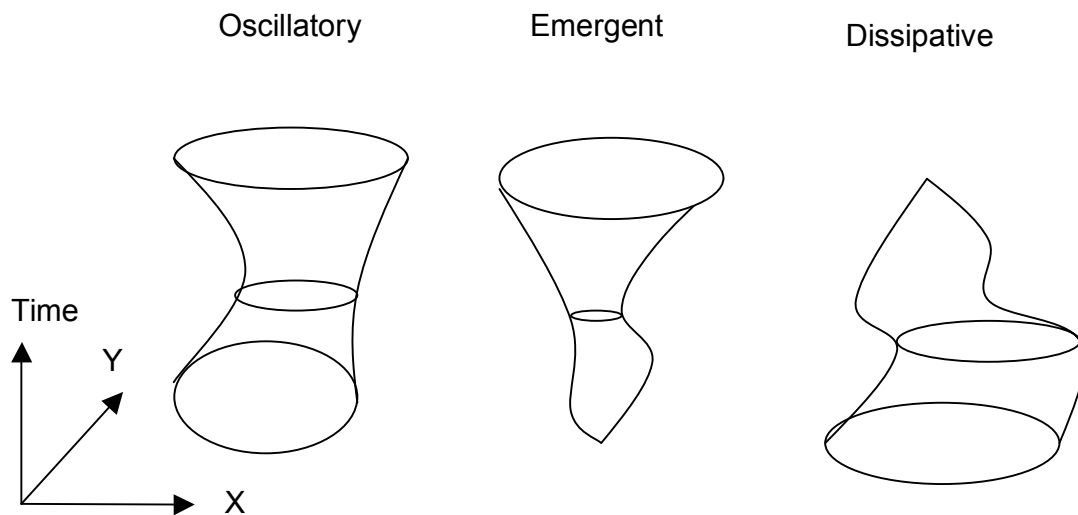


Figure 1: A tube model to represent three basic lifecycle types of spatiotemporal anomalies.

The tube analogy allows examination of spatiotemporal anomalies with respect to location, spatial extent, internal structure and life cycle. Spatiotemporal anomaly locations define search areas to explore the forcing functions that drive the anomaly. Spatial extent and internal structure give indications of the strength of the forcing function driving the anomaly. Life cycle classification allows the grouping of spatiotemporal anomalies with similar forcing function behavior. The location, spatial extent, internal structure and life cycle information can be used to construct “anomaly trees” and to do correlation analysis.

Methodology

Data for this research was obtained from the National Center for Atmospheric Research (NCAR) GIS Initiative. The NCAR GIS Initiative provides Global Climate Data Sets

generated by the Community Climate System Model (CCSM) for the 4th Assessment Report of the Intergovernmental Report for Climate Change (IPCC). The CCSM data was available in monthly averages for both atmospheric and surface climate variables. Thirty years of monthly data for the variables of interest were used to generate climatological means. Linear regression was used to model the slow rise in background mean temperature that existed in the CCSM scenario models.

El Nino events were determined by using average SST in the Nino 3.4 region: i.e. the area between 5S and 5N and between 170W and 120W. El Nino events were indicated when the monthly SST mean was greater than the climatological monthly mean for the Nino 3.4 region by more than 0.5C for the months of December, January and February (NOAA 2002). The CCSM model output years used were 2069 to 2098. The year 2099 was observed to have somewhat erratic values when compared to the other years. The climatological monthly mean for the Nino 3.4 region was generated by using a linear regression fit on thirty years of Nino 3.4 region SST data.

Monthly specific precipitation data for scenario model runs with El Nino events were then used to generate monthly specific precipitation anomalies for the El Nino event years. For each scenario, model runs generate thirty years of monthly precipitation data based on which we calculated monthly climatological means for each data cell in the CCSM data grids. Similarly, we used the monthly climatological means to identify the monthly precipitation anomalies for the years of interest.

The CCSM global model inherently has a large amount of inter-annual variability. Aggregation over decadal periods and over several model runs were used to filter out the inter-annual variability. El Nino precipitation data for all of a scenario's model runs were aggregated into three decadal periods. Each scenario has El Nino event precipitation anomaly data maps for the following decadal periods; 2069-2078, 2079-2088 and 2089-2098. ArcMap was used to generate GIS layers of the precipitation anomalies for the three decadal periods that differed from the mean precipitation anomaly for the year by more than two standard deviations. Over the three decadal periods, area with the monthly precipitation above the mean plus two standard deviations were separated into data layers of monthly deluge events. Furthermore, area with monthly precipitation below the mean minus two standard deviations were separated into data layers of monthly drought events. ArcScene was then used to visualize the spatial and temporal distribution of the monthly precipitation anomalies.

Two different approaches were taken to analyze the spatiotemporal patterns embedded in the precipitation anomalies for El Nino years. The first approach was a color coded map of precipitation anomalies (Figure 2). The precipitation anomalies have an interesting spatiotemporal pattern off of the east coast of South America. During the decadal period of 2069-2078 there is a deluge region with a drought region just to the south. Both regions have a large east west extent. During the decadal period of 2079-2088 only a deluge region appears midway between the locations of the previous decadal period's anomalies. Finally in the final decal period there is no large anomaly off of the east coast at all. The overall pattern of spatial anomalies has no discernable spatiotemporal pattern.

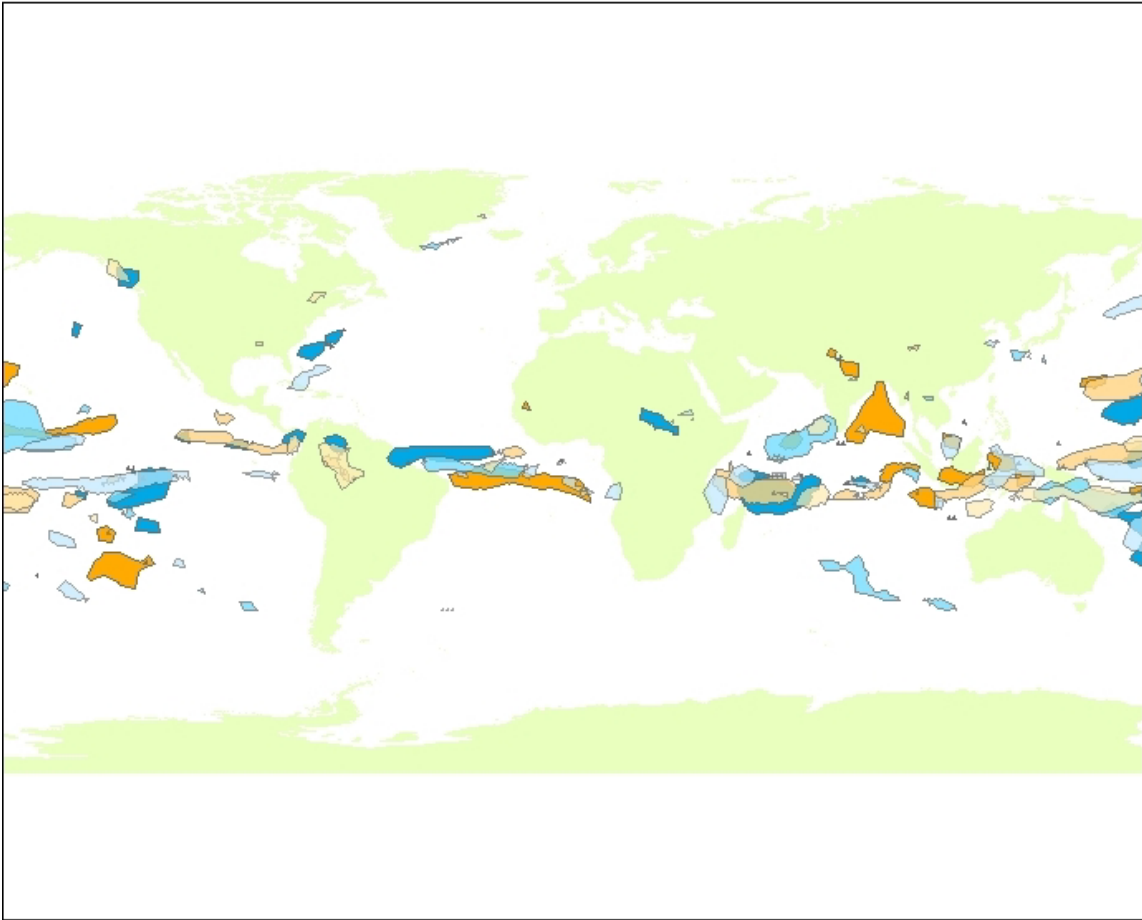


Figure 2: Month of May Anomalies for the IPCC Global Economy with Environmental Focus Scenario (CCSM El Nino Year Precipitation Anomalies for IPCC Scenario B1. Dark blue indicates 2069-2078 deluge regions; Dark gold indicates 2069-2078 drought regions; Medium blue indicates 2079-2088 deluge regions; Medium gold indicates 2079-2088 drought regions; Light blue indicates 2089-2098 deluge regions; Light gold indicates 2089-2098 drought regions.)

The second technique for analyzing the spatiotemporal changes was to construct a layered map in ArcScene. The lower layers were from earlier decadal periods. The following two figures were from the Climate Change commitment scenario where CO₂ is held constant at the current levels. The Pacific Ocean was the only area that shows consistent precipitation anomalies over the three decadal periods. Precipitation anomalies in areas other than the Pacific were independent of CO₂ level as the CO₂ level remains constant in this scenario.



Figure 3: Month of January Anomalies for the IPCC Climate Change Commitment Scenario (CCSM El Nino Year Precipitation Anomalies for IPCC Scenario CC. Dark blue indicates 2069-2078 deluge regions; Medium blue indicates 2079-2088 deluge regions; Light blue indicates 2089-2098 deluge regions.)



Figure 4: Month of January Anomalies for the IPCC Climate Change Commitment Scenario (CCSM El Nino Year Precipitation Anomalies for IPCC Scenario CC. Dark gold indicates 2069-2078 drought regions; Medium gold indicates 2079-2088 drought regions; Light gold indicates 2089-2098 drought regions.)

GIS Analysis Results

Spatiotemporal Patterns across Decadal Periods within a Single Scenario

The Climate Change (CC) scenario displays a repeated spatiotemporal pattern in the Pacific Ocean in the equatorial region during the months of January across decadal periods when El Nino's are occurring. By GIS functions, we stacked the precipitation anomalies vertically along the time line to examine the spatial and temporal persistence of anomalies (Fig. 3 and 4). Precipitation anomaly spatiotemporal patterns are no longer discernable during the month of May in the CC scenario across the three decadal periods. (Fig. 5 and 6) The Pacific Ocean anomalies migrate spatially and change its area extent with time. The single progression in CC scenario drought and deluge regions is the drought region to the northeast of Australia. The CC scenario is the most stable of the scenarios as the CO2 level is constant. The failure to discern a spatiotemporal pattern indicates that the monthly variability removes any El Nino event spatiotemporal signature within four months or less

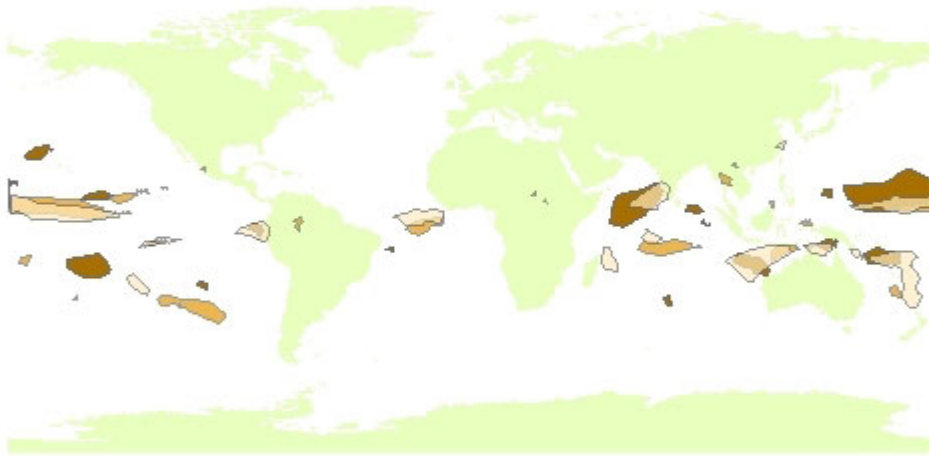


Figure 5: Month of May Anomalies for the IPCC Climate Change Commitment Scenario (CCSM El Nino Year Precipitation Anomalies for IPCC Scenario CC. Dark gold indicates 2069-2078 drought regions; Medium gold indicates 2079-2088 drought regions; Light gold indicates 2089-2098 drought regions.)

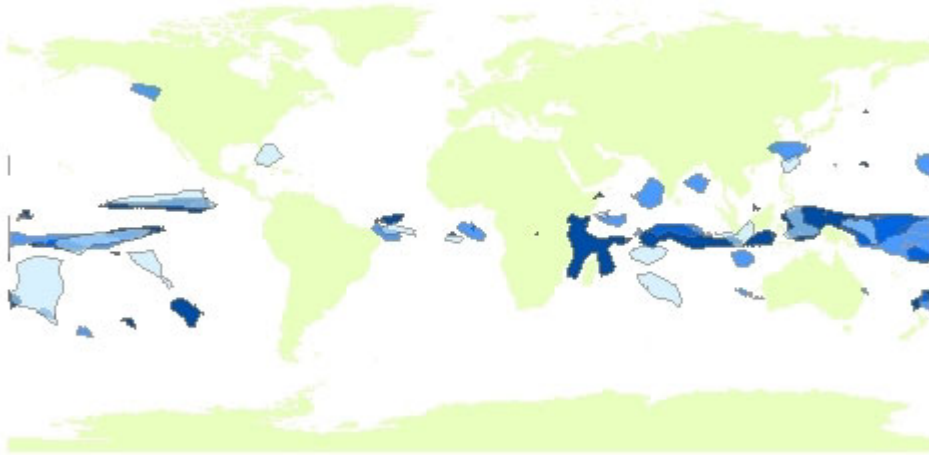


Figure 6: Month of May Anomalies for the IPCC Climate Change Commitment Scenario (CCSM El Nino Year Precipitation Anomalies for IPCC Scenario CC. Dark blue indicates 2069-2078 deluge regions; Medium blue indicates 2079-2088 deluge regions; Light blue indicates 2089-2098 deluge regions.)

Spatiotemporal Patterns across Decadal Periods across multiple Scenarios

The Climate Change Commitment scenario, with static CO₂ levels at the current level, shows a spatiotemporal pattern in the Pacific Ocean for the months of January during El Nino event years. (Fig. 3 and 4) The precipitation anomalies align along the time axis for all three decadal periods. The persistent spatial coverage and magnitude in certain area is expected as the CO₂ level is constant for the CC scenario. The A2 and B1 scenario January precipitation anomalies are compared to discern spatiotemporal differences. However, the B1 scenarios showed the same spatiotemporal pattern as the CC scenario as B1 scenario results are compatible with results from the average CC scenario, therefore, the following discussions emphasize the comparison between results from A2 and averaged CC scenarios.

The A2 precipitation anomalies, droughts and deluges, exhibited uncoupled behavior. A single El Nino occurred for the 2089-2098 decadal period during five runs of the A2 model. This single event is not associated with any decadal precipitation anomalies due to significantly high variability in precipitation throughout the 2089-2098 decade. In addition, A2 scenario assumes the largest increase in CO₂ of the model scenarios. The ENSO events essentially disappear in this scenario by the year 2089. Accordingly, the droughts diminished in spatial extent and shifted between the two decadal periods in all locations in the A2 scenario with the exception of west of Mexico, over central Australia and southeast of Africa. In the west of Mexico and over central Australia, new drought regions emerged. Several drought regions north of Australia and in the Indian Ocean exhibit dissipative behavior. The drought region southeast of Africa appears to be growing. Deluges exhibit growth in two regions during the 2069-2079 and 2079-2088 decadal periods: the central Pacific and the west coast of North America. There is no

other discernable pattern in the spatiotemporal patterns of precipitation anomalies suggested in the A2 scenario.

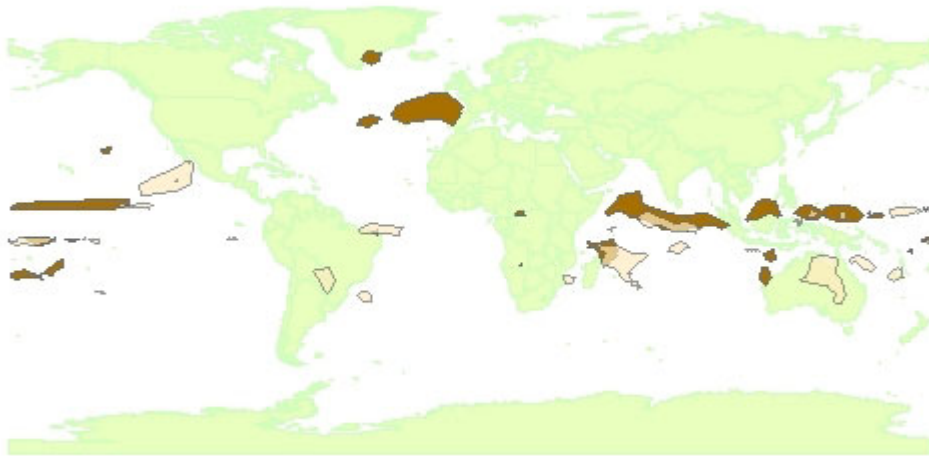


Figure 7: Month of January Anomalies for the IPCC Economic Focus Scenario (CCSM El Nino Year Precipitation Anomalies for IPCC Scenario A2. Dark gold indicates 2069-2078 drought regions; Medium gold indicates 2079-2088 drought regions.)

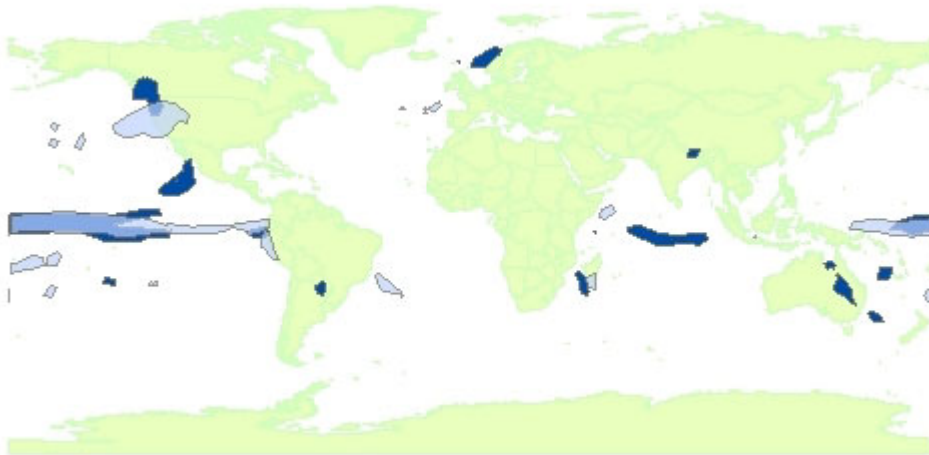


Figure 8: Month of January Anomalies for the IPCC Economic Focus Scenario (CCSM El Nino Year Precipitation Anomalies for IPCC Scenario A2. Dark blue indicates 2069-2078 deluge regions; Medium blue indicates 2079-2088 deluge regions.)

Concluding Remarks and Future Work

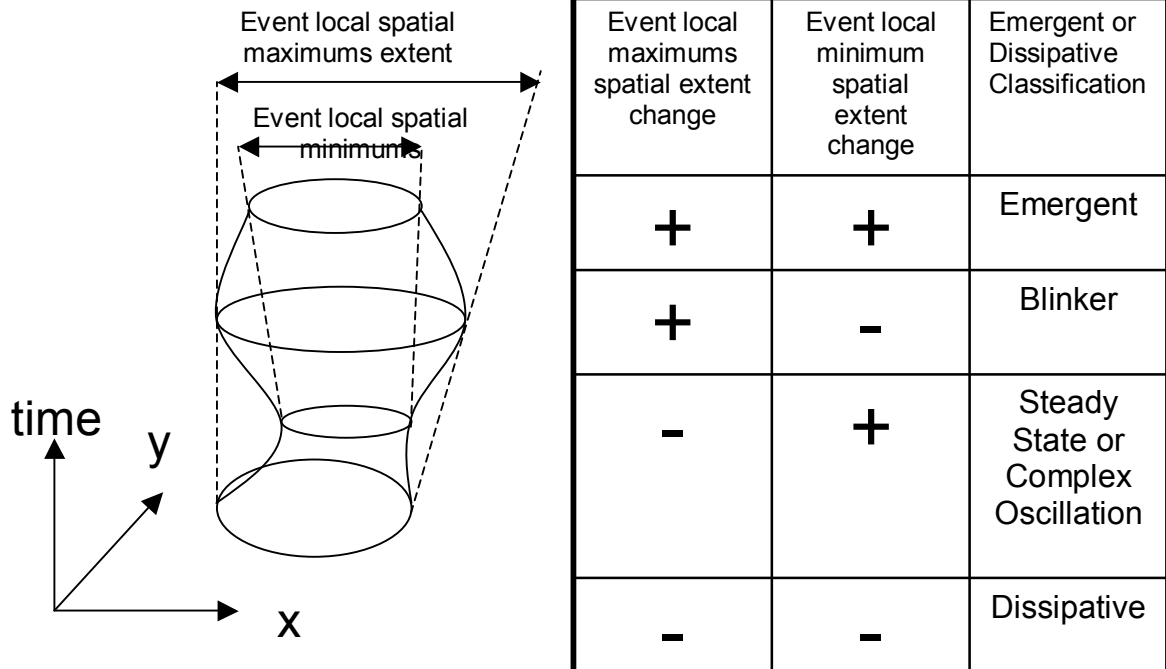
As shown in Fig. 5 and 6, several deluge and drought regions suggested in the A2 scenario exhibit dissipation or emergence behavior. Further research will be required to determine if these regions are truly dissipative or emergent and to map out their life cycles. The presented work sets forward a GIS-based methodological framework to explore and compare spatial and temporal patterns associated with three climate change scenarios. An implementation of an algorithm for the spatiotemporal aggregation of the anomalies is required to mine such spatiotemporal regions from a large data set of the IPCC scenarios. Recognizing emergence and dissipation behavior in regions of anomalies and comparing their behavior will enable the investigation of underlying forcing functions that may have generated the spatiotemporal regions.

In the presented analysis, the CCSM climate data suggest January precipitation anomalies during El Nino years until when CO₂ reaches a threshold level and climate warming has occurred. Establishing this threshold value may provide new insights into the affect of climate change on the ENSO event. The A2 scenario exhibits this transition into an expected diminished ENSO regime (Timmerman 2005). With the proposed GIS approach, algorithms can be developed to identify periods of missing precipitation anomalies and extract correspondent CO₂ levels for inspection.

The proposed life cycle classification for spatiotemporal phenomena provides a new approach to examine spatiotemporal behavior of climate events. Still, the life cycle classification needs further development. Simple classification as emergent, dissipative or oscillating is not enough. A definition of the rate of growth, positive and negative, oscillatory amplitude and frequency is required to compare phenomena of like classification. Oscillatory and growth are not mutually exclusive classification. One possible approach to combining the two is shown below.

Our study also suggests that precipitation anomalies persistent more than four months after the January El Nino are affected by the monthly variability, making it difficult to discern spatiotemporal relationships between the later month's precipitation anomalies and the January anomalies. Analyzing the spatiotemporal patterns of a climate variable of less spatial and temporal variability than precipitation may simplify anomaly identification. In light of the issue of spatiotemporal variability, we plan to investigate how climate zones defined by Koeppen and Thornthwaite climate classification schemes may vary in space and time among IPCC climate change scenarios. Long term climatological changes will have a large effect on the global distributions of flora and fauna and on human activities and adaptability. Mining of climatological data to determine the location of emergent and dissipative spatial events enables researchers to recognize spatiotemporal patterns, and based on which to hypothesize the forcing function or environmental variable behind the emergence or dissipation of the spatial event.

Dynamic Spatial Phenomena Life Index Algorithm



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