Integrating GIS Visualization Tools for Ecosystem Management

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***Abstract*—This paper presents a targeted view into the current development stage of the 3.X version of TACCIMO, a web-based application delivering climate change science to the forest management and planning community. The interactive TACCIMO GIS Viewer delivers custom visualizations and reports combining climate change projections with peer-reviewed literature and planning language. We present our work integrating externally hosted, heterogeneous data sources into the TACCIMO GIS Viewer, including our efforts to accommodate minimal changes to existing source code, along with advanced geospatial analysis methods using integrated climate change data. Our real world case studies demonstrate the contexts motivating our work for users assessing, managing, and monitoring forest resources within the conterminous United States.**

Keywords-ecosystem management; forestry; Geographic Information Systems; geospatial map service; web service; climate change.

I. INTRODUCTION

Climate change science plays an important role in forest planning and management [1]. Land managers pose seemingly straight-forward questions, e.g., "what tree species do we need to plant," whose answers depend on a myriad of parameters including climate change science. Scientists and researchers develop tools used by land managers and policymakers to improve their understanding of climate change and its impact on forests, rangelands, and urban areas [2]. Land managers and policymakers then use this information in developing policies and management techniques to sustain and improve ecosystems of interest [3][4].

Given the ever-increasing volume of scientific knowledge and tools regarding climate change and forest ecosystems, their quantity and rate of increase places a burden on our partners and users attempting to efficiently consume and utilize this information. The Template for Assessing Climate Change Impacts and Management Options (TACCIMO) was created to address this need for a standardized, credible, and concise science delivery tool relevant to forest planning and management [5]. As a collaborative effort of the Eastern and Western Forest Environmental Threat Assessment Centers (EFETAC and WFETAC), along with the Southern (R8) and Pacific Southwest (R5) Regional Forest Planning units of the USDA Forest Service, TACCIMO provides an interactive resource for consuming the combination of climate change science and related peer-reviewed literature and land management planning options.

The work highlighted here focuses on TACCIMO's Geographic Information Systems (GIS) Viewer, a web-based geospatial user interface that allows users to explore climate change science model visualizations within the conterminous United States. The GIS Viewer addresses the demand from research and industry partners for a tool that combines geospatial visualization and summarization.

In this current release, the 3.X version aims to move away from custom-built point-solutions specific to individual needs towards a widely usable integration of geospatial applications. This move from a data repository toward support and guidance includes integration of multiple external hosted data sources into the TACCIMO framework, particularly the TACCIMO GIS Viewer. One of the main changes to the updated TACCIMO GIS Viewer is integrating externally hosted data while minimizing development costs by minimizing changes to existing source code. We also present examples of advanced geospatial analysis methods that leverage this integrated approach and support our goal of providing support, guidance, and unique data interpretations for new and existing partnerships.

This paper is structured as follows: Section two, related work; Section three, architecture and design; Section four, data integration and spatial analysis paradigms; Section five, case studies; and Section six, conclusion and future work.

II. RELATED WORK

There are a wide range of frameworks and techniques for integrating applications, some of which are specific to their domain or a particular technology, while others are generalizable. We present a few as follows.

Service-oriented architectures (SOA) and their associated web services facilitate communication between separate, independent components and specify the protocols governing these communications; this in-turn allows for integration and interoperability of stand-alone applications over the web. Many frameworks and techniques build upon these concepts. SOAP [6] and representational state transfer (REST) [7] are two widely-known and widely-utilized technologies towards these ends, which are in turn used in other techniques and architectures. We too adapt REST in our communications.

Creating software federations is another approach to the ever persistent software integration problem. Some

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approaches look at Commercial-Off-the-Shelf components [8] for design and integration. Aspect-oriented programming or AOP [9][10] is used in several federation building concepts. AOP separates structures which cross-cut programming abstractions. One approach [11] uses AOP to refactor middleware systems, while another [12] uses AOP as the middleware itself. In techniques applicable to many domains, AOP is used as an exchange for manipulating and processing data between federation components [13]. Our work uses AOP concepts without use of an AOP library.

Tuple-spaces [14][15][16], a generative communication technique coordinating indirect communication between programs, is used in conjunction with several techniques. XMLSpaces [17] is an extensible markup language (XML) focused middleware solution extending IBM's TSpaces implementation [18]. The communication aspects approach [19] uses AOP to uncouple communication and computation, combined with tuple-spaces for communication between aspects. We adapt the communication aspects approach for use in an environment sans AOP.

There are approaches specific to GIS and geospatial analysis domains, such as the webGIS model [20], which uses web 2.0 services to integrate heterogeneous geospatial/geographic databases. Sahina [21] and Aydin [22] amongst others look at GIS-centric usage of SOA and web-services for sharing data between GIS applications. Our approach focuses on interoperability without an overarching architecture.

III. ARCHITECTURE AND SYSTEM DESIGN

The architecture and system designs descriptions for the TACCIMO GIS Viewer and the associated independent geospatial applications present a high-level view into their underlying structures.

A. *TACCIMO Architecture and Design*

TACCIMO's overall system architecture for the hosting and technology stack utilizes a multi-tiered system. Content for peer-reviewed literature and planning data are accessed through relational database queries managed by Microsoft SQL Server. Internally hosted geospatial data is managed using Esri ArcGIS Server 10. Development for the TACCIMO web application hosted on the web server was done in Visual Studio. The front-end for the TACCIMO GIS Viewer was built in Flash Builder 4.6 using the Adobe® Flex 4® SDK. The Esri ArcGIS API for Flex is used to access both internally and externally hosted ArcGIS Server resources. Figure 1 gives an overview of the architecture as used within TACCIMO.

B. *Climate Wizard*

Climate Wizard [23], created in partnership between The Nature Conservancy, the University of Washington, and the University of Southern Mississippi, is a web-based tool [24] providing analyses and geospatial representations of projected global climate change throughout the world in the form of maps, graphs, and tables. It includes temperature and precipitation measurement changes over a historic and two future time periods, using 16 general circulation models (GCMs) and seven GCM ensembles run against three greenhouse-gas emission scenarios. Climate Wizard provides these averages and change in averages for annual, monthly, and seasonal time frames.

This 'big data' application uses ArcGIS Server REST web-services for geospatial data, with underlying data values served through the Amazon Web Services 'on the cloud.' While Climate Wizard provides global climate change predictions, we focused on those for the conterminous United States.

C. *California MC1*

MAPSS-CENTURY 1 (MC1), created in partnership between Oregon State, Colorado State, and the USDA Forest Service Pacific Northwest Region (R6), provides a dynamic global vegetation model (DGVM) based on the interaction between the MAPSS biogeography model, the CENTURY biogeochemistry model, and a dynamic fire disturbance model [25][26][27]. California MC1 presents the MC1-based predictions for California. The geospatial maps delivered by the California MC1 model are split between the 'MC1 Inputs' for climate change predictions and 'MC1 Outputs' for vegetation and other associated change predictions.

The parameters used for MC1 Inputs are similar to those used in Climate Wizard: two general circulation models run against two greenhouse-gas emission scenarios, measuring average temperature and precipitation for annual and seasonal time frames for one historic and four future time periods. For MC1 Outputs, we use the same two GCMs run against the same two emission scenarios for the same historic and future time periods, but only the annual time frame is used. Instead of measuring temperature and precipitation, vegetation and other climate change indicators are used. These geospatial maps are accessed using ArcGIS Server REST web-services.

D. *Climate Change Atlas*

The Climate Change Atlas, created by the Northern Research Station of the USDA Forest Service, documents the

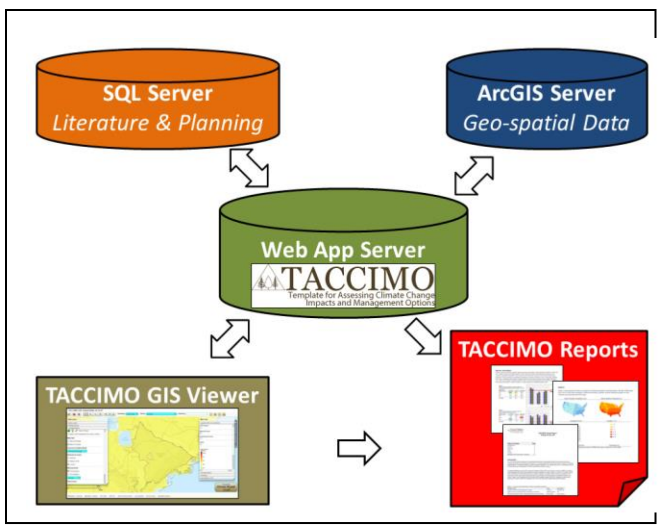

Figure 1. TACCIMO Architecture

current and potential habitat distribution shifts for tree and bird species throughout the eastern United States [28][29][30]. The Tree Atlas, a subset of the Climate Change Atlas, delivers the current and possible future distribution for 134 tree species and their underlying environmental predictors using a habitat prediction model (DISTRIB), a colonization likelihood model (SHIFT), and outside factors model (MODFACs).

Habitat suitability is given as importance factor, a measure of relative abundance accounting for tree basal area and the number of stems [31]. The Climate Change Atlas database [32] uses three GCMs and an ensemble average, each run against two greenhouse-gas emission scenarios. Each tree species has a separate model reliability factor. While the original source data is hosted externally, ArcGIS web services are hosted internally.

IV. SOFTWARE PROGRAMMING PARADIGMS

As part of the integration of Climate Wizard, California MC1, and the Climate Change Atlas into the TACCIMO GIS Viewer, we had to address several technical and practical needs: integrating external resources, minimizing changes to existing data, and developing analysis methods using the integrated external data that provide support and guidance to partners and other interested users.

A. Data Integration: Adapted Communication Aspects

The task of moving from internally hosted resources to leveraging data from our collaborative partners was restricted by the limited time and resources of our small development team. The communication aspects technique appeared promising, as it uses aspect-oriented programming and tuple-space modules to connect separate programs into a combined software federation. With Adobe Flex as our programming language for the GIS Viewer front-end, the AOP libraries we explored were not ready for production level use.

AS3Commons AOP, built on AS3Commons Bytecode [33], was an inactive project using older AS3Commons libraries that make it incompatible with our Flex 4 project. It was based on the Loom project [34], commonly cited as the foundation for most AOP endeavors in Flex. Flapper [35], an alternative Flex AOP library based on the Parsley application framework for Flex [36], also had compatibility issues due to development inactivity. The Swiz Framework [37] was another option for AOP within Flex that uses inversion of control and other AOP relevant techniques. Its 2.0 version was slated to include many AOP features we needed, but development of 2.0 was halted and the project donated to Apache Flex in summer 2013 [38], eliminating another option from our list.

Since there were no freely available production-ready AOP libraries for Flex, we looked into bringing the foundational concepts of communication aspects into the GIS Viewer sans AOP. We needed something requiring the effort of one primary developer, ruling out more exhaustive options such as switching languages. In communication aspects, communication and computation are separated using AOP. We achieve a similar separation adapting the ArcGIS Server REST web-services with the observer design pattern [39]; internal communication between components is through the design pattern, while communication between the internal TACCIMO components and data hosted on ArcGIS uses REST.

B. Spatial Analysis: Tree Atlas Summarization

Another thrust of our development changes for the TACCIMO GIS Viewer is developing methods integrating the external data from our partner applications to provide unique data analysis. Here, we explore one of the techniques using a new partner, the Tree Atlas within the Climate Change Atlas.

There are currently distributions for 134 tree species in Tree Atlas; we use the distributions provided across nine climate change model scenarios: three GCMs (Hadley CM3, PCM, and GFDL) and the average of the three GCMs, with all four of these run against two emission scenarios (A1FI and B1), plus the current historical baseline. These combinations make it difficult to synthesize. There is also data in tabular format, but when a user selects a geographic area of interest, these tables often include entries for species not within the area of interest. Inter-species comparisons are limited to two tree species within the selected scenario, even though several dozen trees may exist within the area of interest across the scenarios. The data are there but are not easily consumable for the non-specialist.

Our real-world driven geospatial analysis method is to develop a tool within the TACCIMO GIS Viewer that will, for a user-selected area of interest, create a non-standard visualization comparing all tree species within the area across all nine climate change model scenarios. The original data are arranged by species, yielding 134 data layer tables. We transposed the data matrix into nine data layer tables, allowing for faster data selection and querying through placement in an ArcGIS Server.

Once the user selects the custom area of interest, it is checked for size constraints. The underlying selectable area of interest map is broken down into polygonal cells; if the initial user selected area of interest falls below the constraint threshold, we retrieve the map points bounding each polygon cell in the selected area and run a nearest neighbor search. Those neighboring map points are added to the area of interest. We use this technique to grow the area of interest until it passes the size constraint.

After passing the size constraint check, each climate change model scenario is fetched and queried using REST web-services, bounded by the area of interest. We calculate the adjusted importance value for each species. Since Tree Atlas returns the importance value for each species respective to its entire range of habitability, we average that value over the selected area of interest. An adjusted importance factor of 100 would indicate a monotypic forest stand within the selected area of interest for the climate change scenario. After all scenarios are completed, each species is summed across all climate change scenarios, and those with zero occurrences across all scenarios are pruned. Finally, the species for the current historic climate change scenario are sorted by relative importance from highest to

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lowest; the eight other scenarios then use the same ordering for their tree species.

V. CASE STUDIES

We show several case studies using two national forests (Francis Marion National Forest and Yosemite National Forest) of interest to our research and industry partners, highlighting the integration of the Climate Wizard, California MC1, and Climate Change Atlas external data sources into the TACCIMO GIS Viewer, plus the utility of our advanced geospatial analysis technique created for the Climate Change Tree Atlas.

A. TACCIMO GIS Viewer Usage Overview

The TACCIMO GIS Viewer is organized around customized themes. There are themes for various case studies requested by our collaborators and partners, in addition to the new themes for California MC1 and the Climate Change Atlas. Each theme provides parameters for users to select which geospatial maps to display in the visualization, along with identification and other spatial analysis tools. Users can also generate a climate change report linking the visualization with peer-reviewed literature and planning language.

B. Climate Wizard

The Climate Wizard integration is available across all themes in the GIS Viewer, as the climate change scenarios it provides are not specific to a particular region or case study. Our parameterization yields 9,384 future climate change scenario permutations: 16 GCMs and seven GCM ensembles, run against three greenhouse-gas emission scenarios (A2, A1B, B1), for 17 time frames (12 months, four seasons, and annual) in three temporal dimensions (future time periods), for the average and changes in average temperature and precipitation. The current historic time period gives 68 permutations, as the GCM and greenhouse-gas emission scenarios do not apply in its case.

Figure 2 shows the change in average annual temperature using the ensemble average GCM and the low (B1) emission scenario projected for the mid-21st century time period at Yosemite, and Figure 6 shows the same climate change projection for Francis Marion. Both show an increase in the mean temperature of approximately four degrees Fahrenheit.

C. California MC1: Yosemite

The California MC1 integration is available through the California MC1 theme. There is a further split of the geospatial visualization layering: MC1 Inputs for climate change predictions and MC1 Outputs for vegetation and other associated change predictions.

MC1 Inputs parameterization yields 160 future climate change scenario permutations: two GCMs (GFDL and PCM) run against two greenhouse-gas emission scenarios (A2 and B1), for five time frames (four seasons and annual) in four temporal dimensions, for the average temperature and precipitation. The current historic time period gives 40 permutations, as the GCM and greenhouse-gas emission scenarios do not apply in its case.

The MC1 Inputs parameterization yields 320 future climate change scenario permutations: the two GCMs run against two greenhouse-gas emission scenarios for five time frames in four temporal dimensions are all identical to those in MC1 Inputs. They measure four climate change indicators: biomass consumed by fire, stream flow depth, maximum snow precipitation, and vegetation habitat classifications. The current historic time period gives 80 permutations.

Here, we look at Yosemite National Forest in California. Figure 3 shows the MC1 Input projected change in average annual temperature using the GFDL GCM run against the B1 low emissions scenario projected for the mid-21st century. This is matched with the MC1 Output projected change in maximum snow precipitation for the same climate change scenario in Figure 4 and the MC1 Output historic maximum snow precipitation in Figure 5. Under this low emissions scenario, users noticed the projected climate impact is a decrease over time in snow along the western slopes of the Sierra Nevada mountain chain in Yosemite National Forest, correlating with the projected temperature increase for the same area in Figure 3.

Having these external climate change science tools gathered in a shared user interface allows decision makers to visually note the projected changes and impacts, and make comparisons. Users can now simultaneously view changes and impacts, gaining insight into interactions between indicators across a large array of climate change scenario configurations.

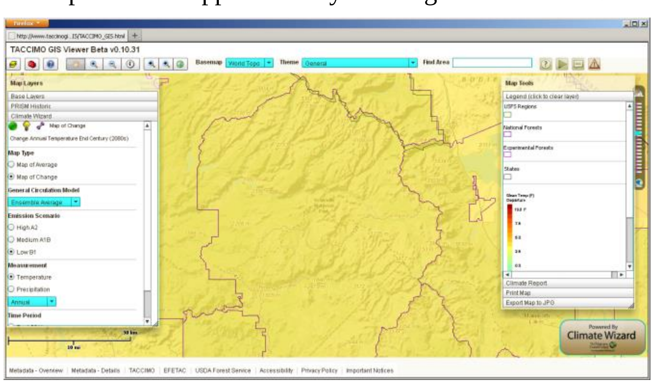

Figure 2. Yosemite projected change in average annual temperature using GCM average ensemble and low B1 emissions in Climate Wizard

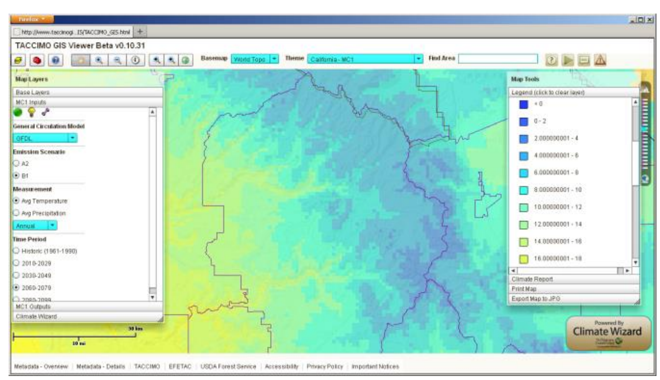

Figure 3. Yosemite projected change in average annual temperature using GFDL and low B1 emissions in California MC1 Inputs

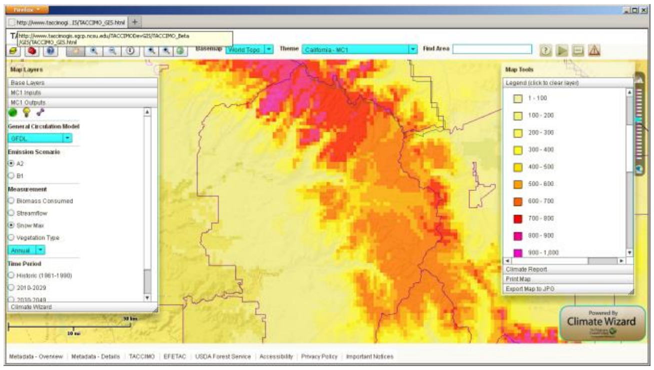

Figure 4. Yosemite projected change in maximum annual snow precipitation using GFDL and low B1 emissions in California MC1 Ouputs

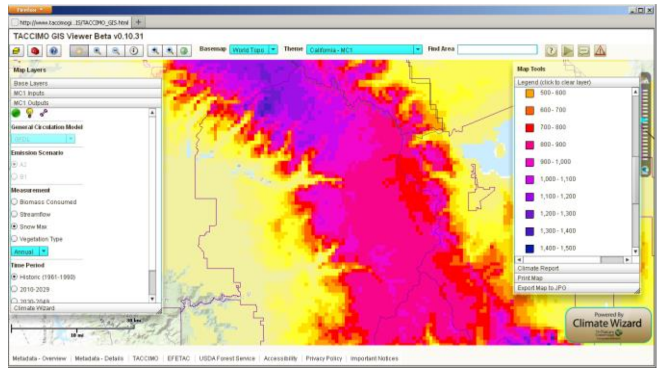

Figure 5. Yosemite current historic maximum annual snow precipitation in California MC1 Outputs

D. *Climate Change Tree Atlas: Francis Marion*

The Climate Change Tree Atlas integration is available using the Climate Change Atlas theme. Along with the visualization of suitable habitats for each of the 134 tree species, there is a tool for selecting an area of interest and generating a non-standard visualization summarizing the relative abundance of each tree species.

Our Tree Atlas parameterization yields three scenarios for each tree species: current historic, average GCM for the A1FI (high emissions) scenario, and average GCM for the B1 (low emissions) scenario. We do not use any of the temporal dimensions for the GCMs. The Climate Change Tree Atlas summarization tool allows the user to select an area of interest, and then calculates and generates a chart showing the relative importance of each tree species. It uses all nine climate change scenarios available through Tree Atlas: the Hadley CM3, PCM, and GFDL GCMs, plus the average GCM run against the A1FI and B1 emissions scenarios, along with the current historic baseline scenario.

Here, we look at Francis Marion National Forest along the coast of South Carolina. We used the GIS Viewer to explore scenarios using *Pinus taeda* or loblolly pine, the dominant tree species for that area [40]. Comparing the GCM average run against the B1 low greenhouse-gas emissions scenario in Figure 7 with the historic in Figure 8, users noted a decrease in relative habitability dominance for the tree species. Users then asked several questions: "is loblolly pine still the dominant species with regards to habitat in future scenarios, how much does it decrease relative to the other species, and does it decrease enough so that another surpasses it with respect to habitat suitability?"

The charts in Figure 9 and 10 generated by the Tree Atlas advanced geospatial analysis summarization tool allowed users to quickly look further into these questions without having to manually search each of the 130+ other tree species across the various climate change scenarios. In Figure 10, users hovered their mouse over the data point for the GCM average run against B1 of loblolly pine, showing its adjusted importance value at around 15.53. Users noted the spike for *Pinus elliottii* or slash pine in the same GCM average run against B1, with its adjusted importance value at approximately 10.98. Forest, land management, and other experts then use this information towards further investigation.

VI. CONCLUSION AND FUTURE WORK

The current development stage of the TACCIMO GIS Viewer allows for integrating externally hosted geospatial data sources with peer-reviewed literature and planning language. Internally, this integration was managed by a combination of aspect-oriented programming-like observer patterns, with external communications centered on ArcGIS REST web-services. These integrations allowed policy developers and land managers to conveniently investigate multiple climate change science resources using interactive visualizations for a wide range of permutations parameterized using GCMs, greenhouse-gas emission scenarios, temporal dimensions, time frames, and climate change measurement indicators. We then used the integrated data to create a new, non-standard, advanced geospatial analysis. These techniques aid our roles in providing support and guidance to our users, who in turn use this to assess, manage, and monitor forest resources. Small numbers of users are responsible for a large amount of land, meaning large land management impact.

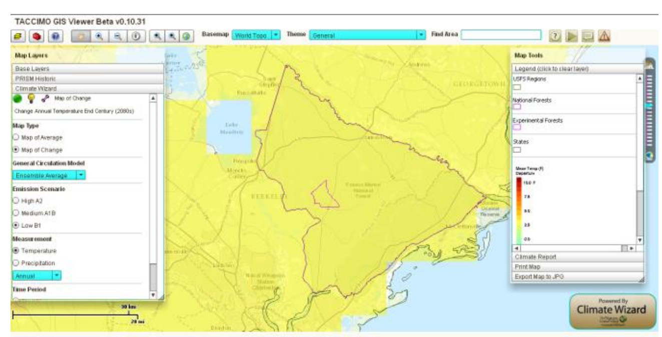

Figure 6. Francis Marion projected change in average annual temperature using GCM average ensemble and low B1 emissions in Climate Wizard

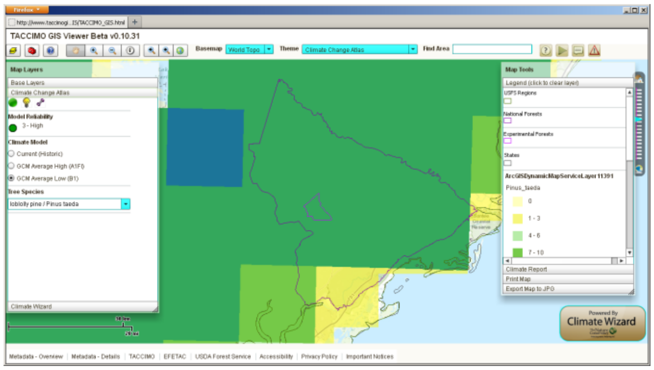

Figure 7. Francis Marion projected change in relative importance of loblolly pine using GCM average for B1 emissions in Tree Atlas

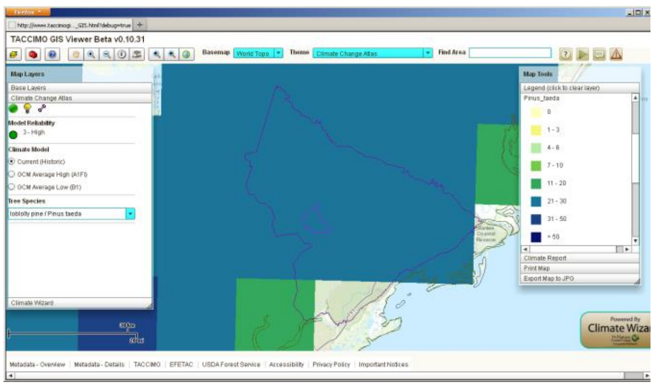

Figure 8. Francis Marion current historic relative importance of loblolly pine in Tree Atlas

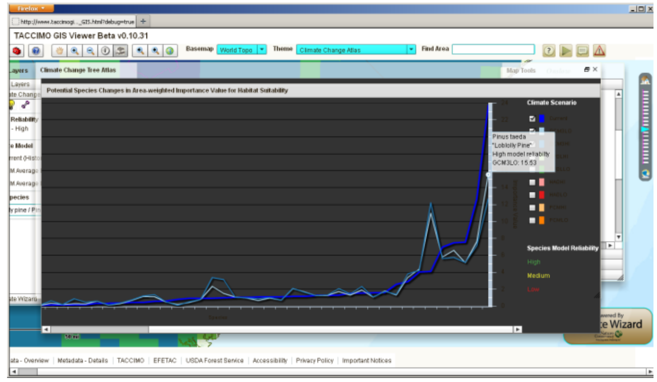

Figure 9. Francis Marion advanced geospatial analysis chart highlighting relative importance of loblolly pine in GCM average for B1 emissions

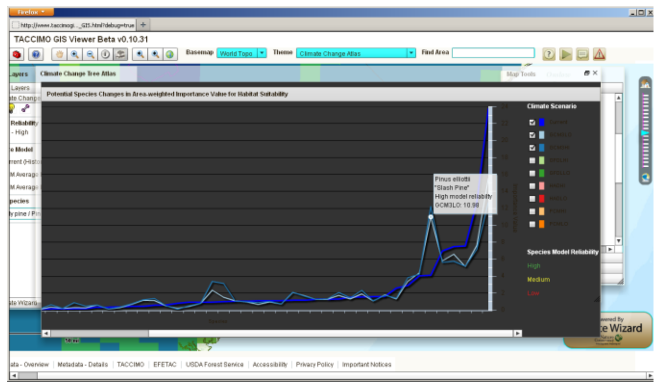

Figure 10. Francis Marion advanced geospatial analysis chart highlighting relative importance of slash pine in GCM average for B1 emissions

Future work can be explored on several fronts. From the external data integration front, additional content sources, such as the Climate Change Bird Atlas, are under consideration. Another area is exploring updates to the climate report generation process. For geospatial tool analysis, the area of interest selection process could be fine-tuned. Domain experts have suggested several ideas, such as adding or removing individual cells, automatically pruning cells based on ecoregion boundaries, and selecting species of interest for summarization charts.

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