Translating big data into big climate ideas: communicating future climate scenarios to increase interdisciplinary engagement

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In Brief:

Climate change has emerged as the significant environmental challenge of the 21st century. Therefore, understanding our changing world has forced researchers from many different fields of science to join together to tackle complicated research questions. The climate change research community now faces the daunting task of disseminating massive amounts of information about possible future climates under differing scenarios, to a broad audience and make the data readily accessible so that it can be used by scientists in other research fields. One potential solution for distribution and communication of the climate scenario information may be through the EnviroAtlas, a new geospatial application developed by the United States Environmental Protection Agency and its partners. This interactive mapping tool allows users to access and explore climate change modeling information in easily understandable formats while at the same time providing a range of information on different ecosystem goods and services, or the benefits people receive from nature. By incorporating future scenarios such as land use and climate change within EnviroAtlas, we can evaluate specific components of complex ecosystems within the context of forecasted futures. Linking climate change impacts to ecosystem services, such as clean air and water, allows for opportunities to demonstrate how climate change will impact ecosystems, societies and human health.

Key Concepts:

- Climate change modeling provides the foundational information and data necessary to evaluate potential impacts to ecosystem services, however the size and complexity of plausible "future climate scenarios" requires significant resources and expertise, making it difficult to communicate climate change information to non-climate scientists.

- Understanding climate change and its impacts to humans and ecosystems is an inherently difficult task and requires expertise from many different fields of research that transcend the typical science paradigms and disciplines.

- EnviroAtlas is a web-based interactive mapping application that allows for the most recent climate change modeling and science to be explored while simultaneously providing information on ecosystem services for the entire US.

- When specific parts of the environment can be evaluated in the context of predicted land use and climate changes, it is possible to understand and disseminate the information of how those impacts will change in both space and time, and what the affect to ecosystems and humans will be.

Feature Article:

Global climate change has emerged as the significant challenge of the 21st century. While discussions tend to center on greenhouse gases, other factors, such as technological developments, land and energy use, economics, and population growth play a critical role in understanding climate change. As a result of the interconnected nature of these factors, traditional and often disparate science fields are joining together to tackle a set of extremely complex and compelling climate science questions. Scientists from diverse fields as economics, engineering, forestry, health, and medicine, are increasingly working together with climate scientists and modelers to improve understanding of how climate change will impact different sectors.[1]

To assess the risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems, researchers must consider a range of climate change rates and magnitudes.[2] Since 1990, the Intergovernmental Panel on Climate Change (IPCC) has released regular Assessment Reports that aim to "assess on a comprehensive, objective and transparent basis the scientific, technical and socio-economic information relevant to understanding the…risk of human induced climate change, its potential impacts and the options for adaptation and mitigation."[3] The IPCC recommends using a standard set of climate scenarios that apply uniform starting conditions, historical data, and projections for all future climate modeling efforts to facilitate consistent climate change research across the globe. These "future scenarios" describe plausible trajectories of different aspects of possible future climates and serve as a common method for passing global change science to other research foci to explore the implications in social, economic, political and environmental fields.[4]

The scope and complexity of these scenarios has vastly increased since the first installment released by the IPCC in 1992. With this increasing complexity, the resources necessary to understand and translate IPCC information to non-climate science research fields have also grown, creating a relative disconnect between climate science, the general public, and other interdisciplinary research. Recognizing the inherent role that climate change variables (e.g. temperature, precipitation, potential evapotranspiration) can have on multiple sectors of interest, many research fields are now incorporating climate research into their work. However, interdisciplinary scientists in these fields are not likely to be explicitly trained climate modelers. Therefore, two major challenges face climate change research: 1) the dissemination of voluminous amounts of future climate information to broad audiences in meaningful ways, and 2) the integration of climate model information with other research disciplines. Global change research that establishes and effectively conveys the interactions among the biological, physical and social systems to broad audiences, both in the public and in the academic arenas, has the potential to influence future policy and personal choices.

In this article, we discuss a possible solution for addressing the aforementioned challenges through the use of EnviroAtlas, a new application developed by the United States Environmental Protection Agency (USEPA) and partners. EnviroAtlas is a web-based, geospatial tool that allows users to interact with climate change modeling information in easily understandable formats while simultaneously providing a range of information on different ecosystem goods and services. The benefits people receive from nature are broadly defined as ecosystem services[5-7] and when viewed in relation to future climate scenario information, meaningful forecasting and understanding can be achieved. Here, we first describe the evolution of the IPCC's future climate scenarios, including the most recent modeling efforts, and their inclusion within EnviroAtlas. We then explain how EnviroAtlas provides a useful platform for interdisciplinary lines of inquiry and wide dissemination of information. Lastly, we acknowledge this is a first step in a large and complex solution, and provide recommendations for future analysis and visualization tools that will be necessary to facilitate novel, interdisciplinary global change research.

Future Climate Scenario Modeling

Research scientists have traditionally been the sole users of climate change information; however, resource managers have expressed a growing need and desire to access climate change scenarios and data to inform policy and decision making.[8] Recently, policy-makers have begun to rely on future climate scenarios to craft alternative adaptation and mitigation strategies.[8] The IPCC has published several sets of climate change scenarios, beginning with the first set in 1992, called IS92. Later, in 2000 the IPCC released a Special Report on Emission Scenarios (SRES) that provided the backbone for the climate modeling research of the last decade. The SRES marked the beginning of an explosion of climate data as the IPCC began archiving and publically sharing all climate model outputs that used the same scenario framework.[9] The Coupled Model Intercomparison Project (CMIP) relied upon 16 international modeling groups using 23 individual global circulation models (GCMs) to simulate current and future climates based on the SRES.[9-11] This project, named CMIP3, made all relevant data and information open to the public to facilitate greater accessibility, analyses, and new research.[9] The SRES also specified socio-economic circumstances that were fixed for each scenario. Limitations to this method were later identified as some variables (e.g. social, economic, and policy) were proscriptive and inflexible in ways that emissions and climate change outcomes are not.

The climate modeling community has continued to improve its numerical modeling based on recent scientific advancements, increased computational abilities, and development of greater spatial resolution of geographic information. Therefore, periodic developments of new future climate scenarios have, and will continue to be, required. Decision-makers and scientists alike will always require greater development in climate scenarios as they perpetually desire faster results, greater detail, better validation and easier exchanges of data and information between climate modelers and other fields of research. In 2014, the IPCC released the CMIP5[12] as its updated climate modeling effort. Most importantly, they moved away from the SRES and developed the Representative Concentration Pathways (RCPs) process. This process developed emissions and socioeconomic scenarios in parallel, building on different trajectories of radiative forcing over time. Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and is an index of the importance of the factor as a potential climate change mechanism.[2] In practice, radiative forcing can be thought of as the difference between the radiant energy (incoming sunlight) received by the Earth and the energy that is radiated back to space. Simply put, a positive forcing in energy (as in the RCPs) will cause temperatures to increase, while a negative forcing (more outgoing energy) will decrease global temperature. This forcing is usually measured in the amount of energy applied to an area (typically in watts per square meter). Each RCP scenario makes certain assumptions about future land-use and energy development, population growth, and other socio-economic factors, which help to drive the emission scenario. Based on these assumptions, each scenario provides information on a different emissions pathway and total emission concentration at the year 2100. The RCPs represent current emissions scenario literature and span a wide range of radiative forcing levels (or CO2-equivalent concentrations).[4] In contrast to the SRES, the RCPs allow for flexible socio-economic options to provide a more realistic representation of changing political and economic influences at regional scales.

Challenges Associated with Expanding Data Size and Complexity

Several challenges accompany the RCP process, in particular the steady expansion of climate data size requirements and the ease of accessing specific climate model information. These challenges are especially apparent in research that relies on climate modeling, but is conducted by other fields such as economics, ecology, and social sciences. Overpeck et al. (2011) identified two major objectives that must be addressed with regards to this expansion of data: 1) the increasing data volume should be easily and freely available to promote novel research, and 2) the data and results should be useful and understandable to broad, interdisciplinary audiences. The CMIP5 dataset is extremely big, estimated at approximately 2.5 petabytes (there are approximately 1 million gigabytes in a petabyte), and thus is problematic to visually represent.[8] There is a pressing need for the development of software tools for accessing, sifting through, and visualizing the outputs of the climate models (e.g. temperature, precipitation, etc.) for each of the years provided in the RCP scenarios (2001-2100).[8]

Including future climate scenario information and a climate variable viewer as components of the publicly available EnviroAtlas provides a preliminary solution for addressing the growing disconnect among climate science and other disciplines. As a web-based tool, the geospatial nature of EnviroAtlas allows users to access, view, and analyze diverse information focusing on the benefits that humans receive from the environment and how these benefits affect human health and well-being. Integrating the newest geospatial technologies and recent ecosystem service research, users with only an internet browser can access EnviroAtlas and its wealth of spatially explicit data and analysis tools. In response to the growing demand for global change information, EnviroAtlas has invested considerable time and effort into the integration of future climate, population, and land cover scenarios. Using future scenarios, it is possible to understand the forecasted impacts of climate change, which can then be used to project impacts to ecosystem services. Tangentially, incorporating these scenarios into EnviroAtlas provides a visualization tool for climate data. By combining many fields of research through this easy-to-use interface, the result is a novel tool that is spatially and temporally explicit and enables better decision making across multiple sectors.

EnviroAtlas Climate Data and Visualization

Effective policy formation, mitigation, and resiliency strategies depend on the spatial scale of the information being used to inform these decisions. Often, decisions are made at localized scales that differ greatly from the coarse spatial resolution provided by climate projections of the GCMs. For example, GCM experiments conducted under the CMIP5 are run at spatial resolutions ranging from 150 to 300 square kilometers. If resource managers were concerned with climate impacts related to New York City, the entire city would fit into one grid cell of the CMIP5 model runs. However, using downscaling methods that combine empirical techniques with high resolution gridded historical climate data, fine-scale climate information can be interpolated from the GCMs.[13] The NASA Earth Exchange (NEX) scientific collaboration platform has made available downscaled CMIP5 climate projections for the conterminous United States with a spatial grid resolution of approximately 800 meters. Named the NEX-DCP30 Downscaled Climate Projections, this dataset was released in 2013 to support scientific inquiry of regional climate change impacts and to provide meaningful information to natural resource managers in the United States.[12] This dataset is made freely available through multiple web services as Network Common Data Form (NetCDF) files, ASCII, and other formats. NetCDF files are data formats that support the creation, access, and sharing of array-oriented scientific data.[14] While publicly available, this information can be difficult to work with without sufficient computer programming knowledge. Additionally, data storage requirements limit some users from actively using the dataset. A single climate variable for one year (12 monthly measurements) at 800 meter resolution for the US needs approximately 1 gigabyte of storage. With three climate variables, over 90 future years, 34 climate models, four RCP scenarios, historical runs, and ensemble statistics, the storage requirements quickly become far too large for many users. As climate science spans diverse new research fields[1], there is a need to present this information without the programming prerequisite and large storage requirements necessary for analyzing conventional climate projections. EnviroAtlas contains one possible solution to this problem by bringing climate data into its interactive mapping application. This eliminates the requisite for computer programming knowledge and provides a means to access the standardized NetCDF format.

The interactive mapping application within EnviroAtlas (Figure 1) allows for viewing and manipulation of select data at multiple spatial resolutions and by geographic area. By March 2015, EnviroAtlas will provide in its mapping application all four RCP scenarios for the conterminous US, for every year from 2006 to 2100. Additionally, historical climate models will be available for every year from 1950-2005, providing 150 years of continuous climate information. Both the retrospective and future datasets are based on the NEX-DCP30 Downscaled Climate Projections. EnviroAtlas provides a time slider control bar that lets users manipulate and view temporal data converted from the NEX-DCP30 Downscaled Climate Projections. This time slider functionality can be used to query years or seasons of interest, zoom to specific geographic locations, and show animations of multiple years or seasons in the web application. Through the use of web services, users can import this data and information directly into their own online and desktop applications. In addition, this information can be viewed in conjunction with ecosystem services data and information served in EnviroAtlas. Climate variables are summarized annually and seasonally (fall, winter, spring, summer) and include maximum and minimum temperature, precipitation, and potential evapotranspiration (PET). PET was developed by EnviroAtlas researchers based on the foundational climate data of the NEX-DCP30 Downscaled Climate Projections. Therefore, the initial release will include a total of 16 different variables for viewing (4 scenarios x 4 climate variables), with additional climate related metrics planned for future updates. Each of the climate variables are based on the ensemble mean, which is the average of the downscaled climate projections from 34 CMIP5 GCMs. There can be considerable variability among the different GCMs; therefore, EnviroAtlas serves the ensemble mean to represent a plausible forecasted trend. Each climate variable was chosen specifically for its broad, widespread use in a multitude of research fields.

While EnviroAtlas focuses on general trends within the CMIP5 information, other web applications have concentrated efforts on providing information about the variability among the different GCMs. The best example is the National Climate Change Viewer (NCCV, www.usgs.gov/climate_landuse/clu_rd/nex-dcp30.asp) developed by the United States Geological Survey, which includes future climate projections for each of the CMIP5 GCMs for the RCP 8.5 and 4.5. In addition to coarse scale visualizations of the two scenarios, the NCCV also has tools that allow for comparisons of the different model outputs. These tools allow users to understand the differences and range of variability among the different GCMs. While the NCCV tool provides a powerful resource for understanding individual climate model variability in relation to the ensemble average, it contains no geospatial component and does not allow for its data to be viewed in relation to other geospatial environmental data. In comparison, EnviroAtlas provides a wealth of geospatial ecosystem service data that can be viewed, queried, and analyzed in relation to the RCP climate information. EnviroAtlas and the NCCV aim to communicate and provide climate related science in very different ways. Users can access climate modeling trends and see their relationship to ecosystem services within EnviroAtlas, and use the NCCV to further investigate the spatial and temporal range of variability and uncertainties of the different individual modeling efforts. When used in support of one another, these two publically available web applications make climate science easily digestible for broad audiences and facilitate the investigation of climate change effects in relation to ecosystem services.

Linking Ecosystems and Climate Change

EnviroAtlas uses an ecosystem services framework that integrates data on ecology, demographics, economics, public health, and recently, climate change. The implementation of this framework relies on an ecosystem based approach that allows for the evaluation of how humans and natural ecosystems influence and interact with each other. Data within EnviroAtlas are organized into multiple categories that characterize the production of ecosystem services, the benefits derived, and the attributes that may affect an ecosystem’s ability to continue producing those services. Maps and information are organized into seven benefit categories to maximize accessibility to a large volume of diverse data. There are three types of geospatial data provided: ecosystem services indicator data that have been summarized to standard EnviroAtlas reporting units, ecosystem services data in their native derived resolutions, and reference data (e.g. land cover, demographics) to help place the ecosystem services data into context.

Due to their complexity, ecosystem services typically cannot be assessed at a single point in space or time, as they may be influenced by surrounding and distant patterns of land use, biophysical attributes, and changes in climate. Therefore, by incorporating future scenarios such as landscape and climate change into EnviroAtlas, assessments can be made that evaluate specific components of an ecosystem within the context of forecasted futures. Housing a variety of data in one publicly available online tool encourages users to think in new, trans-disciplinary ways. By including the IPCC climate scenario information in EnviroAtlas, users will be able to explore the interconnectedness of climate and physical conditions of anthropogenic and natural systems.

Analyzing the location and distribution of climate vulnerable crop failures in relation to future climate change is one example of the trans-disciplinary work that EnviroAtlas facilitates. Biophysical factors such as increasing temperatures and changing precipitation and potential evapotranspiration regimes are main drivers of agricultural responses to climate change[15] and have been shown to impact agricultural systems in region specific ways.[16-18] For example, the agricultural sector in the southeast US may be forced to deal with greater ranges of precipitation, including more intense storm events, throughout the growing season. In contrast, farmers in the southwest may be more greatly impacted by increased drought events. Given these regional differences individual farmers, and to a larger extent the entire agricultural sector, should be keenly aware of the spatial and temporal nature of forecasted changes to climate. EnviroAtlas provides information on several crop yields (including cotton, fruit, grain, and vegetables), the number of crop types, and the total hectares of crops. This information is spatially explicit and can be viewed simultaneously with forecasted seasonal temperatures, precipitation, and potential evapotranspiration. Having the power to evaluate and view this information simultaneously allows for the identification of areas where crop failure is likely to increase both in the immediate (e.g. 2025) and distant future (e.g. 2080) due to changing temperature and precipitation regimes.

Initial uses and applications of EnviroAtlas

A main goal of EnviroAtlas is to reach a broad and interdisciplinary audience, including those involved in education, conservation, land management and policy, as well as scientists. Prior to making EnviroAtlas publically available, a pre-release beta test was conducted. Approximately 660 people registered as beta-testers. In addition to providing feedback on EnviroAtlas, each beta-tester was asked for information on their job field. Responses ranged from ecology and environmental science, GIS professionals, research scientists, educators, public health, urban planning, conservation and restoration. Subsequently, since its public release in May 2014, the EnviroAtlas interactive map has had approximately 120,000 map views. Based on the web tracking data, a conservative estimate of daily site use is 880 individual EnviroAtlas users per day. These early results, combined with our pre-release testing, indicates that EnviroAtlas is reaching broad, interdisciplinary audiences and is also being used by the public. As EnviroAtlas continues to gain traction, daily site traffic and complex spatial analyses applying EnviroAtlas tools and data is anticipated to increase.

The tools and data provided within EnviroAtlas have been employed in several diverse projects aimed at mitigating climate change, ranging from micro-scale to regional and national applications. From a regional perspective, the Southeast Atlantic Landscape Conservation Cooperative (SALCC) has incorporated EnviroAtlas layers as web services in its Conservation Blueprint currently under development. SALCC is a partnership of federal, state, nonprofit, and private organizations focused on conserving a landscape capable of sustaining the natural and cultural resources for current and future generations. The SALCC has a large focal area, including portions of Virginia, North and South Carolina, Georgia, and Florida, therefore the data and information provided by EnviroAtlas has helped to guide development of a conservation plan aimed at dealing with climate change, urban growth, and increasing human demands on resources. Given the priority of the SALCC to conserve natural and cultural resources for future generations, the ability to model future climate scenarios is a key component of identifying the places and actions needed to meet conservation objectives in the face of future global change. The SALCC Conservation Blueprint 1.0 has been created with version 2.0 in early development; EnviroAtlas data and tools will continue to assist in this work.

The multiscalar capabilities of EnviroAtlas has allowed for city specific applications as well. Trees Across Durham (TAD), an organization funded by the city of Durham, N.C. has used EnviroAtlas to prioritize tree plantings across their city. A key goal of the Durham Sustainability Pilot Project is to increase the cities resiliency to climate change. TAD utilized the EnviroAtlas to determine strategic placements of urban trees on public property throughout the city limits to maximize environmental, social, and economic benefits to the community. The strategic planting of hundreds of trees were aimed at offsetting (through sequestration) pollutants such as nitrogen dioxide and particulate matter, reducing the formation of smog, and creating a more climate resilient city by potentially mitigating the urban heat island phenomena[19]. TAD's next planting project is scheduled for Fall 2014, and with the continued use of EnviroAtlas will be able to include estimates of future climate variables, such as temperature and precipitation, to prioritization planting schemes for anticipated global change in the near and distant future.

The Tip of the Melting Iceberg: Future Challenges for Interdisciplinary Climate Science

Novel climate research often combines several traditional science disciplines to answer compelling questions.[1] Yet, this interdisciplinary nature creates significant hurdles when communicating climate research to multiple audiences, each of whom have different perspectives on how research is to be conducted, different syntax for discussing science, and even distinct outlets for publication and sources of funding.[1] EnviroAtlas seeks to provide a credible initial solution to these hurdles by providing a space to disseminate the newest climate modeling efforts in concert with ecosystem services. This climate viewer eliminates the need for massive storage capabilities, the ability to program and handle multiple complex data formats, and provides easy comparison of climate scenarios. Many levels of complexity are built into the web-based geospatial application where an understanding of the interactions among the biophysical, social, economic, and human health spectrums can be achieved.

There is increasing urgency for methods to forecast how different sectors may be altered as a result of climate change. EnviroAtlas has demonstrated one method for doing so, but much work remains. Continued investment in geospatial visualization and analysis tools focusing on climate modeling efforts are imperative for trans-disciplinary climate science in the future. Model limitations must be effectively communicated to improve climate system understanding and forecasted changes, therefore it is critical to couple the capabilities of the EnviroAtlas with tools to highlight model variability such as the NCCV. As important will be the ability to forecast ecosystem services based on these modeling efforts. Linking climate change impacts to ecosystem services, such as clean air or water, allows for opportunities to clearly demonstrate how climate change will impact our societies and human health. Climate modeling has provided a crucial foundation, but now research and tools that transcend traditional science paradigms are necessary to answer interdisciplinary questions that focus on the impacts to ecosystems.

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Figures:

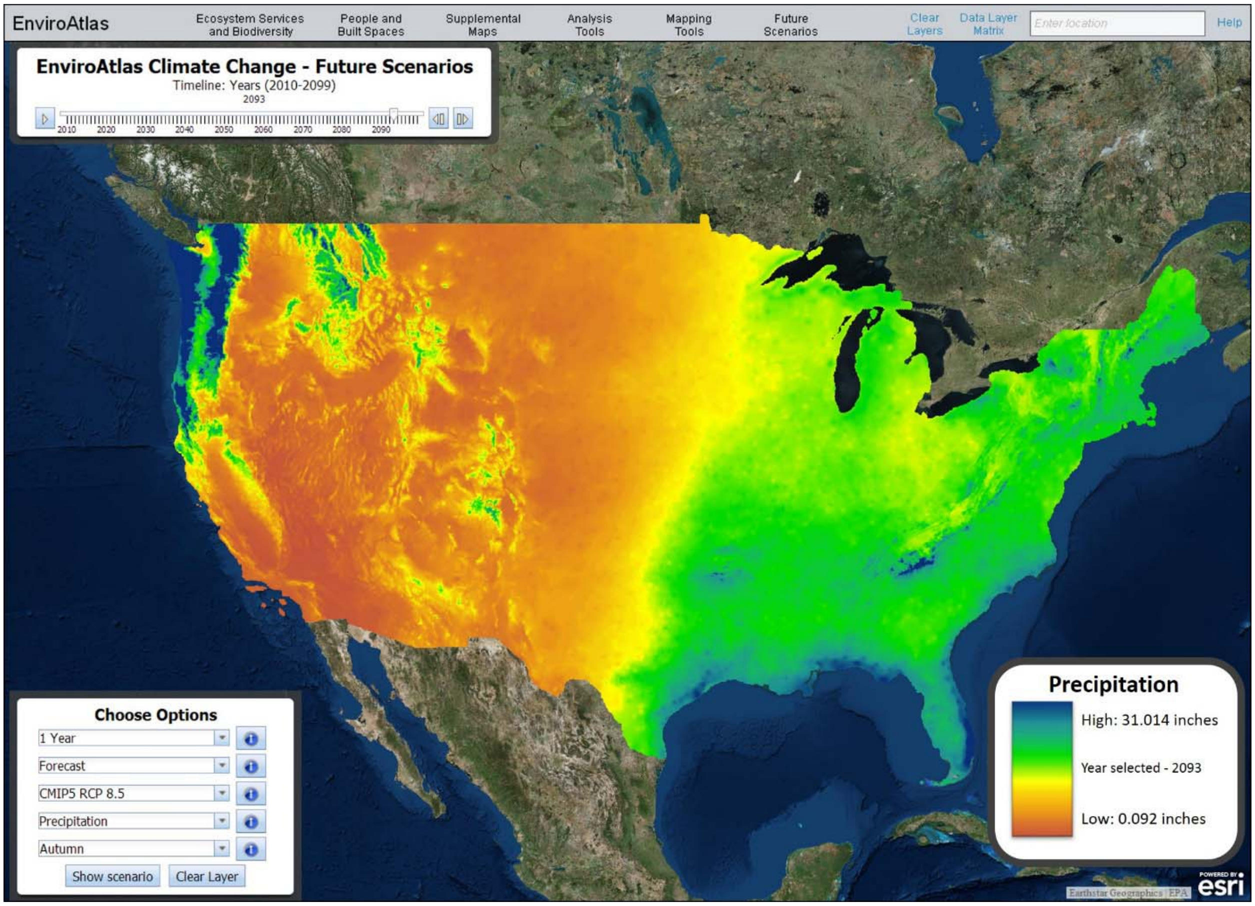

Figure 1. Example of the EnviroAtlas future scenario time slider widget displaying forecasted autumn precipitation for the years 2010 to 2100 (the year 2093 is displayed) based on the RCP 8.5 future scenario. Users can select from multiple options, including the number of years to represent in the time slider, specific RCP scenarios, climate variables and corresponding seasons.