Integrated Ecosystem Model for Alaska

A collaborative project for the Arctic Landscape Conservation Cooperative

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Summary

This pilot project has initiated a long-term integrated modeling project that aims to develop a dynamically linked model framework focused on climate driven changes to vegetation, disturbance, hydrology, and permafrost, and their interactions and feedbacks. This pilot phase has developed a conceptual framework for linking current state-of-the-science models of ecosystem processes in Alaska – ALFRESCO, TEM, GIPL-1 – and the primary processes of vegetation, disturbance, hydrology, and permafrost that they simulate. A framework that dynamically links these models has been defined and primary input datasets required by the models have been developed. Finally, a proof-of-concept asynchronous coupling exercise has been completed and the results of that exercise are summarized below (and reported in depth within this report).

There is evidence that ongoing climate change is affecting fire frequency, extent, and severity in the interior boreal region of Alaska, and these changes are likely to continue into the future. In this study we coupled a landscape fire dynamics model with an ecosystem model in an application to evaluate the long term effects of changes in climate and fire regime on soil organic horizons and permafrost dynamics in interior Alaska. Changes in fire regime were simulated by the Alaska Frame-based Ecosystem Code (ALFRESCO) model driven by downscaled global climate model) outputs from CCCMA-CGCM3.1 and MPI ECHAM5 models under the A1B emissions scenario at 1km x 1 km resolution for the Yukon River Basin in Alaska. The fire regime outputs of ALFRESCO were used to drive the dynamic organic soil version of the Terrestrial Ecosystem Model (DOS-TEM) and then the moss and organic layer thickness outputs from DOS-TEM were used to drive the Geophysical Institute Permafrost Lab Model (GIPL-1).

Fire as simulated by ALFRESCO was enhanced through the middle of the 21st Century, after which fire activity reverted to pre-1990 levels because of a shift in forest composition to more low flammability deciduous forest. Simulations by the Dynamic Organic Soil version of the Terrestrial Ecosystem Model (DOS-TEM) driven by ALFRESCO fire indicate that carbon in vegetation and in soil organic horizons will decrease in response to more frequent fire in the first half of the 21st Century, but will generally accumulate after fire became less frequent in the middle of the 21st Century, with accumulation being slower for the warmer ECHAM5 climate. In contrast, carbon in the mineral horizon accumulated throughout the 21st Century. Soil temperature simulated by DOS-TEM continues to warm throughout the 21st Century for both climate projections, with the rate of warming greater for the warmer ECHAM5 climate. Similarly, DOS-TEM predicts that the area occupied by permafrost will decrease from occupying 68% of the basin in 2006 to occupying 20% and 30% of the basin by 2100 for the warmer ECHAM5 and less warm CCCMA climates, respectively.

Simulations by the GIPL-1 model driven by ALFRESCO coupled with DOS-TEM organic layers indicate fire produces significant changes in ground temperatures and permafrost throughout the 21st Century for both climate projections. These results suggest that there are important linkages between the fire regime, forest composition, and the

structure of soil organic horizons that influence the vulnerability of permafrost degradation in interior Alaska.

Background

The physical and biotic components of arctic and boreal ecosystems - permafrost, hydrology, disturbance (e.g., fire), and vegetation - are tightly linked and sensitive to climate change. Since the release of downscaled climate models for Alaska following the IPCC AR4 in 2007, researchers at the University of Alaska Fairbanks (UAF) have developed three ecosystem models that link changing climate scenarios to different ecological processes. These processes include the response of permafrost, hydrology, vegetation and fire to changing climate. The individual models provide important information on how the Alaskan landscape may respond to climate change. An integrated model, however, will provide resource managers the ability to better visualize potential future landscapes resulting from the interaction of ecosystem components and physical processes.

More specifically, the integrated framework will couple (1) a model of disturbance dynamics and species establishment (the Alaska Frame-Based Ecosystem Code, ALFRESCO), (2) a model of soil dynamics, hydrology, vegetation succession, and ecosystem biogeochemistry (the dynamic organic soil/dynamic vegetation model version of the Terrestrial Ecosystem Model, TEM), and (3) a model of permafrost dynamics (the Geophysical Institute Permafrost Lab model, GIPL-1). Together, these three models comprise the AIEM (Alaska Integrated Ecosystem Model). The AIEM will provide a framework for forecasting ecosystem change and will aid with vulnerability assessments, and guide inventory and monitoring activities.

Project Objectives

The need for ecosystem model integration in Alaska was initially identified in the interagency and partnership WildREACH workshop. In this, the first phase of the AIEM project, our aim was to develop a conceptual model for an integrated modeling platform and conduct an initial static coupling exercise.

The main objectives of Phase I include:

(1) Through collaboration between the leads of the three primary models (ALFRESCO, TEM and GIPL-1) develop a conceptual modeling framework for integrating important components of vegetation succession, disturbance regimes, permafrost dynamics and hydrology.

(2) Produce data streams and spatial layers important to future modeling and integral in the implementation of a coupled ecosystem model framework for Alaska.

(3) Conduct initial static coupling exercises between some model components as a proof-of-concept for this approach.

For Objective 1, we developed an overall conceptual modeling framework to simulate potential response of ecosystems to climate change in Alaska and to provide a decision support tool for improved understanding of simulated change (Fig. 1). Our long-term objective is for the AIEM to interact with secondary impact models to inform conservation and resource management decisions. For example, the data outputs from the AIEM could be used to drive an impact model simulating habitat change for caribou populations in Alaska. The AIEM model outputs that could drive such an impact model would be variables such as canopy cover, probability of thermokarst or fire, and species composition.

In addition for Objective 1, we developed a framework to allow implementation of a fully coupled AIEM that dynamically links ALFRESCO, TEM and GIPL-1 (Fig. 2). Here, model integration is synchronous and for each time step data outputs are exchanged among models. The main forcing variables in common between each model are climate variables (air temperature and precipitation) and initial vegetation. ALFRESCO then provides vegetation, burned area and fire severity outputs to TEM, while TEM in turn provides vegetation carbon outputs to ALFRESCO. Synchronously, TEM provides soil moisture, soil structure and vegetation canopy properties to GIPL-1. In turn, GIPL-1 provides the soil thermal vertical profile to TEM.

For Objective 2, we shared a list of spatial data layers integral to our modeling effort and worked with the Arctic LCC staff to determine which data sets would most be of interest to the broader research and management community. The chosen spatial data layers produced and shared include: (1) projected mean annual ground temperature, (2) projected active layer thickness, (3) historical and projected stand age/area burned, (4) historical and projected mean annual precipitation and temperature, and (5) historical and projected potential evapotranspiration (Tables 2 & 3). These data are now all publically available via the Arctic LCC data portal (http://arcticlcc.org/products/spatial-data/).

For Objective 3, we conducted an initial static coupling exercise using the Yukon River Basin within Alaska (Fig. 3) as the model domain. This region was chosen to take advantage of existing input datasets and common modeling domains. The next sections of the report contain a description of this modeling exercise.

Introduction

Ongoing and projected climate warming in high latitude regions has the potential to alter the structures and function of terrestrial ecosystems in the region. Such changes in ecosystem structure and function will influence the services provided by ecosystems to society. In interior Alaska, climate warming has the potential to influence interactions among fire regime, the composition of forests, the structure of soil organic matter, and the integrity of permafrost across the landscape. The fire regime in interior Alaska depends on interactions among climate, fire ignitions, and ecosystem flammability. However, more frequent fires tend to increase the fraction of less flammable deciduous forest at the expense of more flammable coniferous forest (Johnstone et al., 2011). This type of shift in the composition of boreal forest may already be taking place (Barrett et al., 2011; Beck et al., 2011). Such a change in forest composition has the potential to slow increases in fire activity associated with climate warming. Increases in fire activity also have the potential to reduce the thickness of the insulating soil organic horizons to allow more efficient conduction of heat into permafrost during the summer (Yoshikawa et al., 2003; Yuan et al., in review), which in a warming climate can make permafrost more vulnerable to degradation. Thus, because of feedbacks between fire regime and vegetation composition, it is not clear the degree to which soil organic horizons and permafrost integrity in interior Alaska are vulnerable to climate warming.

In this study, we evaluate whether ecological feedbacks to fire regime play a role in the degree to which soil organic horizons and permafrost integrity in interior Alaska are vulnerable to climate warming. To evaluate this issue, we couple a landscape-level model that represents interactions between fire regime and forest composition to a biogeochemical model that represents interactions between the dynamics of organic soil horizons and soil thermal regime. We also couple the organic layer outputs of the biogeochemical model to a permafrost dynamics model to understand the relative roles that changes in climate and fire regime play in permafrost degradation. This model framework was applied for the Alaska portion of the Yukon River Basin (AKYRB) for climate scenarios through the 21st Century.

Materials & Methods

Overview of modeling approach

In this study we coupled the outputs of the Alaska Frame-Based Ecosystem Code (ALFRESCO; Rupp et al., 2002; Rupp et al., 2007; Johnstone et al., 2011) to the Dynamic Organic Soil version of the Terrestrial Ecosystem Model (DOS-TEM; DOS-TEM; Yi et al., 2009a, 2009b, 2010, Yuan et al., in review) and then to the permafrost dynamics model GIPL-1 (Sazonova and Romanovsky, 2003; Sazonova et al., 2004) to evaluate the degree to which feedbacks between forest composition and fire regime influence soil organic horizons and permafrost integrity in a warming climate in interior Alaska. The coupled model framework was driven by downscaled global climate model (GCM) output at 1 km x 1 km for the AKYRB from 2007-2099.

ALFRESCO is a landscape simulation model that simulates interactions and feedbacks among fire, climate and vegetation in Alaska. DOS-TEM has been designed to explicitly represent the effects of fire on interactions among soil thermal and hydrologic dynamics, the structure of organic soil horizons, and ecosystem biogeochemistry. DOS-TEM, which represents multiple soil C pools of different quality within different layers of the organic and mineral soil horizons, was parameterized, calibrated and validated for black spruce forest, white spruce forest, deciduous forest, and tundra in interior Alaska (Yuan et al., in review). GIPL-1 is a spatially distributed physically based transient model that calculates active layer thickness dynamics and mean annual soil temperatures. Input parameters to the model are spatial datasets of mean monthly air temperature and precipitation, prescribed vegetation, soil thermal properties and water content, which are specific for each vegetation and soil type and geographical location.

In this study ALFRESCO, DOS-TEM, and GIPL-1 models were driven by downscaled GCM outputs under the A1B emissions scenario. The outputs of fire occurrence and severity simulated by ALFRESCO were also used to drive DOS-TEM. Output from DOS-TEM model was used to prescribe the surface vegetation and organic layer thicknesses and properties used in GIPL-1. From these simulations we analyzed changes in organic soil horizon thickness and C stocks, soil thermal dynamics, and permafrost area and active layer depth (ALD) in relation to the warming and fire regime changes from 2007 - 2099. To evaluate the degree to which responses to projected climate alter these dynamics, we also include the simulation results of DOS-TEM driven by historical climate changes and fire occurrence in the AKYRB from 1950-2006. To evaluate the impact of fire on permafrost conditions, we performed a control run of calculations with GIPL-1 model for 2000-2099 time period where the surface vegetation and the organic layer depth and properties were kept the same as for 1980.

Coupled framework of ALFRESCO/DOS-TEM/GIPL-1 and implementation

Two GCMs operating under the moderate A1B emissions scenario were chosen to represent the range of warming and precipitation expected to occur across Alaska. The Canadian Centre for Climate Modeling and Analysis General Circulation Model 3.1 (t47) (CCCMA) and the Max Planck Institute for Meteorology European Centre Hamburg Model 5 (ECHAM5) were chosen among a suite of 15 IPCC AR4 GCMs ranked among the top five for performance across Alaska and the Arctic (Walsh et al. 2008). Model performance was determined by comparing surface temperature, precipitation, and sea level pressure between observation-based ECMWF 40 year re-analysis data and GCM output variables. GCM output was bias corrected and downscaled via the delta method using PRISM 1961-1990 as baseline climate. In addition, the CCMA and ECHAM5 climate models bound the uncertainty associated with ALFRESCO simulations for future fire regime. ECHAM5 climate produces the greatest burned area, while CCCMA climate produces the most moderate burned area.

We first drove ALFRESCO from 2007 – 2099 in the AKYRB using these downscaled GCM outputs. Because ALFRESCO is a stochastic model, an ensemble of model simulations were performed and the median realization of that ensemble in terms of cumulative area burned was selected to drive fire effects module of DOS-TEM with the fire occurrence and severity outputs from ALFRESCO (Fig. 4). Because ALFRESCO doesn’t predict when fire occurs during the summer, we randomly generated fire seasons for each occurrence based on historical fire statistics (1950 - 2006) in the interior Alaska in which 11%, 57%, 29% and 3% of fires occurred in May, June, July and August, respectively. ALFRESCO predicts low, moderate, and high severity classes for upland ecosystems, which we linked to the dry-low, dry-moderate, and dry-high fire combustion parameterizations of DOS-TEM (see Yi et al. 2010). ALFRESCO predicts only one severity class for wet lowlands, which we linked to the wet combustion parameterization for DOS-TEM.

Study region – Alaska Yukon River Basin

The AKYRB is approximately 526,500 km^2, of which approximately 463,000 km^2 is vegetated (or 12% non-vegetated) (Fig. 3). Boreal forests occupy nearly 68% of the AKYRB (black spruce forest 32%, white spruce forest 21% and deciduous forest 15%), while upland tundra and lowland wetlands occupy the remaining 20% of the region. Atmospheric CO_2 concentration is projected to increase to over 700 ppm in association with the A1B emissions scenario (Fig. 5). The region has experienced substantial warming between1970 and 2006 of approximately +0.5^oC per decade, and warming by 2100 is projected to increase by between 6^o and 8.5^o C for CCCMA and ECHAM5, respectively, under the A1B emissions scenario (Fig. 6). The degree of warming estimated by CCCMA and ECHAM5 are comparable during the first half of the 21st century, but after 2050 ECHAM5 predicts greater warming.

Results & Discussion

Dynamics of fire driven by climate

Figures 7 and 8 summarize and compare historical fire occurrences (1950 – 2006) and future fire regimes (2007 – 2099), simulated by the ALFRESCO model driven by downscaled GCM climate outputs from CCCMA and ECHAM5 models under the A1B scenario at 1 x 1 km resolution for AKYRB. ALFRESCO predicts that fire activity, which has already increased since the 1990s in the region, would continue through the middle of the 21st Century, when fire activity will revert to pre-1990 levels (Fig. 7). This pattern is consistent with the influence of near-term increased fire activity that results in an increased proportion of the landscape occupied by less flammable deciduous forest and decreased proportion of more flammable conifer forest. The distribution of simulated annual area burned for 2007 – 2099 (Fig. 8) suggests fewer small fire years (<0.5% area burned) and more intermediate fire years (0.5 – 1.0% area burned) overall in comparison to historical wildfire trends (1950 -2006). Overall differences between simulated and historical large fire years (>1.0%) are minimal.

Dynamics of organic soil horizons driven by climate and fire

The DOS-TEM simulations indicate that the fibrous organic horizon of the AKYRB increased steadily from 1950 to around 2000, after which it decreased drastically in response to the very large fire years in the 2000s (Fig. 9a). This decrease continued into the projected period until around 2020 in the CCCMA simulation and until around 2050 in the ECHAM5 simulation in association with projected fire activity. The fibrous organic layer continued to increase through the remainder of the 21stCentury as the fire regime returned to pre-1990 levels of annual area burned. By 2100, the fibrous organic layer had increased by 3.5 cm in the CCCMA simulation and by 1 cm in the ECHAM5 simulation in comparison to the 1950 thickness. The DOS-TEM simulations indicated that the thickness of the deeper amorphous organic horizon within 0.5 cm of about 10 cm total thickness between 1950 and 2100 (Fig. 9b). In general, the thickness of the amorphous horizon increases abruptly in large fire years as the remaining fibrous organic matter and dead roots are converted to amorphous organic matter. However, the thickness of this horizon decreases after large fire years, as decomposition is greater than inputs into the horizon. If no large fires occur, the amorphous horizon can continue to decrease for approximately 40 or 50 years.

Dynamics of ecosystem C pools driven by climate and fires

In response to fire, vegetation biomass C pools simulated by DOS-TEM declined dramatically in the 2000s and continued to decrease until around 2015 in the CCCMA simulation and until around 2025 in the ECHAM5 simulation (Fig. 10a). After this period of decline, vegetation C pools continued to increase throughout the remainder of the 21st Century. Fire activity in the first half of the 21st Century keeps total soil C pools in both the CCCMA and ECHAM5 somewhat stable throughout the first half of the 21 Century (Fig. 10b) as losses in the organic horizons (Fig. 10c) are compensated for by gains in mineral soil horizon (Fig. 10d). However, after around 2050, the CCCMA simulation gains soil C (Fig. 10b) as both the organic and mineral soil horizons increase (Fig. 10c and 10d). In contrast, the increase in soil C in the ECHAM5 simulation lags that of the CCCMA simulation (Fig. 10b) as the amorphous horizon gains little carbon (Fig. 10c).

Changes in simulated soil thermal dynamics

Soil temperature of the fibrous organic layer increases from approximately -1^{o} C in 1950 to approximately 2^{o} C and 3.5^{o} C in 2100 in the CCCMA and ECHAM5 DOS-TEM simulations, respectively (Fig. 11a). Similarly, soil temperature of the amorphous (Fig 11b), upper mineral (Fig. 11c), and lower mineral (Fig. 11d) horizons increases from approximately -2^{o} C in 1950 to approximately 1^{o} C and 2.5^{o} C in 2100 in the CCCMA and ECHAM5 DOS-TEM simulations, respectively. The stronger soil warming trend by ECHAM5 climate projection is not only related to warmer air, but also may be related to shallower organic layers which allow easier heat penetration into soil.

Permafrost loss and active layer dynamics

In this study we define shallow permafrost in the DOS-TEM simulations as those areas with perennially frozen soil within the top 5.4 m of the surface, which is the maximum depth of the mineral soil layer simulated by the model. The DOS-TEM simulations indicate that the fraction area of the AKYRB occupied by shallow permafrost decreases from the current estimate of 68% to about 30% for the CCCMA climate and to 20% for the warmer ECHAM5 climate by 2100 (Fig. 12). The DOS-TEM simulations indicate that permafrost largely currently exists in the eastern two-thirds of AKYRB (dark blue areas in Fig. 13). Under future climate warming and predicted fire regime changes, areas underlain by no permafrost or deep permafrost would likely expand eastward and northward rather rapidly by 2050. The pattern of changes before 2050 are not very different between the two climate projections, but the decrease in shallow permafrost after 2050 is more dramatic for the warmer ECHAM5 projection.

Similar permafrost loss was observed for the GIPL-1 model (Fig. 14). Model results show most areas with mean annual ground temperatures (MAGT) below 0°C at 1 m depth are concentrated in the central and eastern part of the basin. Present-day permafrost temperatures vary from near 0°C in the central and western part of the region to -5°C and colder in the foothills and mountains in the northern and southern parts of the region (Fig. 14, top right). By the end of the century, mean annual temperatures at 1 m depth will remain below 0°C only in the mountainous regions (Fig. 14, bottom right). Slight differences between permafrost distributions shown on Figures 13 and 14 are the result of differences in the reference depths (5.4 m in Fig. 13 and 1 m in Fig. 14). The DOS-TEM model assumes the absence of permafrost when permafrost is not found in the upper 5.4 m (Fig. 13). GIPL-1, however, produces only mean annual temperature at the depth of seasonally thawed or seasonally frozen layers (Fig. 14). When this temperature switches from below 0°C to above 0°C permafrost at deeper depths is likely to degrade. However, because of the high inertia of this degradation process, it may take many years and perhaps even many decades until the permafrost upper boundary will be lowered below 5.4 m.

By including the effect of wildfire by the coupling of ALFRESCO and DOS-TEM for vegetation and organic layer characteristics, the GIPL-1 model produces significant changes in ground temperatures and permafrost distribution for the time periods 2000-2009 and 2040-2049 (Fig. 14, compare left and right plots in the top and middle). As expected, ground temperatures are warmer and permafrost extent is smaller when the effect of fires is considered. At the same time, differences between these two runs are less so for the 2090-2099 time period (Fig. 14, bottom left and bottom right).

Comparison between the areas with mean annual ground temperature (MAGT) below and above zero degree C at 1 m depth in the control (Ctrl) run and in the model coupling run where affects of fire on surface vegetation and organic layer were taken into account (Fire) shows a significant reduction of permafrost distribution. The percentage of permafrost compared to the total area of the AKYRB region decreased significantly with model coupling (Table 1). During the current century, there is also a gradual increase in MAGT over the AKYRB and in areas occupied by soils with MAGT above 0° C at 1 m depth for both model runs.

Table 1. Comparison of areas occupied by mean annual ground temperature (MAGT) below and above zero degree C at 1 m depth and mean annual ground temperature at the same depth over the AKYRB region using the CCCMA climate forcing.

GIPL Model Run	Year	Area, sq. km			% from the Total AKYRB Area		Soil Temperature Over AKYRB, deg C			
		AKYRB Total	MAGT <=0	MAGT > 0	MAGT <=0	MAGT > 0	MAGT	MIN	MAX	STDEV
Ctrl	2000-2009	526,484	385,509	140,975	73	27	-1.4	-14.2	2.3	1.8
Fire			328,789	197,695	62	38	-1.0	-14.2	5.4	2.0
Ctrl	2040-2049		218,270	308,214	41	59	-0.2	-13.4	3.6	2.0
Fire			187,523	338,961	36	64	0.2	-13.4	6.5	2.0
Ctrl	2090-2099		82,275	444,209	16	84	1.5	-12.2	5.7	1.9
Fire			76,728	449,756	15	85	2.0	-12.2	8.6	2.1

Comparison between the active layer thicknesses in the control run (Fig. 15, left) and in the run where fire induced changes in surface vegetation and organic layer properties were taken into account (Fig. 15, right) shows significant increase of both the active layer and the seasonally-frozen layer thicknesses with model coupling The increase in the seasonally-frozen layer thickness as a result of fire may also lead to colder winter temperatures in the upper meter of soil and to a slower rate of the organic matter decomposition in the mineral soil.

Future Work Needed

In the next phase of the AIEM project, which is already underway, our objectives are to (1) synchronously couple the models, (2) develop data sets for Alaska and adjacent areas of Canada, also known as the Western Arctic, and (3) phase in additional capabilities that are necessary to address effects of climate change on landscape structure and function.

The synchronous coupling of the models is both a technical activity that is necessary so that the models can exchange data while they are running in parallel for the same climate scenario, and a scientific activity to evaluate whether the temporal and spatial dynamics of the model are operating properly. Consideration of the entire Western Arctic (which is essentially Alaska, the Yukon Territory, and parts of British Columbia adjacent to Alaska) allows us to deal with landscape issues that do not necessarily stop at the Alaska-Canada border and will give the AIEM the capability to support assessments of trans-boundary resource responses to climate change.

With respect to current capabilities, the models have substantial expertise in addressing fire disturbance dynamics, vegetation dynamics, and permafrost dynamics in interior Alaska, particularly with respect to upland ecosystems. We have identified three priority issues that need to be incorporated into the AIEM so that it can more fully address issues throughout northern, western, and interior Alaska: (1) tundra fire and treeline/tundra succession dynamics, (2) landscape-level thermokarst dynamics, and (3) wetland dynamics. The incorporation of tundra fire and treeline/tundra succession dynamics will allow us to better forecast changes in landscape structure and function in northern and northwest Alaska. Landscape-level thermokarst changes are important to incorporate into the AIEM because subsidence associated with the melting of previously frozen water in ice-rich permafrost can result in substantial changes in vegetation and habitat (e.g., turning an upland tundra ecosystem into a wetland tundra ecosystem). Wetland dynamics are important to represent because much of Alaska is covered by wetland complexes, and changes in wetland structure and function has the potential to affect numerous animal species that use wetlands (e.g., waterfowl).

Deliverables Cross-walk

The status of original deliverables and additional deliverables achieved in this study are listed in Table 2. In addition, Table 3 provides further information on spatial data products delivered to the Arctic LCC.

Table 2. Deliverables cross-walk.

Deliverable	Description	Delivery Date	Status/Additional Deliverable
Cooperators Meeting	Initiation meeting with Arctic LCC staff and model leads for ALFRESCO, TEM and GIPL-1	Spring 2010	Delivered, University of Alaska Fairbanks
Cooperators Meeting	Monthly meeting of research collaborators and Arctic LCC staff	Spring 2010- Fall 2012	Delivered, University of Alaska Fairbanks
Oral presentation	Present 6-month project progress webinar to Arctic LCC and their stakeholders	Fall 2010	Delivered
Conference proceeding, poster presentation		Winter 2011	Yuan, FM, SH Yi, AD McGuire, KD Johnson, J Liang, J Harden & ES Kasischke. 2011. Dynamical basin-scale responses of taiga forest and soil C stocks to climate changes and wild fire history in the Yukon River Basin during the last century. 3rd North American Carbon All-Investigators Meeting. New Orleans, LA.
Data delivery	Provide draft spatial data products relevant to the major model components to the Arctic LCC for field expert review	Winter 2011	Delivered
Data delivery	Provide final spatial data products relevant to the major model components to the Arctic LCC for public distribution	Spring 2011	Delivered
Oral Presentation		Fall 2011	Breen, AB, TS Rupp, AD McGuire, V Romanovsky, E Euskirchen *et al.* 2011. Development and application of an Integrated Ecosystem Model for Alaska. USGS Climate& Land Use Change Brown Bag Seminar via webinar. Reston, VA.

Table 2. (continued).

Deliverable	Description	Delivery Date	Status/Additional Deliverable
Conference proceeding, poster presentation		Fall 2011	Yuan, FM, AD McGuire, SH Yi, ES Euskirchen, TS Rupp *et al*. 2011. Effects of future warming and fire regime change on boreal soil organic horizons and permafrost dynamics in Interior Alaska. Proceedings of the American Geophysical Union annual meeting, San Francisco, CA.
Conference proceeding, poster presentation		Fall 2011	Euskirchen, ES, C Edgar, MR Turetsky, JW Harden & AD McGuire. 2011. Quantifying CO2 fluxes across a gradient of permafrost in boreal Alaska. Proceedings of the American Geophysical Union annual meeting, San Francisco, CA.
Final Report	Provide a final report with a written description of the conceptual model and demonstration of initial static coupling exercise	Fall 2011	Delivered herein
Journal Article		Fall 2011	Yuan, FM, AD McGuire, SH Yi, ES Euskirchen, TS Rupp, *et al*. Effects of future warming and fire regime change on boreal soil organic horizons and permafrost dynamics in Interior Alaska. *Global Change Biology* In prep.
Journal Article		Fall 2011	McAfee, SM, B O'Brien, AL Springsteen, W. Loya, *et al*. A high-resolution potential evapotranspiration dataset for Alaska. *Arctic* In prep.
Journal Article		Fall 2011	Jaforov, EE, SS Marchenko & VE Romanovsky. Numerical modeling of Permafrost Dynamics in Alaska using a high spatial resolution dataset. *The Cryosphere* In review.
Oral Presentation	Present a summary of research findings webinar to Arctic LCC and their stakeholders	Winter 2012	Will deliver January 25, 2012.

Table 3. Spatial data products delivered to the Arctic LCC.

Model Output	Spatial Data Product	GCM and Emissions Scenario	Time Step
GIPL-1	Projected mean annual ground temps (°C)	5 Model Average* A1B emissions scenario	decadal
GIPL-1	Projected active layer thickness (m)	5 Model Average* A1B emissions scenario	decadal
Boreal ALFRESCO	Historical and projected stand age/area burned (age of vegetation in years since last fire)	ccma_cgcm31 mpi_echam5 A1B emissions scenario	annual
SNAP downscaled climate projections	Historical and projected mean annual precipitation (mm) and temperature (°C)	5 Model Average* A1B emissions scenario	decadal
PET	Historical and projected potential evapotranspiration (mm)	Climatic Research Unit historical data cccma_cgcm31 mpi_echam5 A1B emissions scenario	annual totals and decadal mean totals

*SNAP's 5 Model Average is calculated as a composite mean of the following 5 IPCC AR4 Global Climate Models that were shown to perform best across Alaska and the Arctic (Walsh et al 2008):
(1) ukmo_hadcm3 – UK Met Office – Hadley Centre, Coupled Model 3.0
(2) cccma_cgcm31 - Canadian Centre for Climate Modeling and Analysis, General Circulation Model version 3.1 - t47
(3) mpi_echam5 – Max Planck Institute for Meteorology, European Centre Hamburg Model 5
(4) gfdl_cm21 - Geophysical Fluid Dynamics Laboratory, Coupled Climate Model 2.1
(5) miroc3_2_medres - Center for Climate System Research, Model for Interdisciplinary Research on Climate medium resolution

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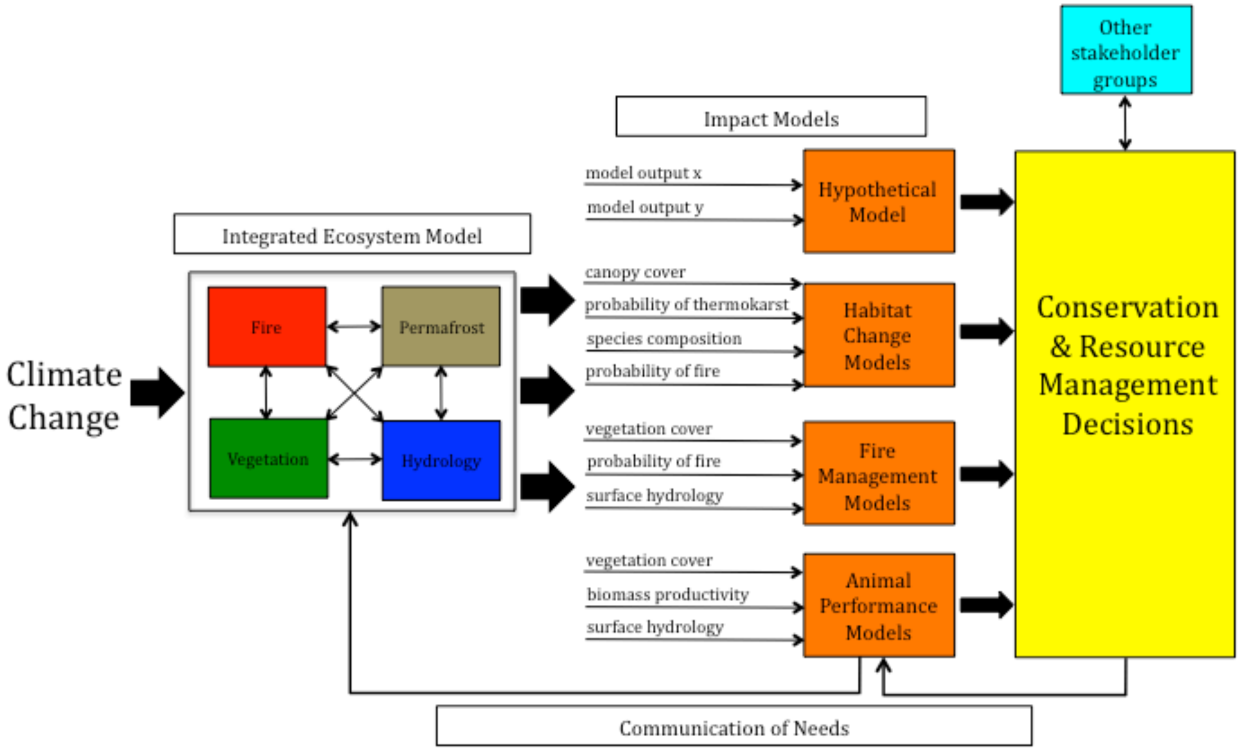

Figure 1. Conceptual diagram showing the Alaska IEM, its relationship to potential secondary impact models, and its applicability to inform conservation and resource management decisions.

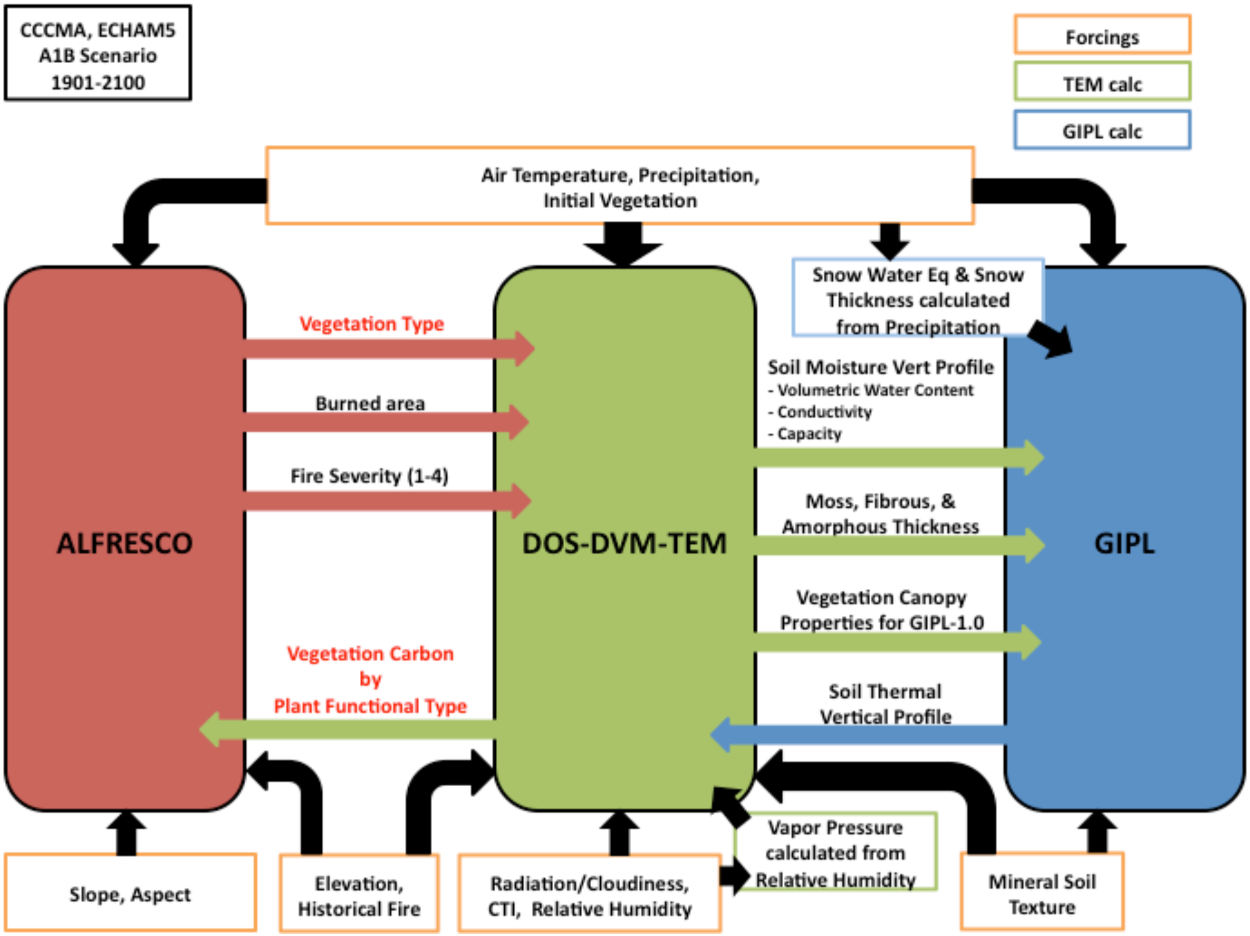

Figure 2. Modeling framework for proposed synchronous coupling among ALFRESCO, TEM and GIPL-1.

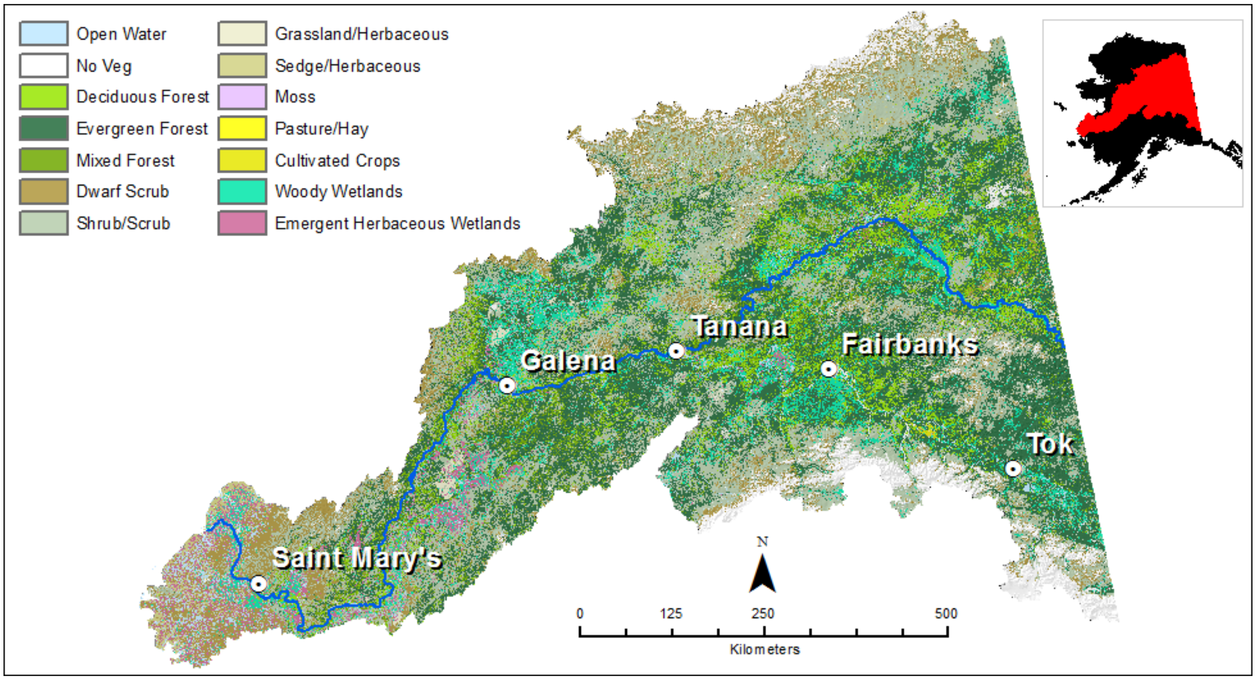

Figure 3. Major vegetation type distribution (source: NCLD data) in the AKYRB region. Note that the drainage type implied landscape classification is based on the USGS compound topographical index (TPI) with TPI>5 as upland and TPI<=5 as lowland.

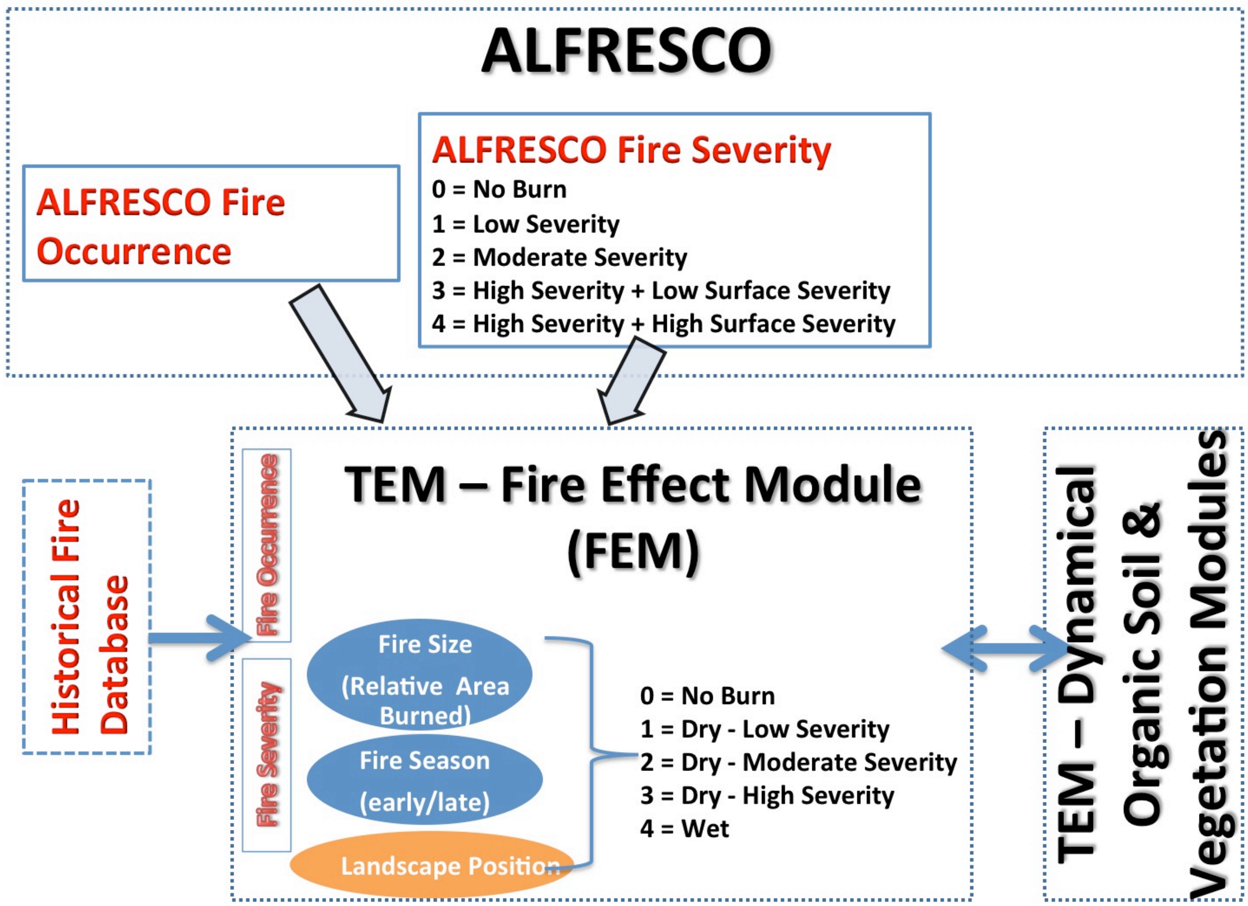

Figure 4. A schematic of the coupling of ALFRESCO fire occurrence and severity outputs with the fire emissions module of DOS-TEM in this study. The DOS-TEM can also be driven by fire occurrence from the historical database of fire occurrence.

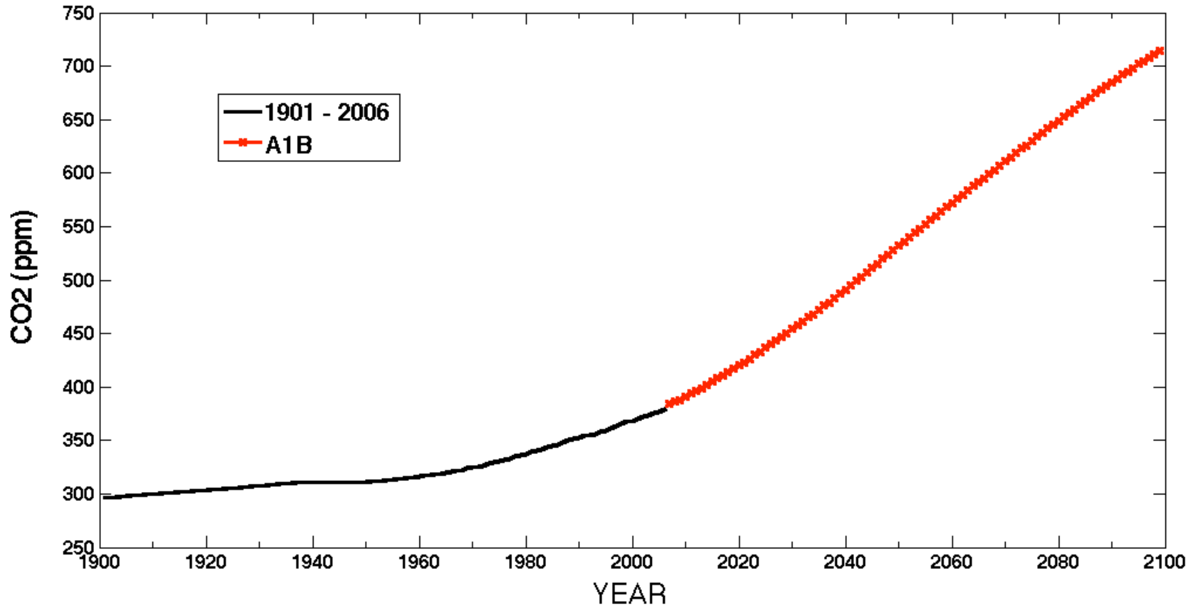

Figure 5. The historical atmospheric CO_2 concentration (1901 - 2006) and its projection (2007 – 2099) for the A1B emissions scenario used to drive DOS-TEM in this study.

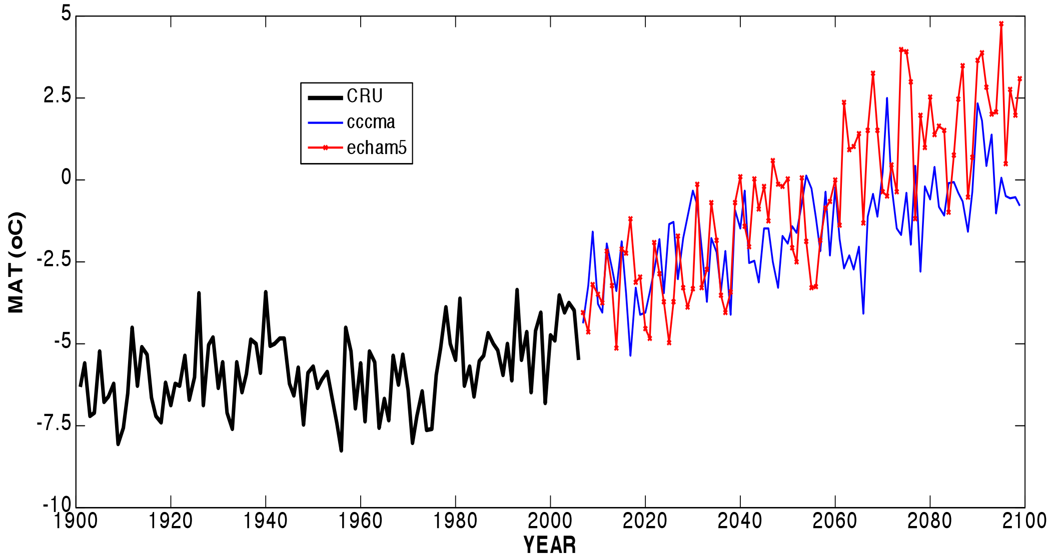

Figure 6. Mean annual temperature (MAT, °C) over the AKYRB region from 1900 – 2006 historical period and 2007 – 2099 projected period. Historical temperature is based on downscaled data from the Climate Research Unit (CRU), and the projections are based on the downscaled GCM data from simulations by the CCCMA-CGCM3.1 (CCCMA) and MPI ECHAM5 (ECHAM5) models for the A1B emissions scenario.

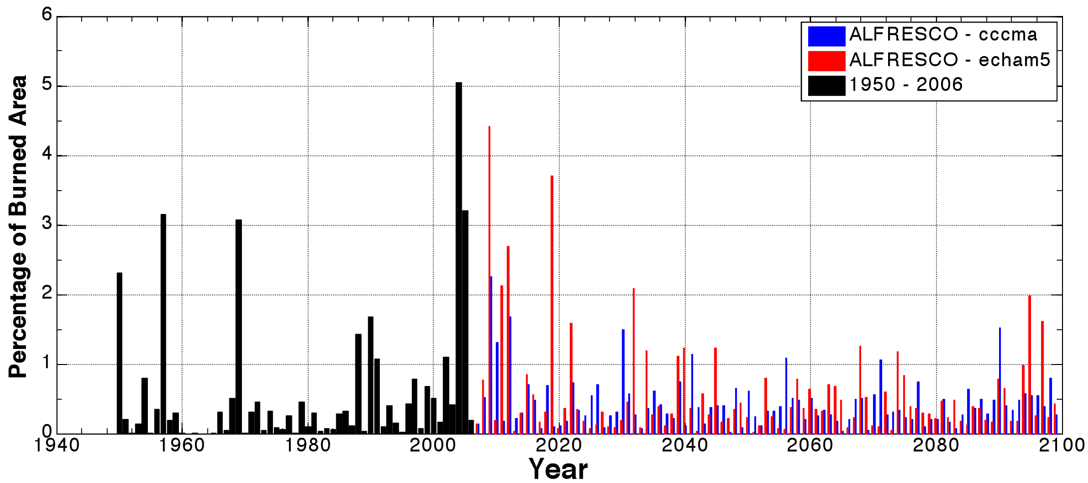

Figure 7. Historical (1950 – 2006) and ALFRESCO predicted (2007 – 2099) annual burned area percentage (%) over the AKYRB region. Note that there are two ALFRESCO fire projections driven by GCM outputs of CCCMA-CGCM3.1 (CCCMA) and MPI ECHAM5 models (ECHAM5) for the A1B emissions scenario.

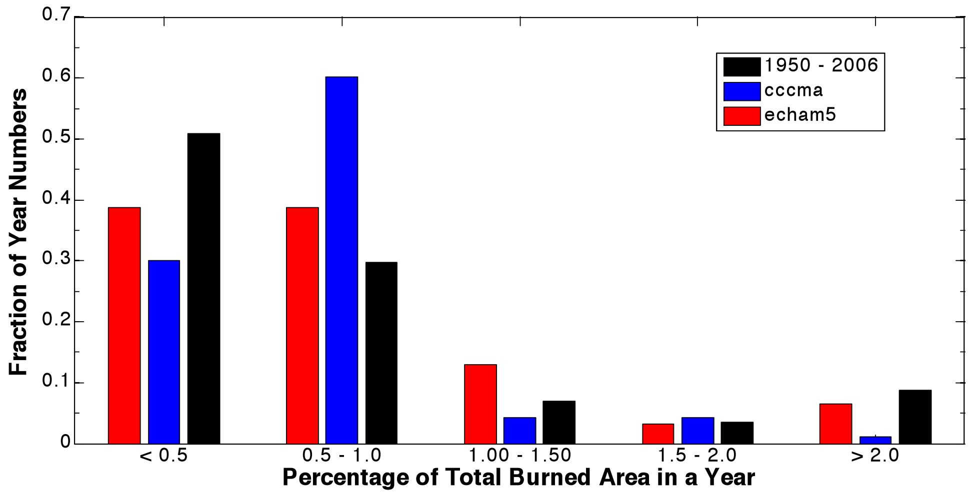

Figure 8. Comparison of the distribution of the relative frequency of annually burned area percentage in bins of <0.5%, 0.5-1.0%, 1.0–1.5%, 1.5-2.0%, and >2.0%, over AKYRB region from the historical database (1950-2006) and ALFRESCO simulations for the projected period (2007 – 2099). Note that there are two ALFRESCO fire projections driven by GCM outputs of CCCMA-CGCM3.1 (CCCMA) and MPI ECHAM5 models (ECHAM5) for the A1B emissions scenario.

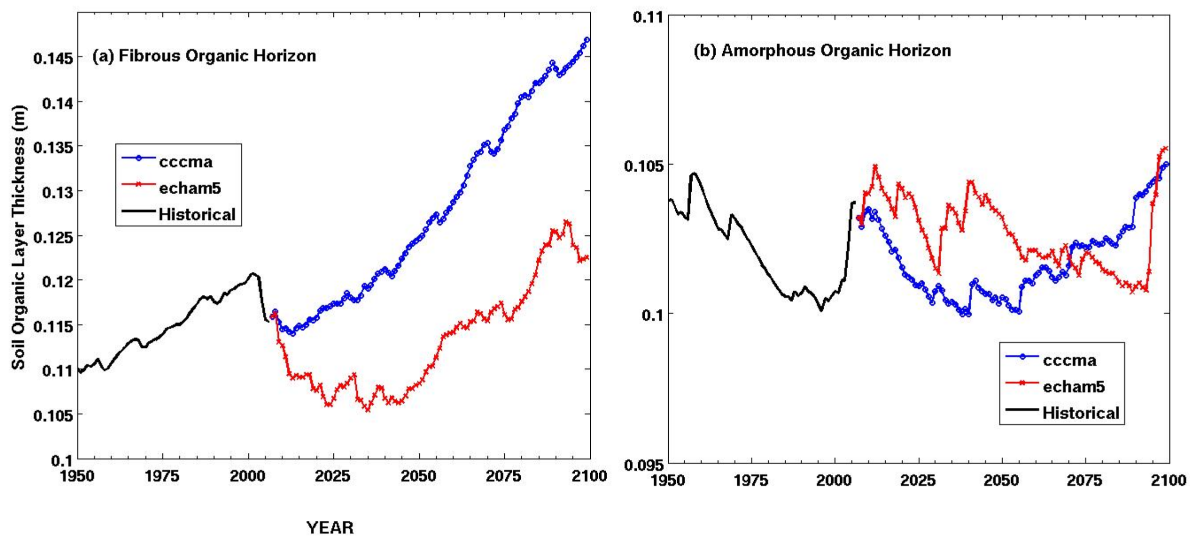

Figure 9. Simulation by DOS-TEM of the mean thickness of (a) fibrous and (b) amorphous organic soil horizons over the AKYRB region from 1950 – 2006 (driven by historical climate) and 2007 – 2099 (driven by CCCMA and ECHAM5 projected climate).

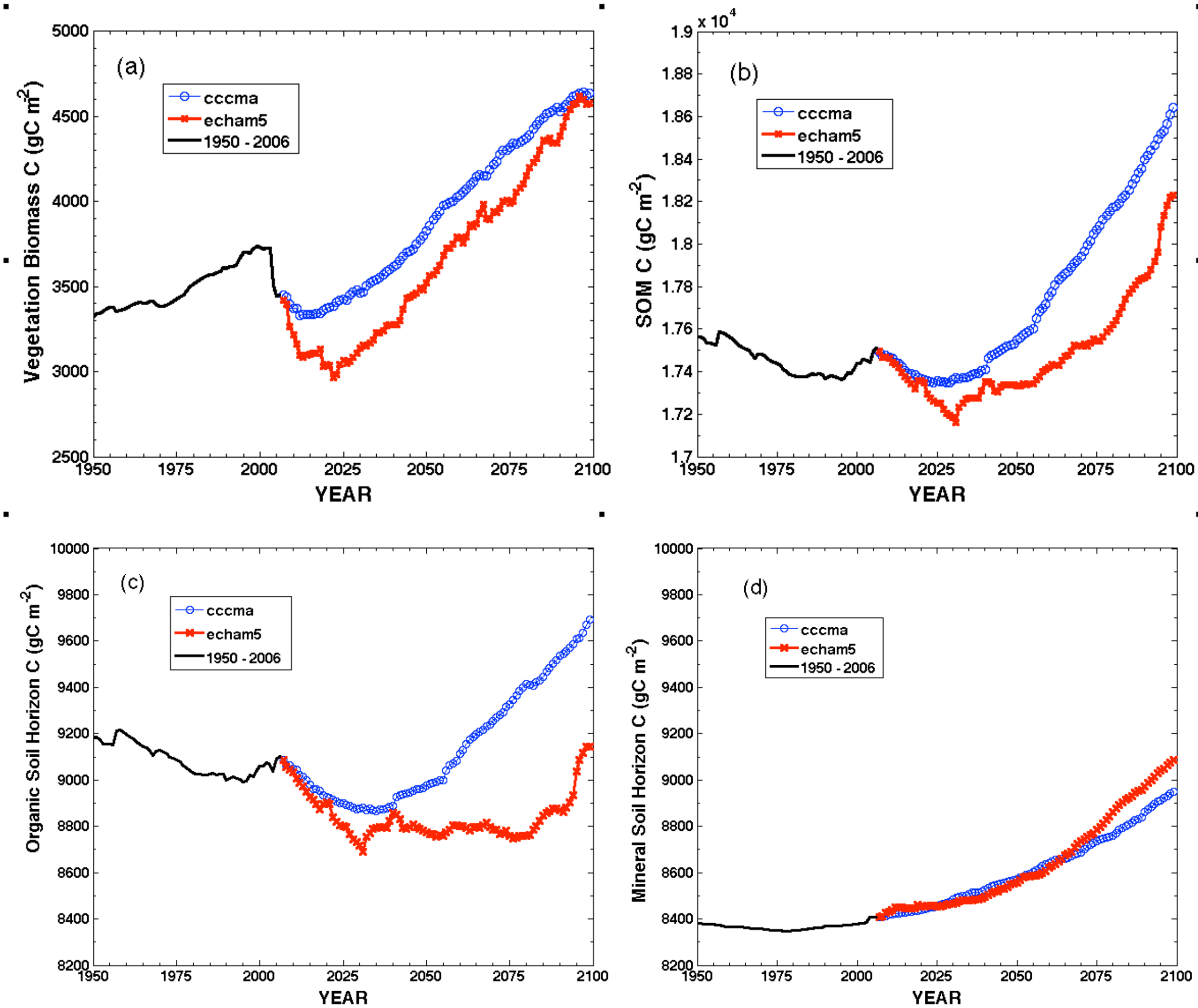

Figure 10. Changes simulated by DOS-TEM of the mean (a) vegetation biomass C, (b) total soil C, (c) soil C in organic horizons, and (d) soil C in the mineral horizon over the AKYRB for 1950 – 2006 (driven by historical climate) and 2007 – 2099 (driven by CCCMA and ECHAM5 climate).

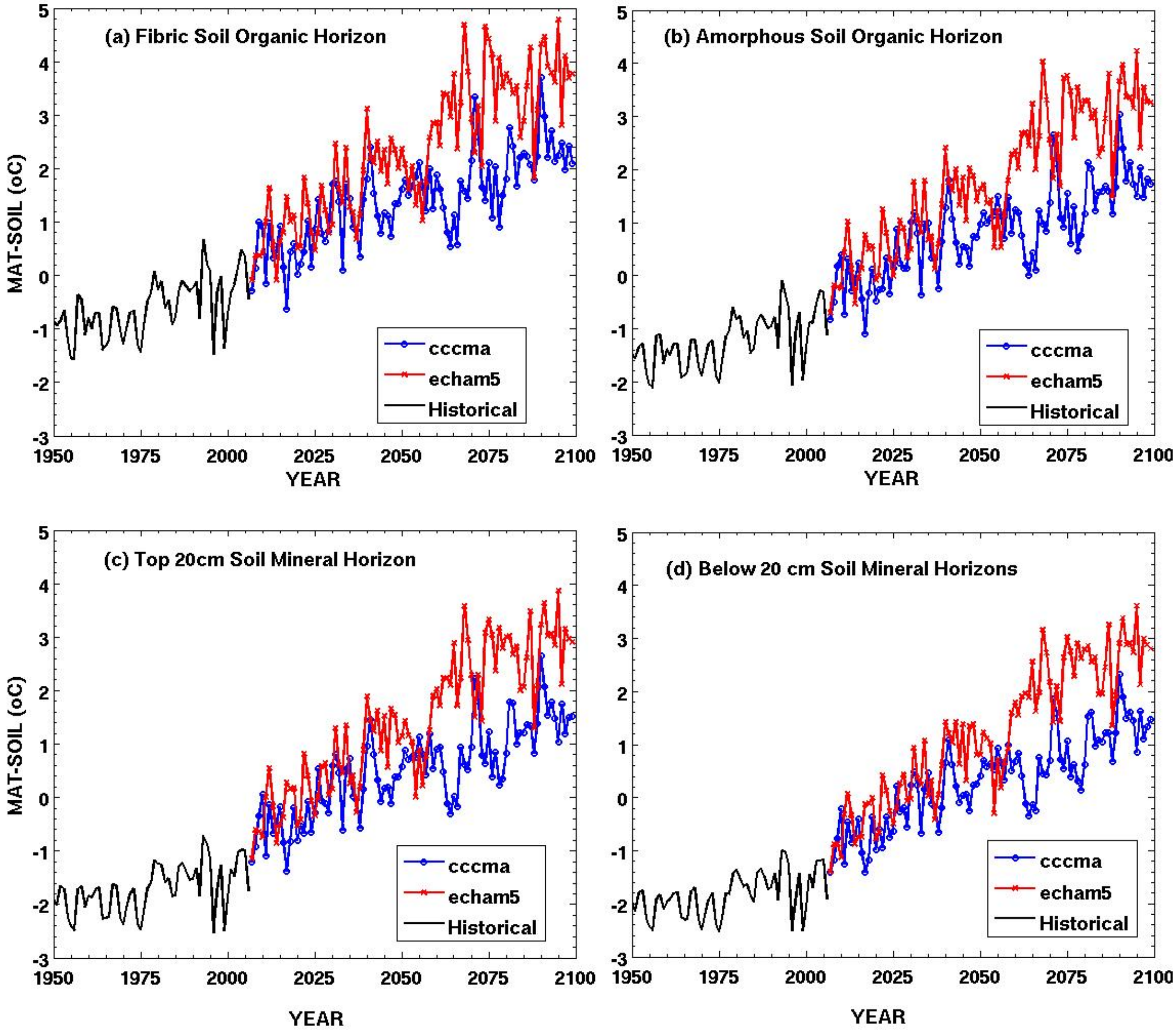

Figure 11. Soil thermal dynamics simulated by DOS-TEM over the AKYRB region for the (a) fibrous organic, (b) amorphous organic, (c) upper mineral, and (d) lower mineral soil horizons from 1950 – 2006 (driven by historical climate) and 2007 – 2099 (driven by CCCMA and ECHAM5 climate).

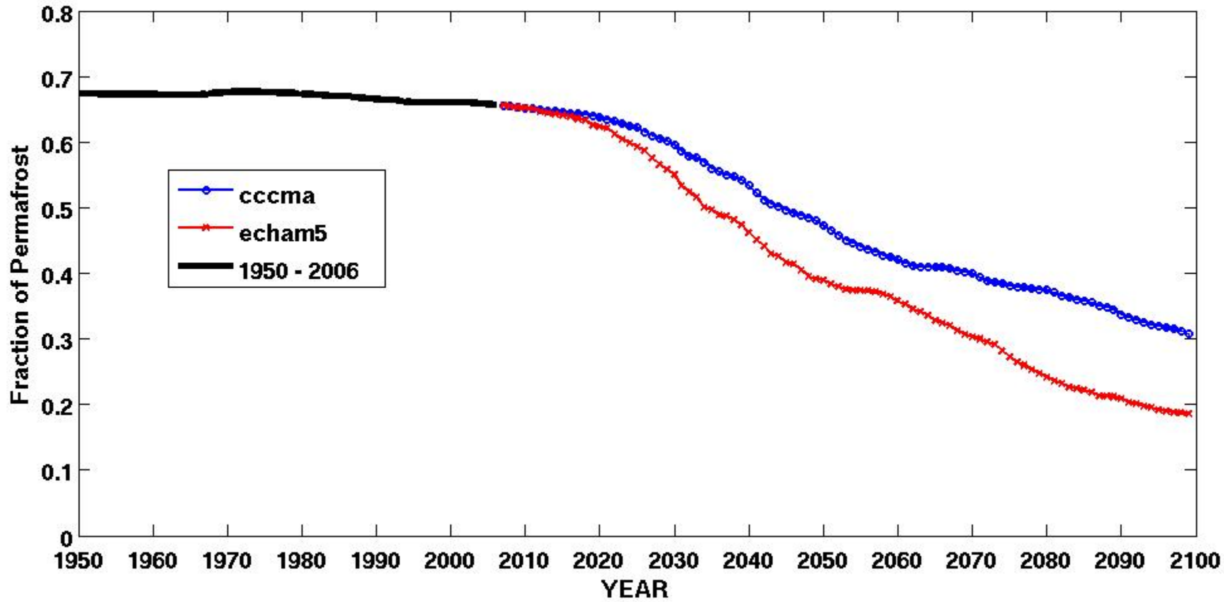

Figure 12. Decrease in the fractional area of shallow permafrost (within top 5.4 m depth of the surface) in the AKYRB as simulated by DOS-TEM driven by the historical and projected climate changes and fire.

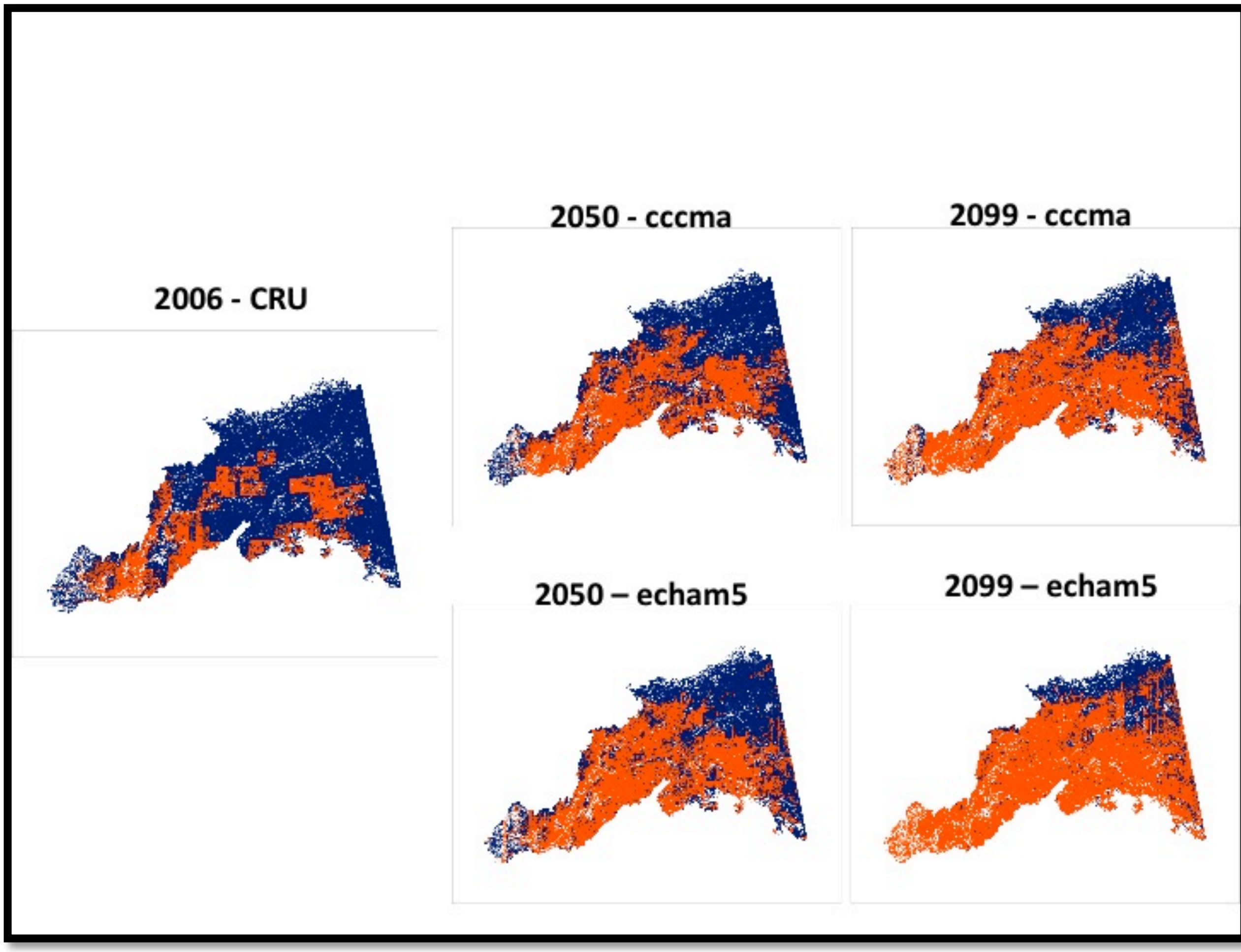

Figure 13. The distribution of shallow permafrost (within 5.4 m of the surface; dark blue – shallow permafrost, orange – non-permafrost or deep permafrost) in the AKYRB simulated by DOS-TEM for two climate projections and associated predictions of fire occurrence.

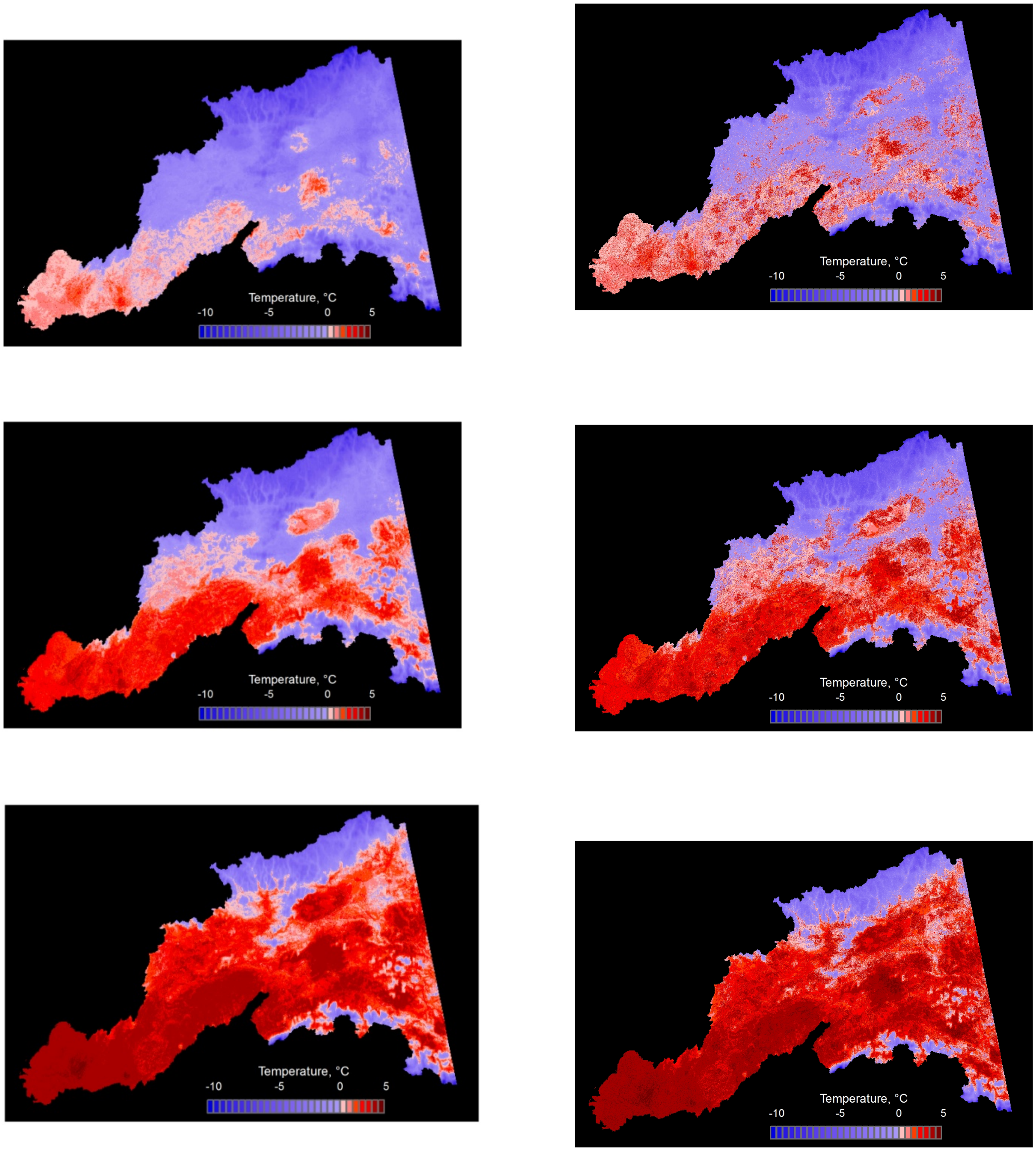

Figure 14. Mean annual ground temperatures (1 m depth; blues – temperature < 0° C and red – temperature > 0° C) in the AKYRB for control run (left) and with associated predictions of fire occurrence and their affect on organic layer and vegetation (right) averaged for (top) 2000-2009, (middle) 2040-2049, and (bottom) 2090-2099 simulated by GIPL-1 driven by CCCMA climate.

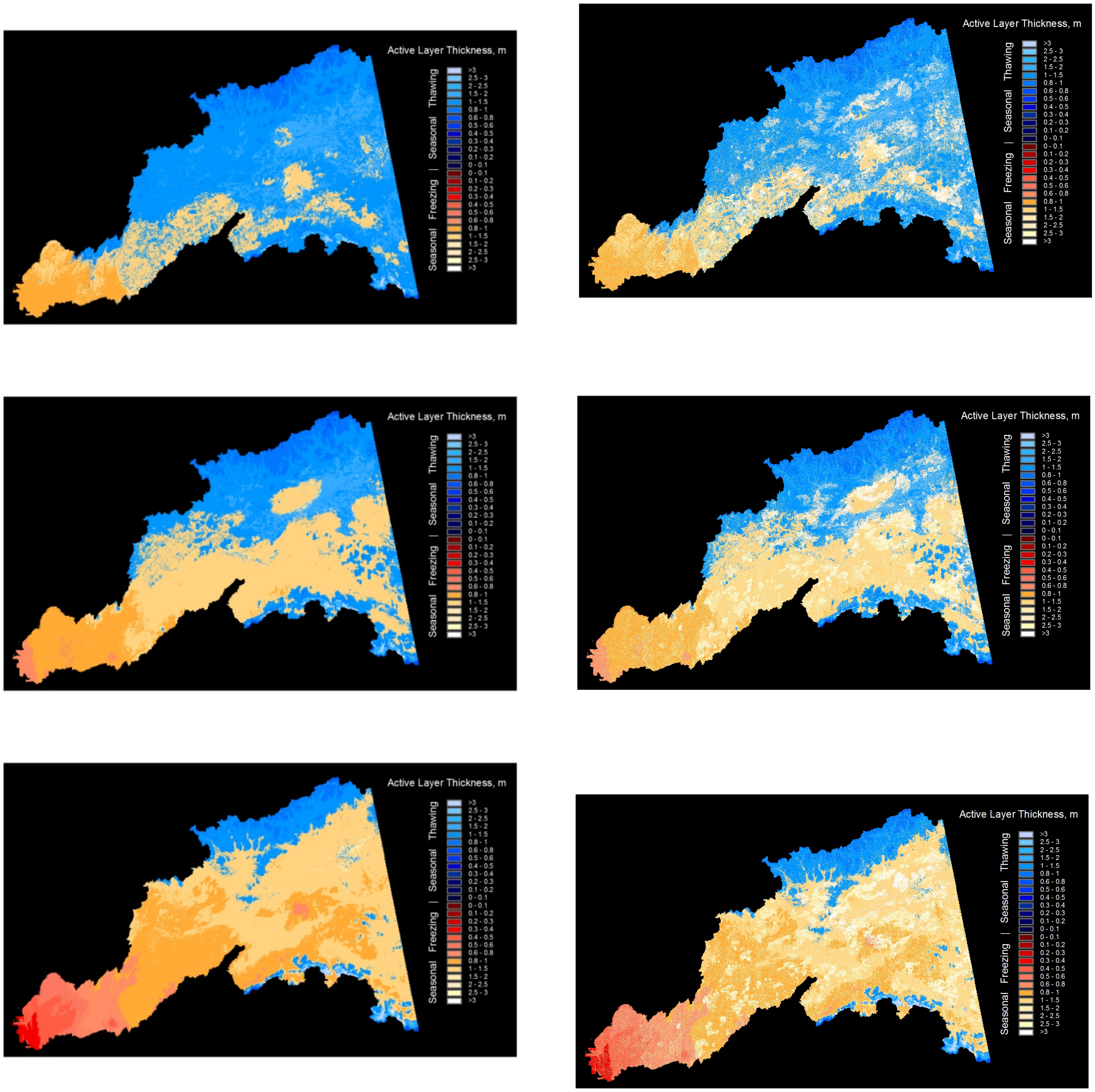

Figure 15. Active layer thickness (m; yellow, orange and red – seasonal freezing and blue – seasonal thawing) for control run (left) and with associated predictions of fire occurrence and their affect on organic layer and vegetation (right) averaged for (top) 2000-2009, (middle) 2040-2049, and (bottom) 2090-2099 simulated by GIPL-1 driven by CCCMA climate.

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