Final Report for the NASA Land Cover Land Use Change Program
Northern Eurasia Earth Science Partnership Initiative (NEESPI)

Wildfire, Ecosystems, and Climate: Examining the Relationships between Weather, Extreme Fire Events and Fire-Induced Land-Cover Change in the Changing Climate of Siberia.

NASA Land Cover Land Use Change (solicitation NNH05ZDA001N-LCLUC)

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Abstract

The purpose of this research was to utilize historic NASA-derived satellite and meteorological data and a Siberian ground-based extreme fire events dataset to statistically analyze the coincidence in severe fires and the meteorological and synoptic-scale weather characteristics that generate the conditions necessary to sustain extreme fire events. Then, after establishing these relationships, to expand the scope of bioclimatic models to predict fire regimes under climate change scenarios for 2030, 2060 and 2090 and to simulate phytomass change and change in the extent and distribution of the dominant vegetation.

The geographic region of focus was northern Eurasia, because this is a region that is currently experiencing rapid warming, and it is expected that future temperature increases in northern Eurasian will be in excess of 40% above the global mean. Siberia is particularly unique because: (1) this region has the potential to interact with and feed back to both the regional and global climate systems due to its size and continental extent; and (2) the boreal forest stores the largest pool of terrestrial carbon and 2/3 of the boreal forest is located in Russia.

The dominant force of Land Cover Change in Siberia is fire disturbance. Fire has the potential to feedback to the climate system by: (1) immediately releasing emissions to the atmosphere (positive feedback); (2) altering the albedo of clouds (positive and negative feedbacks); (3) shifting patterns of precipitation through changes in Cloud Condensation Nuclei; (4) transporting black carbon to the Arctic (negative feedback); and (5) altering the albedo of the landscape by changing vegetation, which could result in positive and/or negative feedbacks to the climate system. Climate and weather have the potential to alter fire regimes by (1) altering vegetation that may be more or less conducive to fire; (2) increasing ignitions from lightening; and (3) by generating weather conditions that are more (i.e. hot and dry) or less conducive to fire.

Consequently, the focus of this project was on a major driving force of Land Cover Change in Siberia, fire, and the weather and climate that drives this change. Fire is a natural and necessary component of boreal landscapes, which maintains ecosystem stability under the control of weather and climate, and fire is a catalyst of ecosystem change, which drives ecosystems more rapidly towards a new equilibrium with future weather and climate. For these reasons, under the influence of fire, ecosystems and the carbon stored in these systems could be altered, which ultimately affects human kind in terms of viable logging and agricultural lands, minimally. It is imperative to understand these processes today, historically and in the future. Additionally, if predictions are correct, precursors of climate change should be evident today.

We were able to meet and in some cases, exceed our research objectives, thus we consider this project a success. Achieved goals include the implementation of the Canadian Fire Danger system to simulate fire weather variables over time in Northern Eurasian and relating these data to large fire events, large fire seasons and ecosystem types. Additionally, the Siberian Bioclimatic Model (SiBCliM) was used to simulate ecosystem change under a variety of climate-change scenarios, demonstrating the expected progressive change in ecosystems over time. In addition, using SiBCliM and historic fire data, we focused on a keystone region, the Republic of Tyva, which is expected to be a ground-zero region for climate change, incorporating dendrochronological data and field campaigns. This final report is designed to walk the reader through accomplished work using "Research Highlights" and figures describing our work.

Table of Contents

Keywords

Fire, Satellite, Siberia, Weather, Climate, Biomass Burning, Bioclimatic Model, Phytomass, Carbon, Boreal Forest, Northern Eurasia, Russian

Objectives and Strategy

The overarching goal of this research was to explore the degree to which current and future climate variability affects wildfire-induced Land Cover Change and to highlight the significance of the interaction between the biosphere and the climate system in support of the inclusion of biospheric models in future Atmosphere Ocean General Circulation Models.

Specifically, our intent was to identify the weather and climate processes that precipitate large and extreme fire events, so that this information can be used to enhance the projections of current bioclimatic models and enhance our knowledge of the role an altered biosphere plays in long-term regional and global climate processes. First, a ground-based large fire database was used to define the regions where extreme fire events occurred and then historic satellite imagery was used to precisely geolocate and define area burned. Secondly, the weather conditions that generate the environment necessary to sustain large and extreme fire events was identified. Then, these relationships were used to establish correlations between weather variables, area burned, ecosystem types and fire danger, with the ultimate goal of generating future fire danger maps. The Siberian Bioclimatic Model (SiBCliM) was then used to simulate paleo, current, future (2030, 2060, and 2090) ecosystem types under current climate change scenarios.

We adopted a dual research strategy designed to examine patterns of fire, weather and land cover change on both regional and ecosystem scales. On a regional large-scale, we investigated potential change in ecosystems and fires regimes and how these changes are influenced by and influence weather and climate. Then, we examined smaller-scale ecosystems that were highlighted by our larger-scale regional investigations. Specifically, the Sakhan Republic was a region of focus based on the extreme 2002 fire season, and the Republic of Tyva was highlighted because SiBCliM simulations showed “hot spots” of potential change in this region. Additionally, we have added value to understanding fire regimes in the *Pinus sylvestris* forests of Krasnojarsk, which were subject to the largest fire return interval in the state and were heavily used for wood products.

Addressing NASA’s Goal and Objectives within the Earth-Sun System Division [answering Research Opportunities in Space and Earth Sciences (ROSES 2005)]

This project delivers on near- and long-term Climate Change Science Program (CCSP) and Land-Cover/Land-Use Change (LCLUC) milestones by analyzing existing data to define historic and contemporary rates and the extent of regional Land Cover Change brought about by a major driving force of that change, fire disturbance. Also, the primary large-scale weather and climate variables that drive and sustain large fire events in Siberia were quantified. Then, fire danger mapping and bioclimatic models were used to project the largest driving force of change and the resulting shift in future Land Cover.

Additionally, the results of this project support each of the three major strategic international programs supported by the NASA LCLUC program. This project focused on northern Eurasia, and it is an integral component of the Northern Eurasian Earth Science Partnership Initiative (NEESPI). Fire is predicted to be a major future driver of LCC and the consequences of that change (ecosystem and phytomass stored) are provided using model simulations. Specifically, we quantified the rates of fire-induced land cover change; mapped the ecological characteristics of that change; and simulated potential fire-induced land cover change, which directly supports the goals of the Global Terrestrial Observing System (GTOS) Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) project. Lastly, this project fell under the domain of the International Geosphere-Biosphere Programme (IGBP) and International Human Dimensions Programme (IHDP) joint program, the Global Land Project (GLP) by identifying the character and dynamics of a perturbation (climate interacting with fire over time) and assessing the ecosystems affected (model simulations).

The topical research area addressed was Land Use Land Cover Change (LULCC) and Climate Change/Variability Interactions ("Climate"), although due to the interdisciplinary nature of this research, this topic crossed boundaries to include aspects of "Monitoring" and "Impacts".

NASA products utilized include: (1) Moderate Resolution Imaging Spectroradiometer (MODIS) fire anomaly products to enhance and validate the recent Siberian large fire database; (2) the Global Climate Model (GCM) assimilated Global Modeling Analysis Office (GMAO) Goddard Earth Observing System (GEOS) version 4.03 to generate a meteorological database from 1984 through 2004, which provided large-scale meteorological fields (i.e. winds, temperature, relative humidity, etc.); (3) the NASA/NOAA Global Precipitation Climatology Project (GPCP) data, an additional parameter necessary to model Fire Weather Indices (FWI); and (4) the Global Energy and Water-cycle Experiment (GEWEX) Surface Radiation Budget (SRB) data, which provided long-term surface radiation data.

Background for an International, Interdisciplinary, Interagency Endeavour

Working internationally in Russia was not insignificant and required established relationships with scientists and their organizations. We accomplished our research goals by establishing and maintaining these partnerships (scientist-to–scientist; organization-to-organization), which provided the basis for the successful completion of this project. We entered this project with established working relationships with our Russian and U.S. partners, relationships that are based on a strong history of research, and we expanded our network of research associates. For instance, Nadezda Tchebakova and Elena Parfenova developed a bioclimatic model that is capable of addressing sustentative research questions, and this model evolved through interactions with our project. Amber Soja worked for a decade on several NASA–, EPA- and NRC-funded fire research projects in Siberia. We established working relationship with satellite data processors, foresters, modelers, fire ecologists, meteorologists, and the director of the Tyvan State Biosphere Reserve (Vladislav Kanzai), each of which were necessary to move this inter-disciplinary project forward.

One major accomplishment of this work has been establishing the logistics and data preparation necessary to complete this research. This may sound insignificant, but working internationally and remotely was and continues to be challenging in terms of the distance (less face-to-face interaction) and differences in scientific and institutional perspectives.

Research Highlights

An overview of accomplished work is highlighted below and also in the figures contained in this report. Additionally, a detailed compilation of completed manuscripts and presentations is highlighted in the publications sections of this report. It will be apparent from our publications that we often take advantage of existing research and projects to add value to their research and ours. A list of accomplished tasks follows:

- The spatial extent of fire and area burned across Siberia were assessed and shown in figures 1 and 2.

Meteorological Assessment

- National Climate Data Center (NCDC) ground-based weather data (1983-2004) were used to verify satellite-based meteorological GEOS-4 parameters. A 75% criteria (measurements per day and per month) was determined as the lowest possible to retain a significant number of stations. Both the location of these stations and data availability varied over time (Figures 3a and 3b, initial 87% criteria).
- Meteorological parameters from NASA GEOS-4 reanalysis satellite-based data and the NCDC station-scale data were compared to verify temporal and spatial data consistency [1987-1989 and 1998-1999, April–Sept. (fire season)] (Figures 4-7). This was an essential task because station data are commonly used to estimate fire danger, however 1-degree data was an unknown in estimating fire danger and FWI. These meteorological parameters (temperature, wind speed, relative humidity and precipitation) are the variables necessary to calculate FWI.

Fire Weather Analyses

- The Canadian Fire Weather Index system was calculated using GEOS- and NCDC-based data to establish consistencies and differences between the disparate data sets and to analyze the relationships between large fires, ecosystems, station-, regional- and continental-scale fire weather data.
- Local and regional analyses focus on two fire years, one normal (1999) and an extreme fire season (2002). Station data were assessed at the Jakutsk station and the regional assessment was on Sakha (Figures 8-10). Even though meteorological variables differ, the NCDC and GEOS station data compare well, both cumulatively and over time (Figures 9 and 10).
- In the extreme fire year, the regional assessment highlights FWI values sustained above 20 and often greater than 30 (Figure 10). At this point, the station- and regional-scale assessments demonstrate the viability of using large-scale meteorological data to calculate FWI and then relate these indices to extreme and normal fire years, which establishes the potential for relating future meteorological data to future fire regimes.

- The geographic extent of FWI were mapped and analyzed across Northern Eurasia. Examples of the FWI and several continental-scale assessments are shown in figures 11 and 12. Additionally, a website was generated that provides 3 years of daily geographic FWI data for 3 distinct fire years (with animation capability), monthly severity ratings, absolute error, FWI category difference, percent domain in each FWI category, cumulative domain-scale time series, cumulative average domain-scale time series, daily domain time series and scatter plots.
  http://www.nianet.org/soja/
- Results show these daily and monthly FWI data compare well spatially, temporally and quantitatively (1999 $r^2 = 0.93$; 2002 $r^2 = 0.90$; 2004 $r^2 = 0.96$); 74% of the daily data were one fire weather index category or less different (Figures 13 and 14).
- Seasonal and quantitative relationships were established between large-scale fire weather indices, ecosystems, the number of cells that contain active fire and mean area burned. Mean area burned per ecosystem type and percentage each ecosystem burns per FWI category are shown in figures 15 and 16. These analyses underscore the importance of spatial scale when establishing relationships to estimate future fire emissions; in other words, the base data must be temporally and spatially similar to attain the best precision and accuracy.
- The large-scale meteorological parameters that determine fire weather are able to capture daily, monthly and seasonal patterns of fire and area burned. These relationships, paired with simulated ecosystems and the meteorological parameters available from the Intergovernmental Panel on Climate Change (IPCC) scenarios, could be used to estimate future potential area burned, fire severity and emissions.

Ground-based Assessments

- Fire Weather Indices (FWI) were examined and defined in the *Pinus sylvestris* forests of Krasnojarsk and Tuva using a combination of analysis: area burned; number of fires; and tree ring chronologies (Figures 17 and 18). These analyses demonstrate the largest Fire Return Interval (FRI) was found in the southern taiga, where logging pressure dominates. It was rare to find a logged field that has not burned within a couple years of logging, which increases the FRI in these regions (Ivanova et al. 2010).
- Station-scale temperature analyses were completed that demonstrate that in some regions, winter temperatures have already exceeded 2090 projections (Figure 19) (Soja et al., 2007).
- Growing session length was calculated and is increasing across Siberia (Soja et al., 2007). Figure 20 shows one station example.

Siberian Bioclimatic Model (SiBCliM)

- Several model results were produced using SiBCliM, and we show simulated regional- and continental-scale ecosystem change for 2020, 2080 and 2100 (Figures 21 through 25) (Tchebakova et al. 2010; Tchebakova et al. 2009; Parfenova and Tchebakova 2009; Monserud et al. 2008; Vygodskaya et al. 2007; Soja et al. 2007)
- Potential "Hot Spots" of forest change were modeled that show the regions most likely to be first affected by fire-, weather-, and climate-induced land cover change (Figure 23). This result led to detailed investigations in the Tyvan Republic.

- Potential changes in phytomass (biomass) due to changes in land cover were modeled using the SiBCliM (Figure 24).
- Albedo change that results from shifts in major species and forest types (due to fire, weather and climate) were also simulated using Tchebakova and Parfenova's SiBCliM (Figure 25).

Focused View of the Republic of Tyva

- A focused analysis of the connections between fire, weather and climate was completed for the Tyvan Republic (Figure 26). Locals report that the relic *Pinus sylvestris* forest that had existed since the last ice age were disappearing, however there was no increase in area burned by fire noted in satellite data. A field trip revealed a lack of regeneration, as reported, was attributable to: (1) extreme precipitant fire weather that led to severe fires that burned to mineral soil; (2) an increase in the growing season length on the southern boundary of a steppe/forest-steppe ecotone, which was already at the edge of existence; (3) slightly decreased precipitation and increased temperatures, thus increased evapotranspiration; and (4) an increase in the number of extremely hot days. Thus, seedling establishment was either impossible or inhibited, which led to unhealthy seedlings that could not establish and died shortly thereafter.

Top-cited Manuscript (# 1 in Global and Planetary Change in a five-year period)

- In a top-cited manuscript, we concluded the initial signs of climate change were already evident across the circumboreal (Soja et al., 2007). Previously modeled predictions of the initial ecological indicators of climate change were considered across the circumboreal, and we found evidence of: (1) ecosystem migration, replacement and decreased health, particularly at northern and southern ecotone boundaries and at altitudinal ecotones; (2) increased infestation; and (3) increased extreme fire seasons. (also Groisman and Soja 2009 a, b)

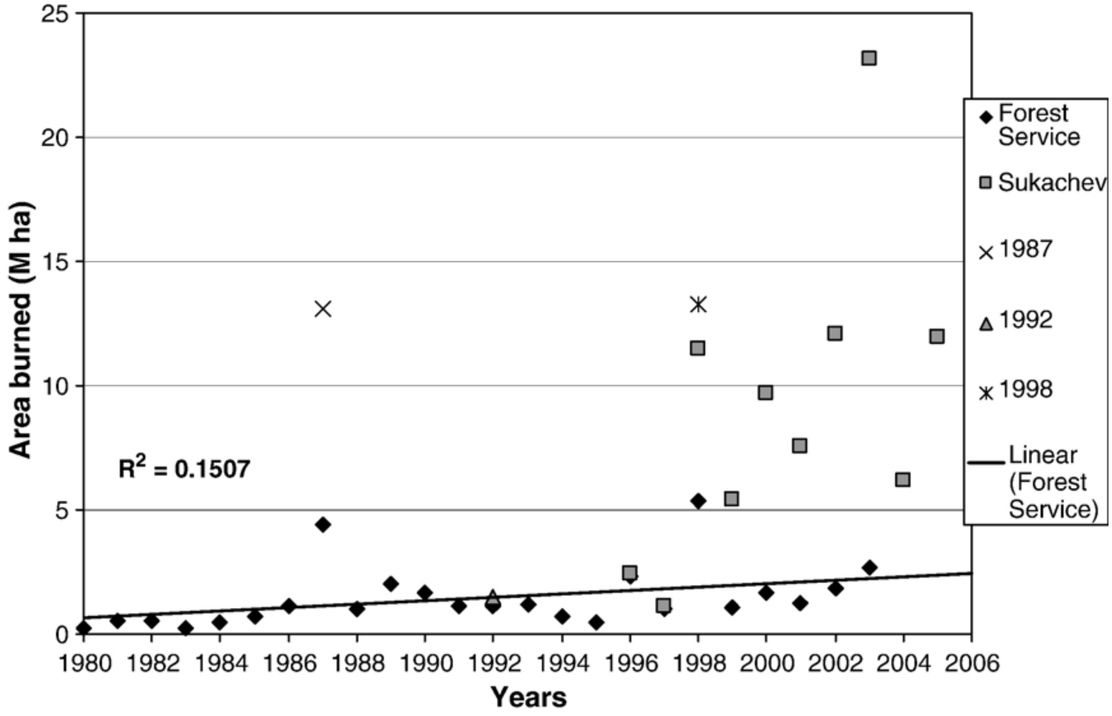


Figure 1. Area burned in Russia. Data for this graph was taken from several sources: Forest Service - ground data from the Russian Federal Forest Service, Sukachev and numerous publications, which can be found in Soja et al., 2007.

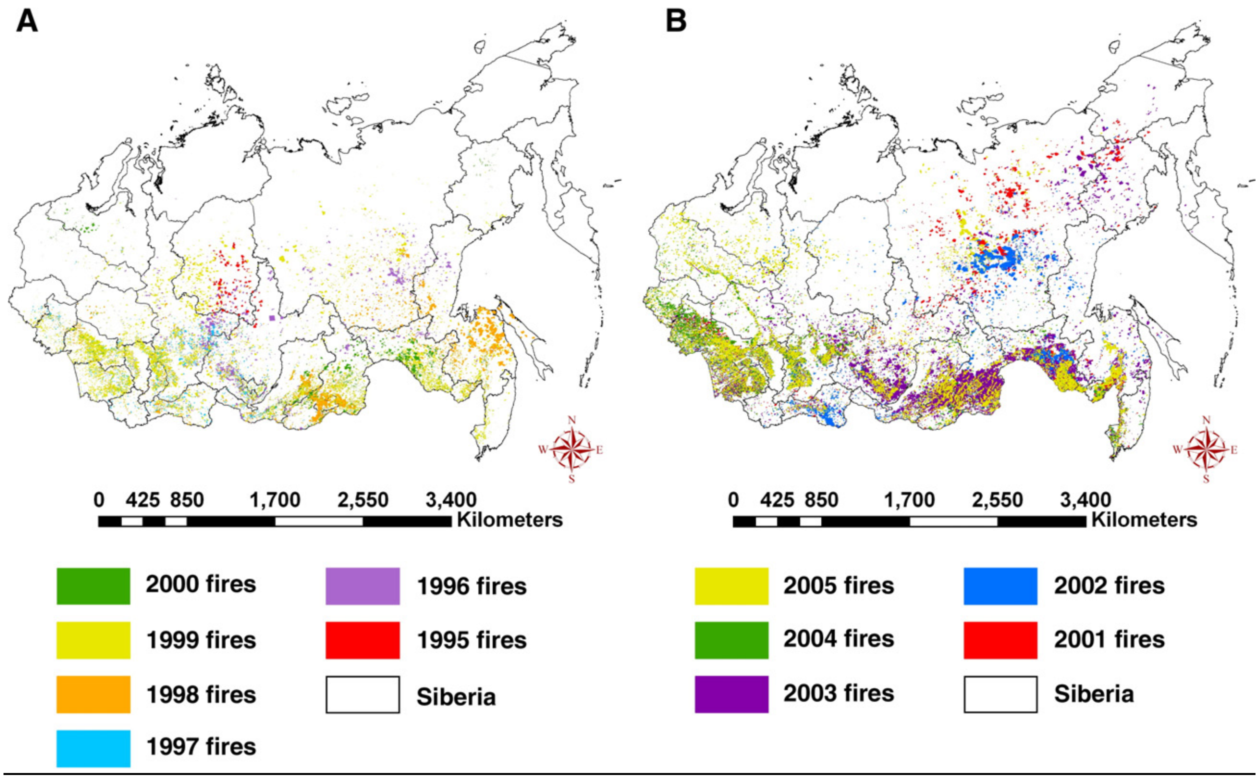


Figure 2. Satellite-derived fires in Siberia from 1995 through 2005.

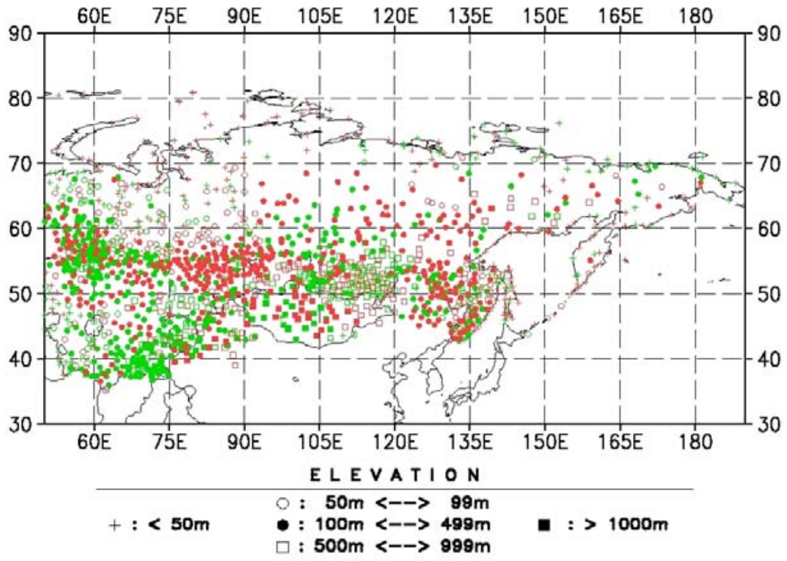
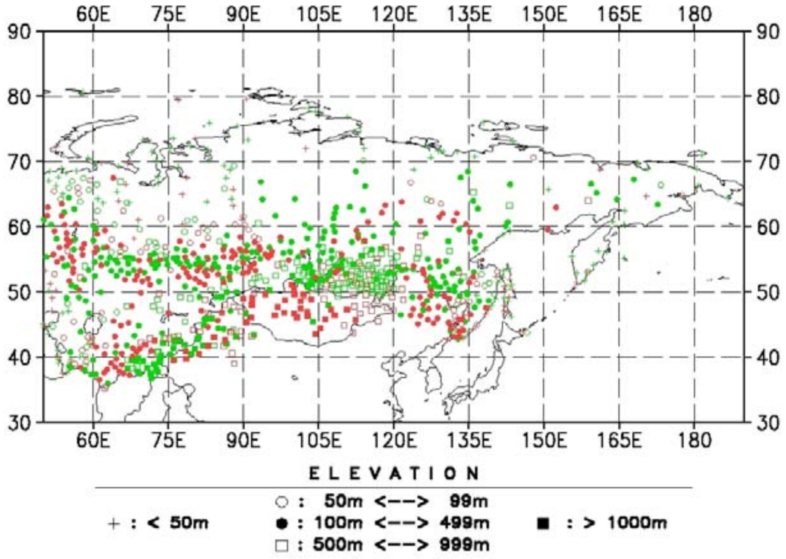


Figure 3. National Climate Data Center (NCDC) stations meeting (red) and not meeting (green) the criteria of reporting 75% of the daily observations and 75% of the days in a month for the years 1989 (A) and 1999 (B).

Notice the number of sites have substantially decreased since the 1980s, representing pre- and post-glasnost.

A.

Additionally, these station locations highlight the potential for inaccuracy when strictly using ground based data over large spatial and temporal domains. For example, if weather data were collected every 6 hours and 50% of those data were missing, this could severely alter the reality of daily weather, unless these missed measurements were random, which is unlikely. Satellite data are consistent and spatially complete.



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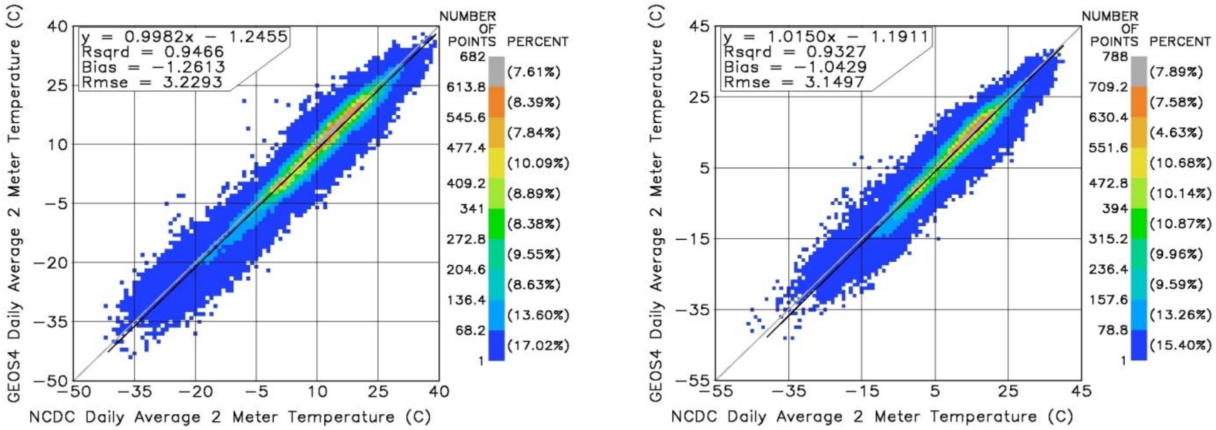
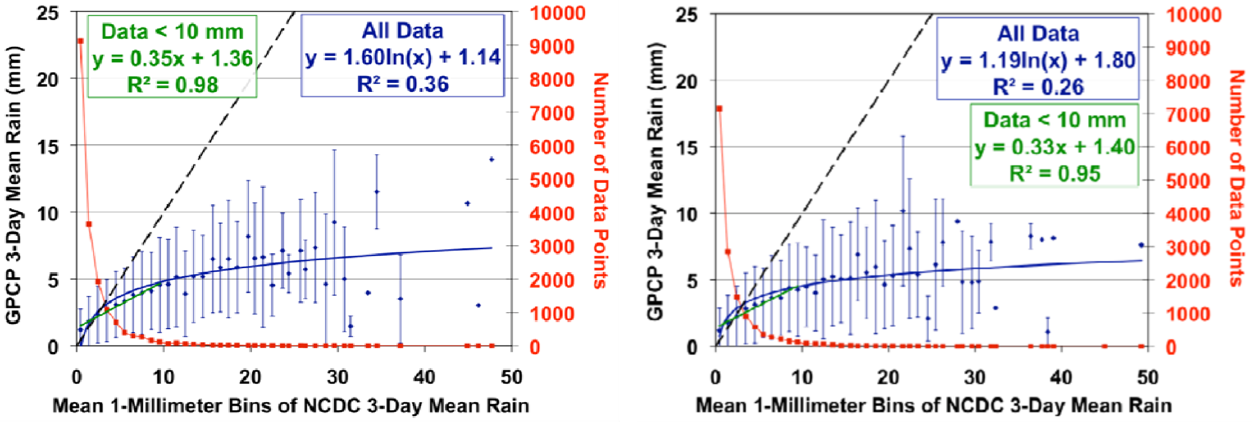


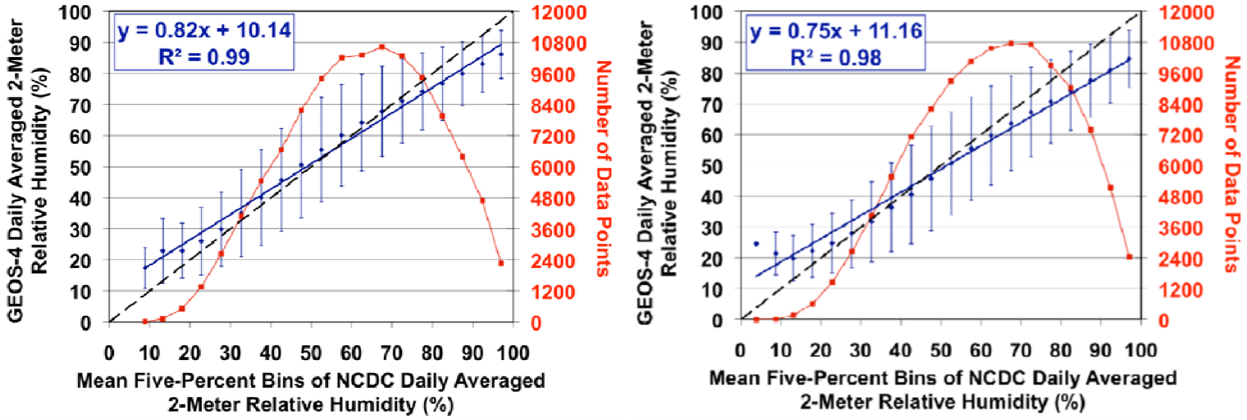
(a) (b)

Figure 4. Density scatter plots comparing GEOS-4 and NCDC average 2-meter temperature (0-4000 m) for (a) an average fire year March-October 1999 and (b) an extreme fire year March-October, 2002. Less than 17% of the data, which is shown in dark blue, resides distant from the 1:1 line. For 1999, 462 stations are represented with 110901 points (2289 missing data points), and for 2002, 482 stations are represented with 115259 points (2831 missing data points). There was no correction for elevation, and the difference between station and satellite data ranges from 0 to 4000 meters.



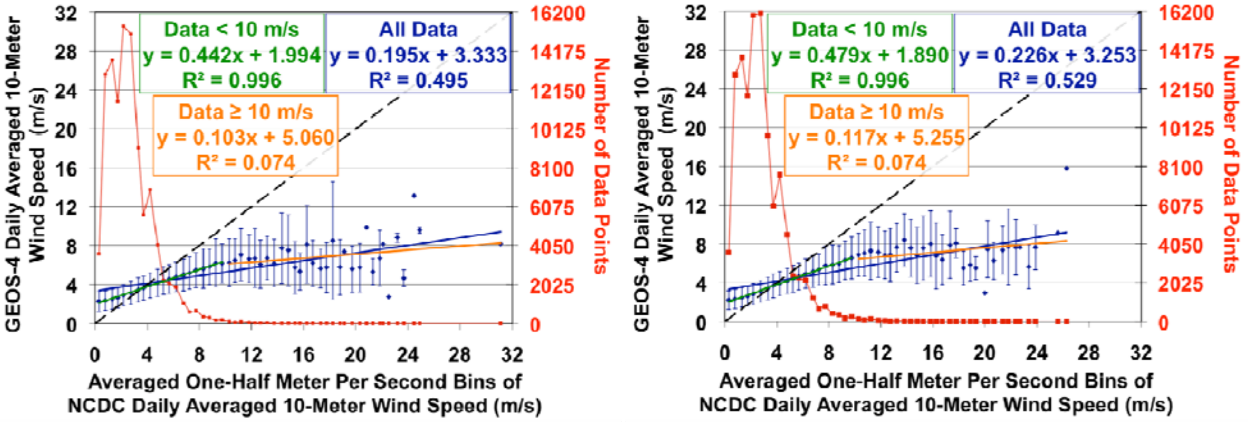
(a) (b)

Figure 5. One-millimeter bins of NCDC versus GPCP 3-day mean precipitation and standard deviation for (a) 1999 and (b) 2002 (both years March-October). The 1:1 line is shown in dashed black.



(a) (b)

Figure 6. Comparison of NCDC versus GEOS-4 five-percent 2-meter relative humidity (RH) bins for (a) 1999 and (b) 2002 (both years March-October). Mean and standard deviation are shown in blue, and the 1:1 line in dashed black.



(a) (b)

Figure 7. Comparison of NCDC versus GEOS-4 10-meter wind speed in 0.5 meter/second bins for (a) 1999 and (b) 2002 (both years March-October). Mean and standard deviation are shown in blue, and the 1:1 line in dashed black.

There are several potential reasons for some of the discrepancies between the station and reanalysis data, in addition to those discussed earlier. Some of the disparity may be partially due to the difference in NCDC site elevation and the GEOS-4 mean grid. More than 50% of the NCDC sites (247 out of 482) have an elevation difference greater than 100 meters relative to the GEOS-4 grid box mean elevation. Station data are representative of local weather and the GEOS-4 assimilation data represent a 1° x 1° area, representing a legitimate source of noise and potential bias in the GEOS-4/NCDC relationships.

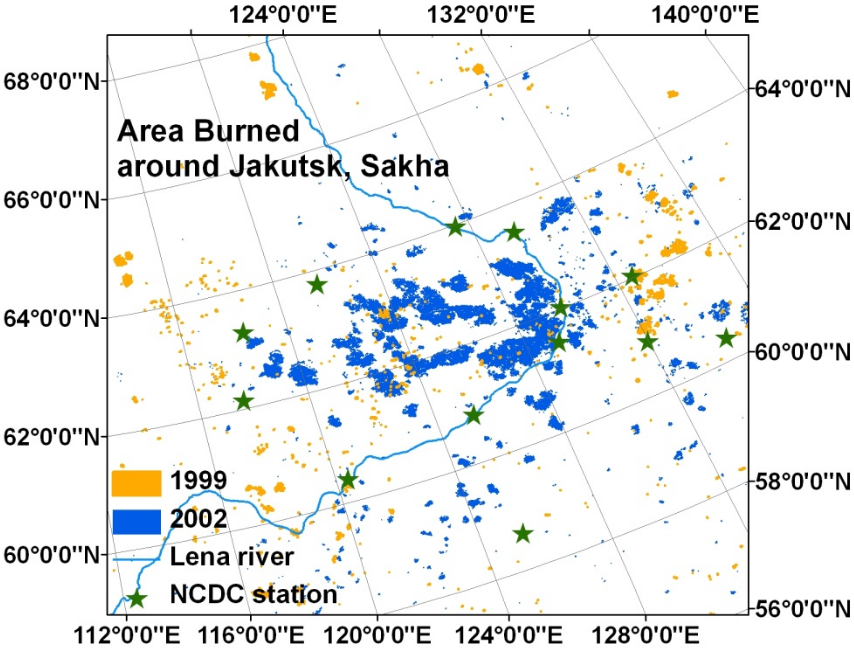


Figure 8. Area burned in Sakha in 1999 and 2002 demonstrating the difference in a normal and an extreme fire year.

Danger Class	*FWI Range*
Very Low	*0-1*
Low	*2-4*
Moderate	*5-8*
High	*9-16*
Very High	*17- 29*
Extreme	*30 +*

Table 1. FWI danger classification scheme.

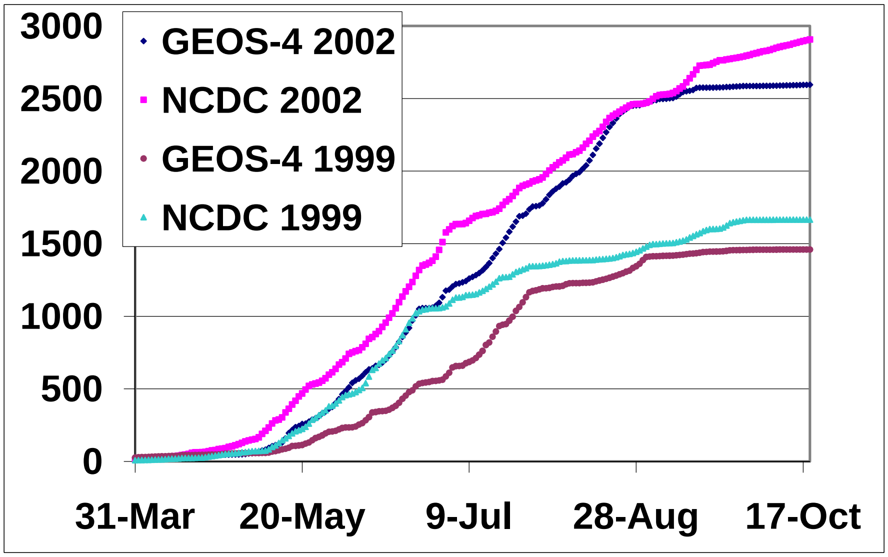
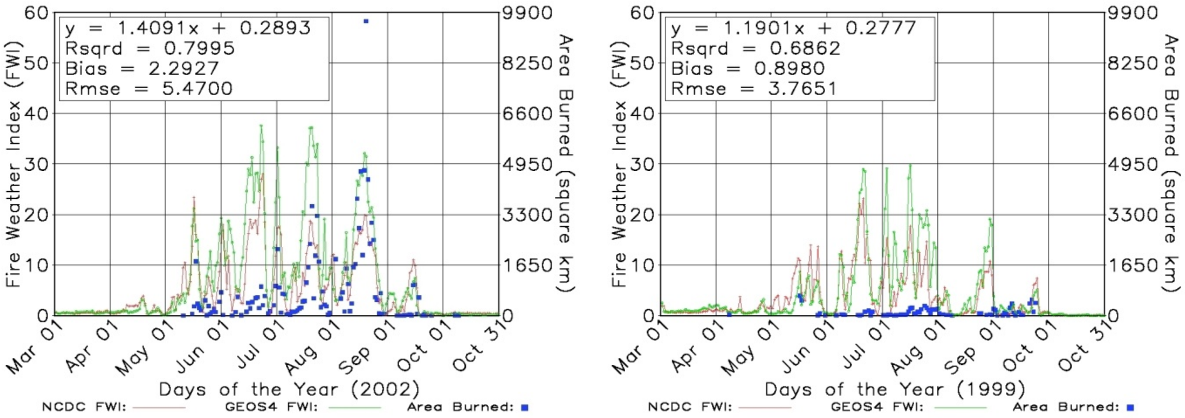


Figure 9. Cumulative FWI for the Jakutsk NCDC station and the coincident GEOS-4 1-degree cell.



(a) **(b)**

Figure 10. FWI time series for the Republic of Sakha for 1999 (a) and 2002 (b), highlighting the similarity between regional NCDC station- and GEOS/GPCP-derived FWI. Regional mean FWI do not register above 30 in 1999 and were not sustained above 20. In contrast, FWI values above 20 were sustained in 2002 and were often greater than 30. FWI were overlaid with daily area burned in 1999 and 2002. The NCDC stations used for this analysis are shown in figure 8.

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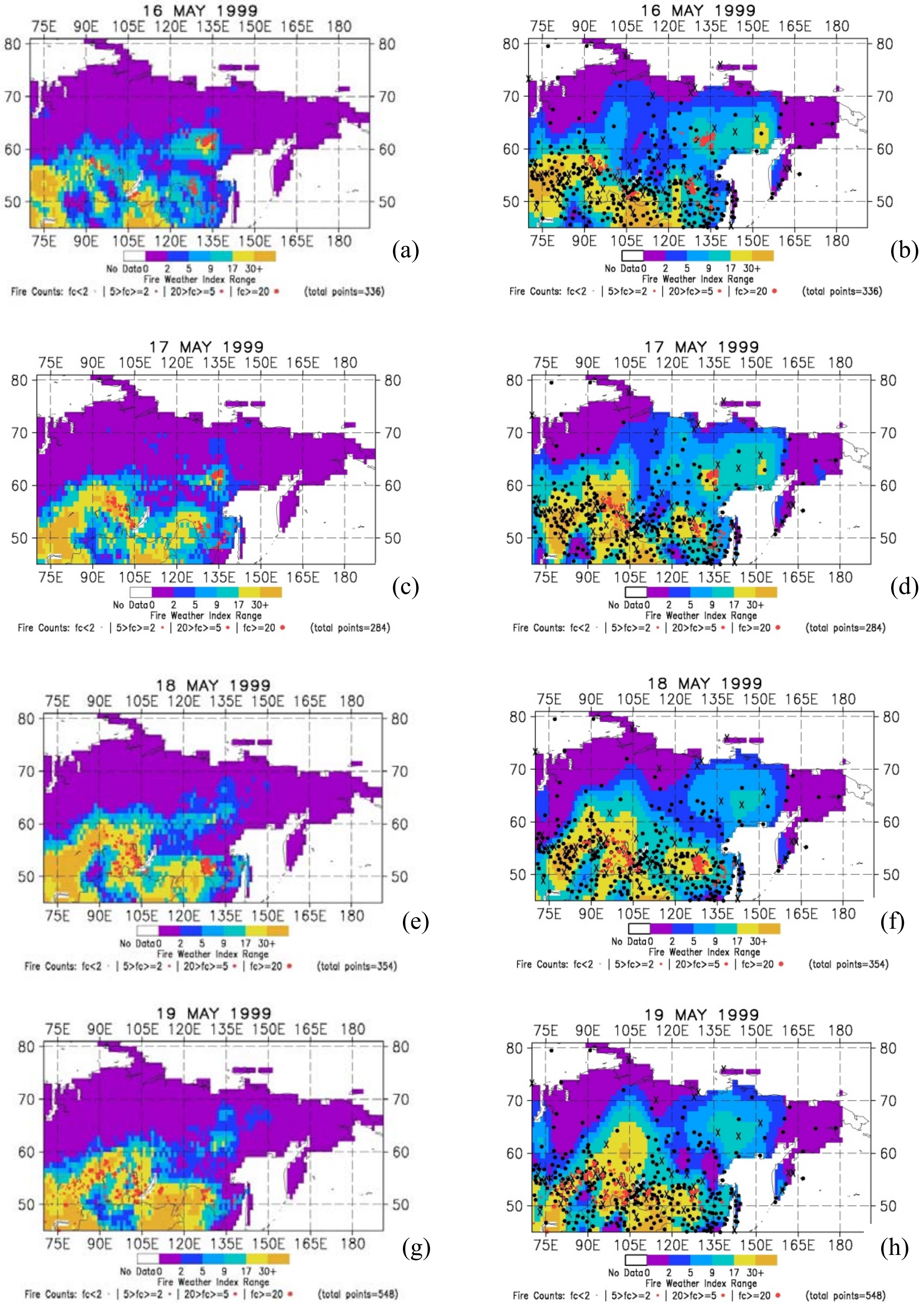

Figure 11. Time series comparison of GEOS4/GPCP- and NCDC station-interpolated FWI on the left and right, respectively. The black dots are station locations, and the Xs represent stations that did not meet the 75/60% reporting criteria. In the domain shown here, there were 648 stations and 232 do not meet the criteria. Fires are shown in red.

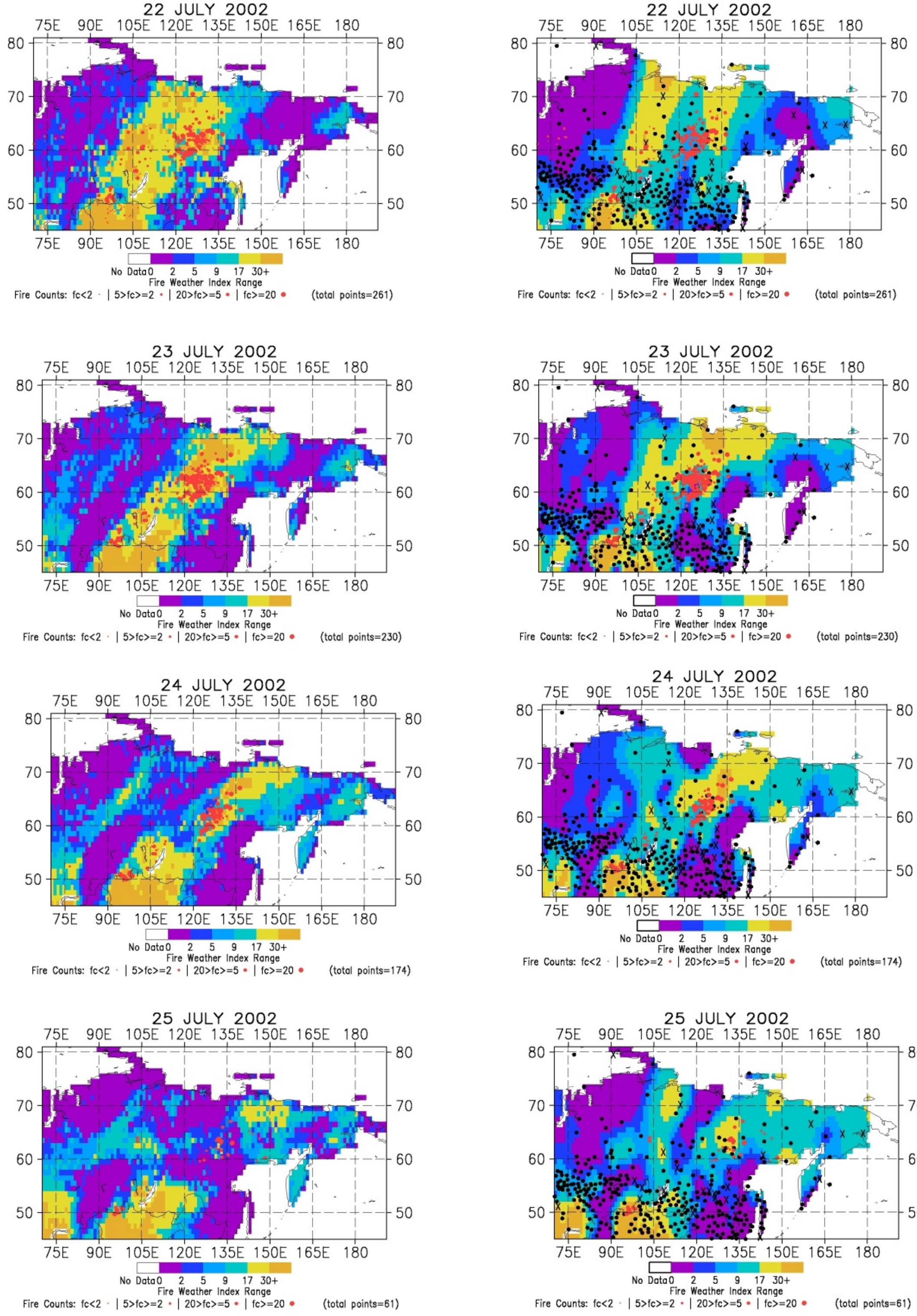
22 JULY 2002

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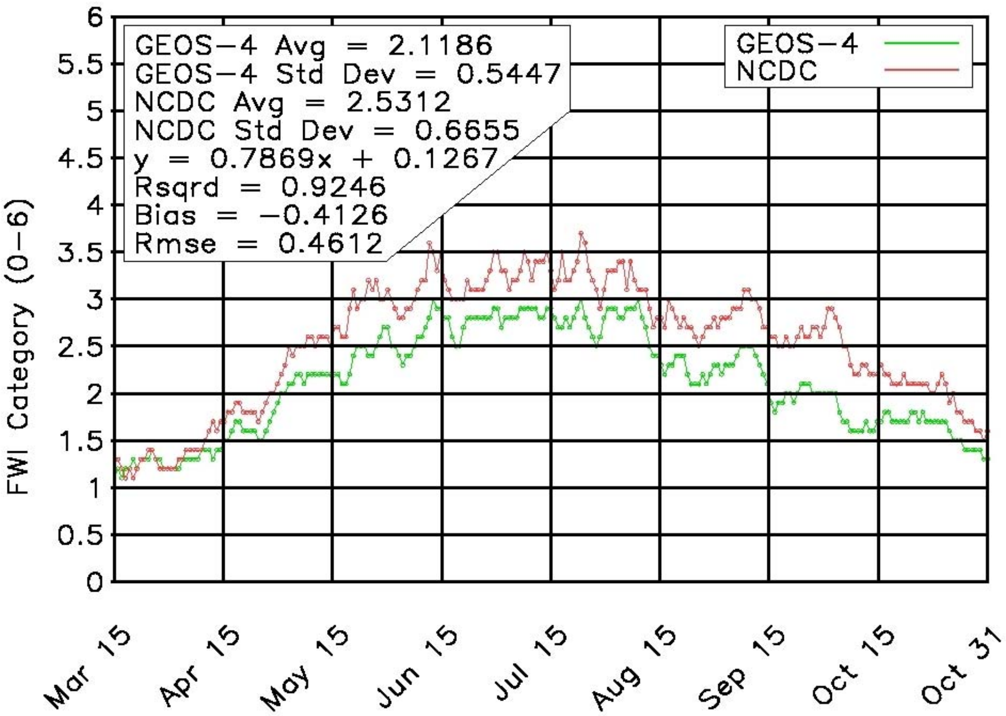
Figure 12. Time series comparison of GEOS4/GPCP- and NCDC station-interpolated FWI on the left and right, respectively. The black dots are station locations, and the Xs represent stations that did not meet the 75/60% reporting criteria. In the domain shown here, there were 635 stations and 209 do not meet the criteria. Fires are shown in red.



(a)

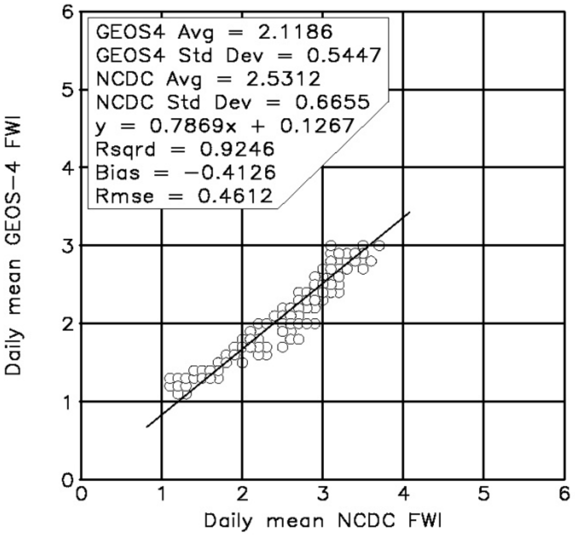


Figure 13. Daily time series of the mean domain GEOS-4-reanalysis and NCDC-interpolated FWI for 1999 (a): and a scatter plot from 1999 comparing the data (b). The GEOS-4 and NCDC FWI correlate well spatially and temporally resulting in overall R^2 values of 0.93 in 1999, 0.90 in 2002 and 0.96 in 2004. Even though the data correlate well, the NCDC mean domain data were consistently larger in 1999, 2002 and 2004, with rare exception. Graphs for additional years are available online.

(b)

http://www.nianet.org/soja/

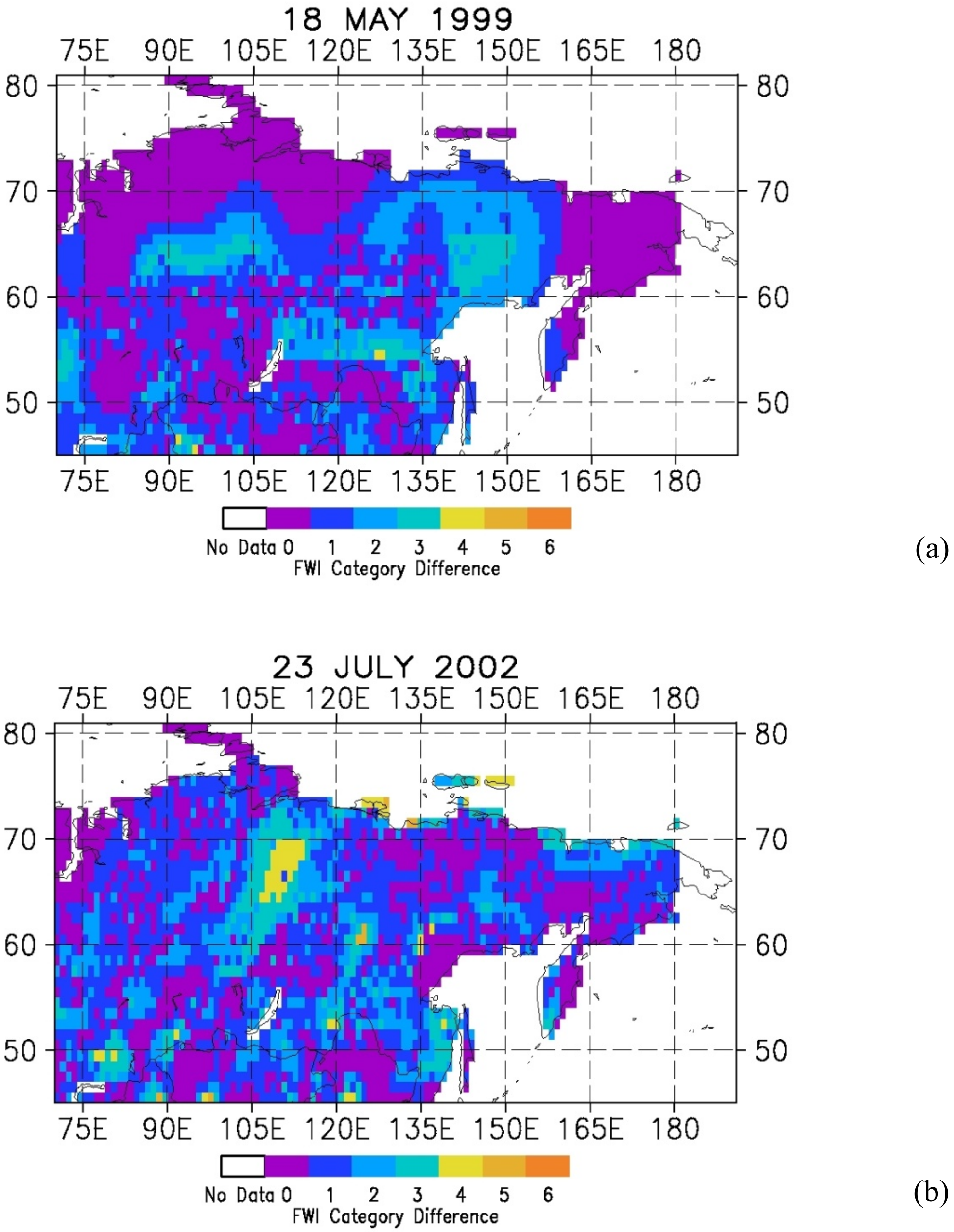


Figure 14. Difference between GEOS-4-reanalysis and NCDC-interpolated FWI for (a) 18 May 1999 and (b) 23 July 2002 (category absolute error). Approximately 74% of the cells contain 1 category FWI difference or less; about 18% of the cells were 2 categories different; and around 7% of the cells were 3 categories different. Larger differences were generally found at the edges of large regions of agreement, at southern boundaries or in regions where surface stations are sparse.

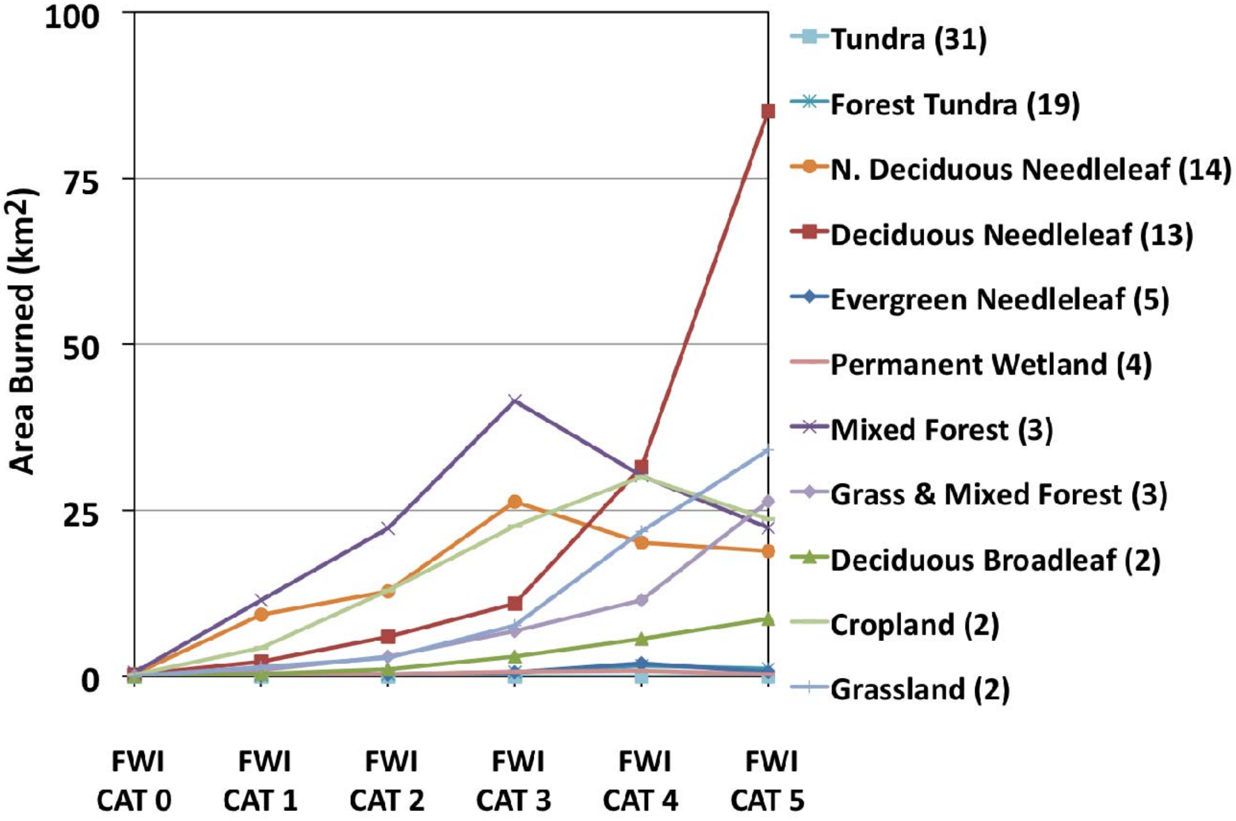


Figure 15. Mean area burned per 1° cell for all years (1999, 2002 and 2004) based on GEOS-4 data. In general, in both normal and extreme fires seasons, area burned increases with increasing FWI, although there were annual, regional and ecosystem differences that must be distinguished.

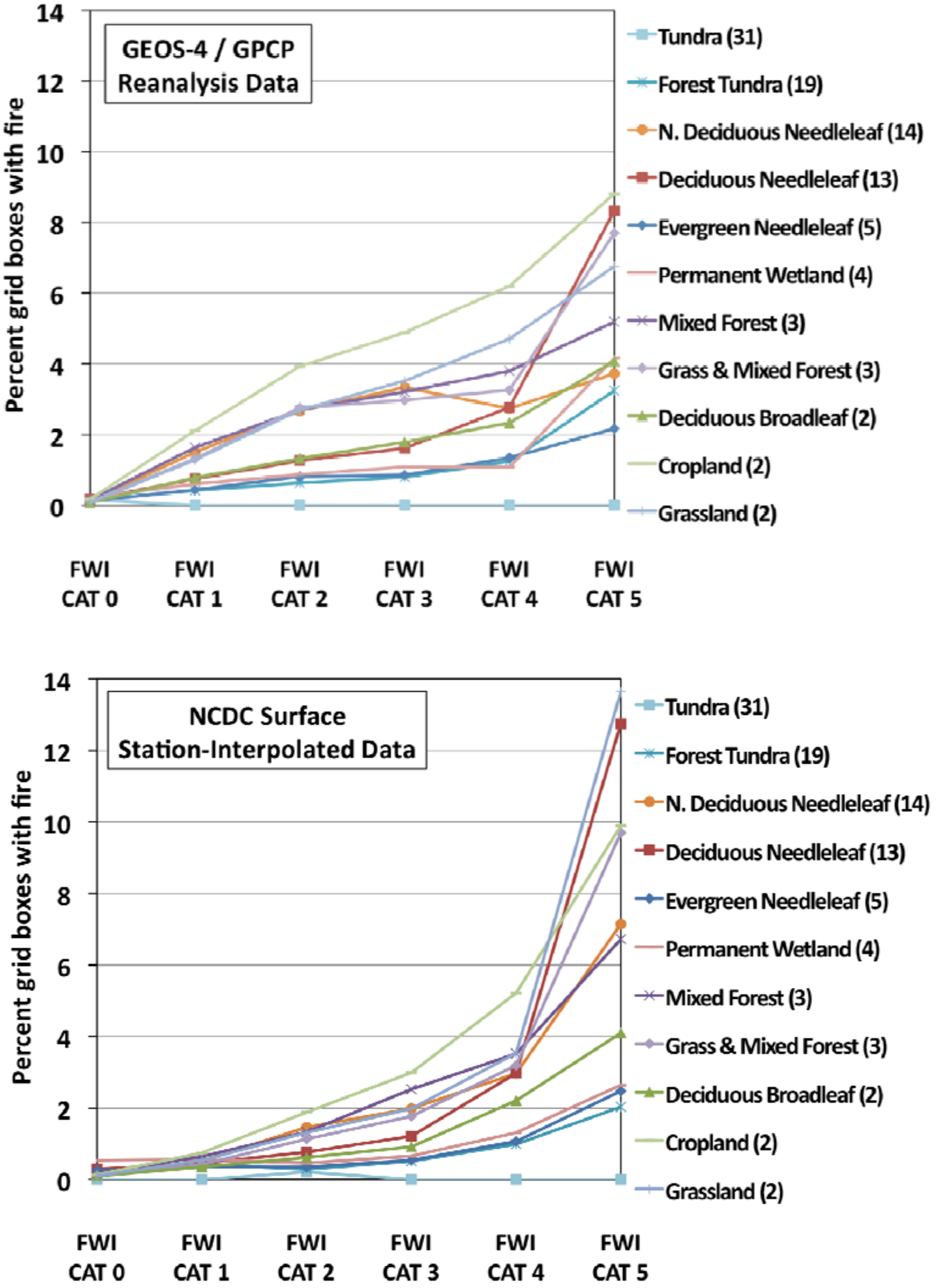


Figure 16. Mean percent grid cells that contain fire in each ecosystem for all years (1999, 2002 and 2004). The percent each ecosystem occupies within the domain is found in parentheses; the tundra holds 31% of the domain; snow, ice and closed shrublands occupy the remaining 1% but do not contain fire. Because the GEOS-4 data contain more total FWI category 5 cells, the fraction of FWI cat 5 burned was lower than the NCDC-interpolated data. This highlights the need to separate the data geographically (larger number of GEOS-4 FWI cat 5 reside at the southern boundary) and if estimating future fire, the source (of established relationships) and base (data used for estimate) FWI datasets must be consistent.

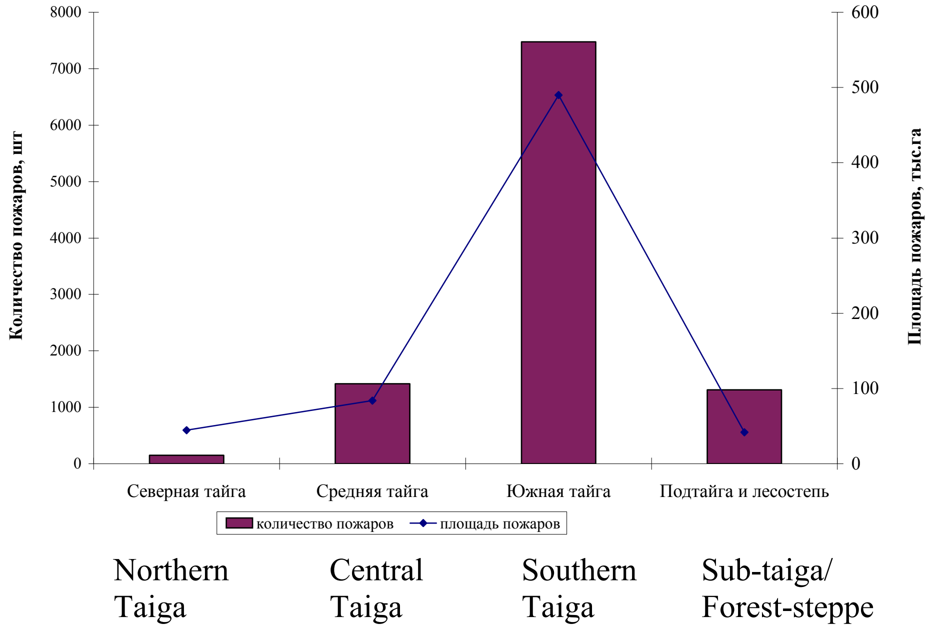


Figure 17. The largest number of fires and area burned in Krasnojarsk were located in the southern taiga [number of fires in purple (left axis); area burned in thousands of hectares – line (right axis)]. This chart was based on Avialesookrana data.

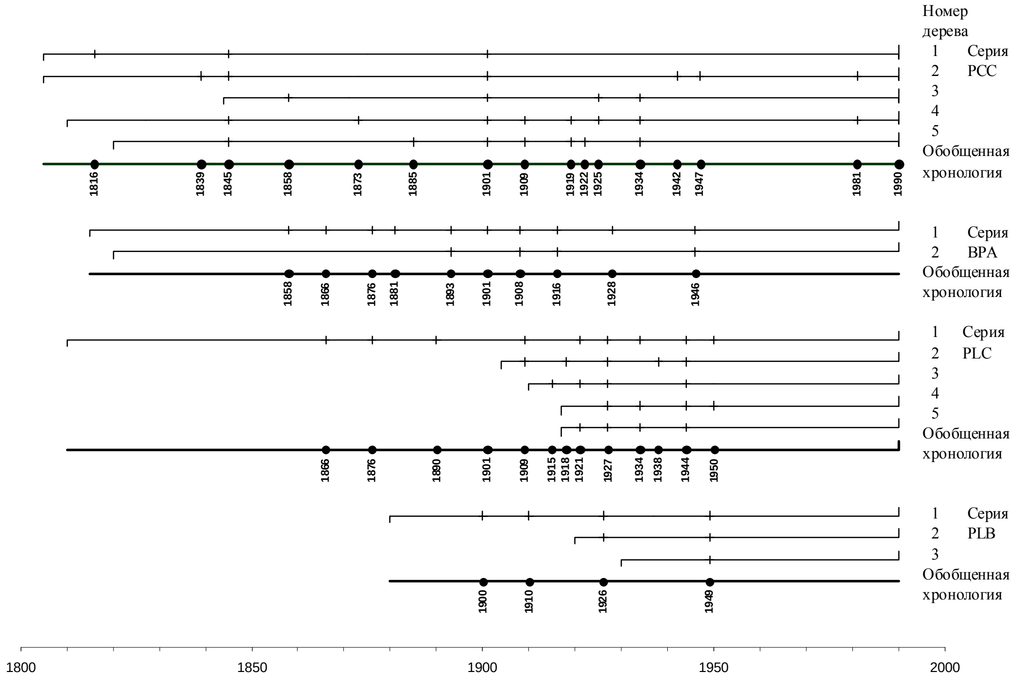
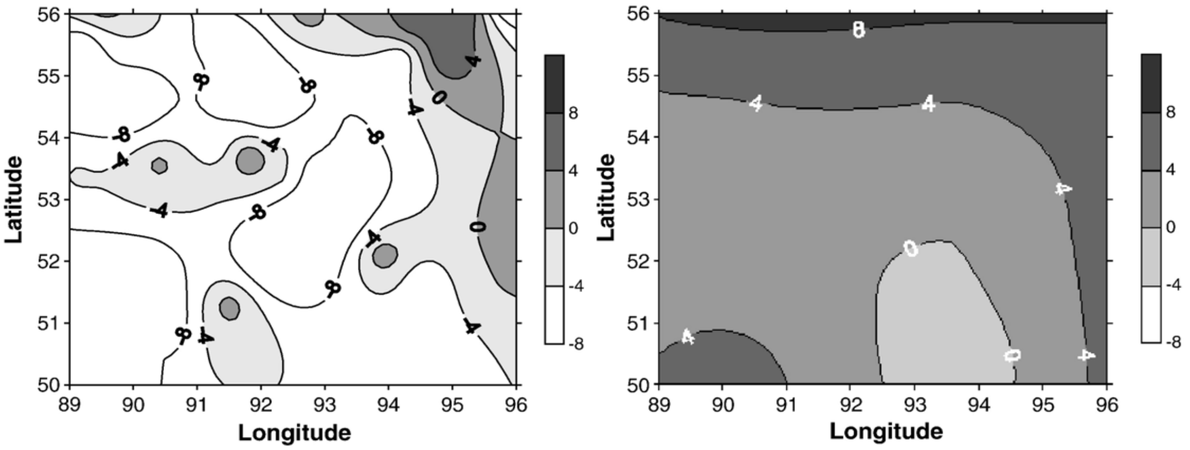
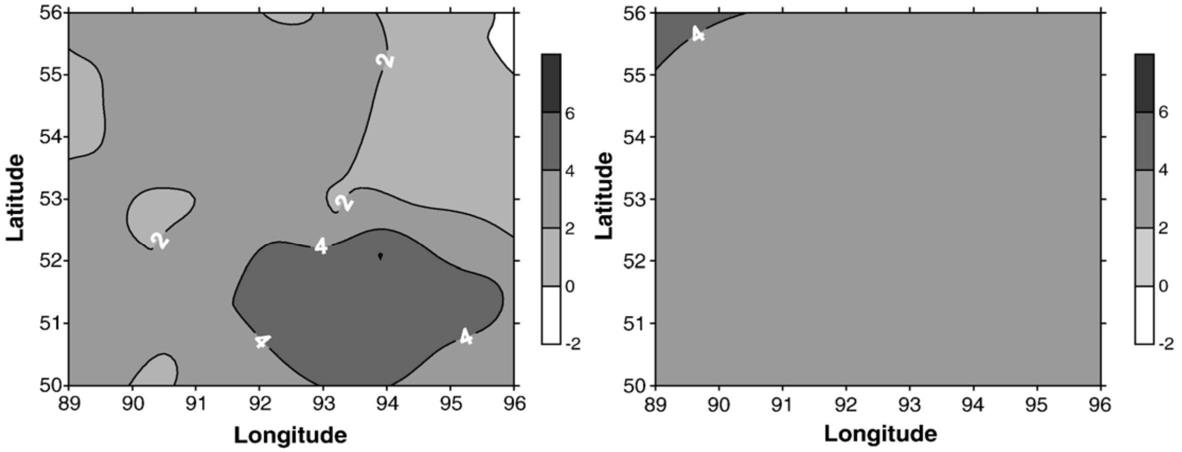


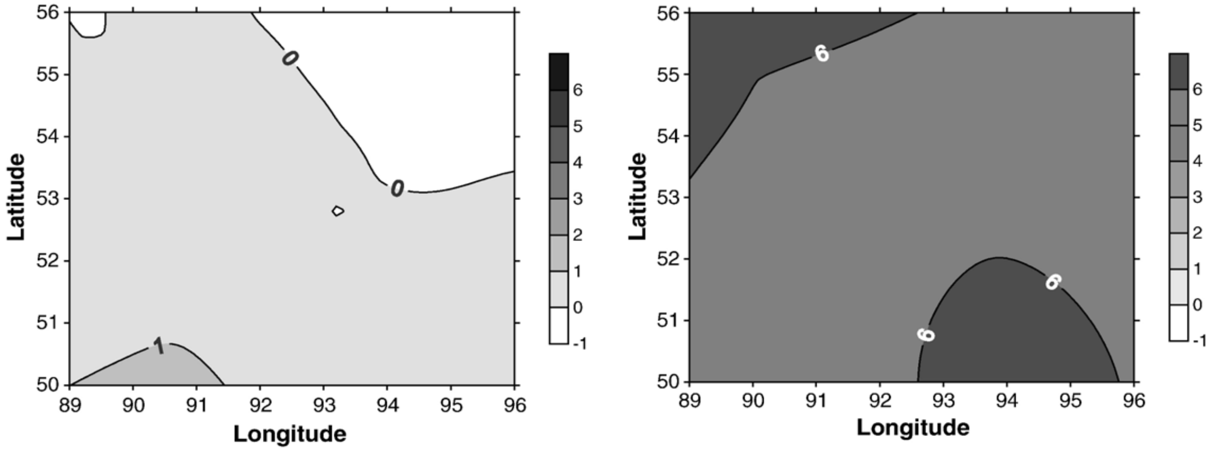
Figure 18. Detailed forest fire chronologies for *P. sylvestris* (pine) stands in southern Krasnoyarsk and Tuva show a range of Fire Return Intervals from 11 to 27.5 years (mean 14.5 years), which was lower than those typically reported (20-60 years). Surface fires that are difficult to detect from space typically dominate this forest type (short-lived, low flame height).



Annual precipitation (%)



January temperature (°C)



July temperature (°C)

Figure 19. Climate change in the Sayan Mountains: observations from 1980–2000 (left) and predicted (right) by a Hadley Centre scenario (HadCM3GGa1) for 2090. Winter temperatures have already exceeded 2090 model estimates, while summer temperatures have not. Patterns of precipitation are currently difficult to predict, particularly at the GCM scale (Soja et al., 2007).

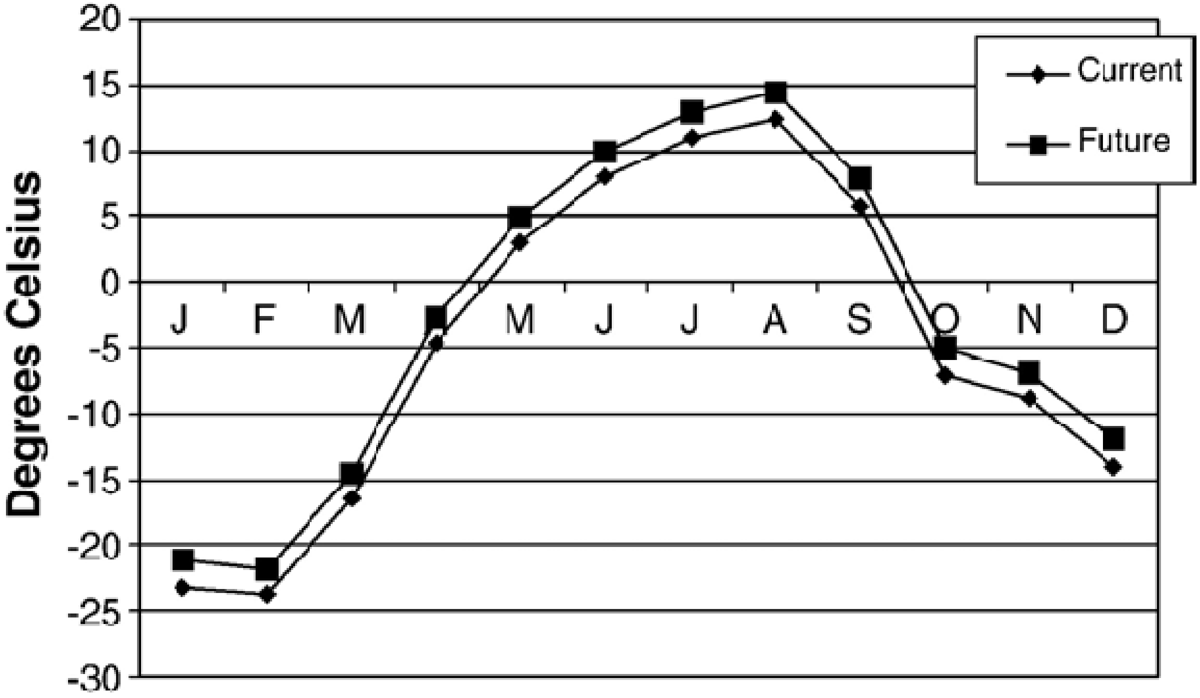


Figure 20. Mean monthly temperatures recorded from the Davsha, Siberia station and projected mean monthly temperatures from a 2 °C warmer scenario. Monthly temperatures cross the 5 °C threshold twice, once in the spring and once in the fall. The warm days between these dates were used to determine long-term Growing Season length (GS). Even though GS is a function of temperature in all months, the GS can be approximated using January minimum and July maximum temperatures (positive degree days, L_5 — days with continuous temperature above 5°C calculated from the formula found for 145 stations located throughout Siberia; L=25.3+1.14(TW)+7.85(TS), R2=0.96, std err 5.6 days) or using the slope of the line, which results in an extension of the GS by 17.44 and 16.45 days, respectively, in this example. [TW—temperature of January or winter (D–J–F) months; TS—temperature of July or summer (J–J–A) months]

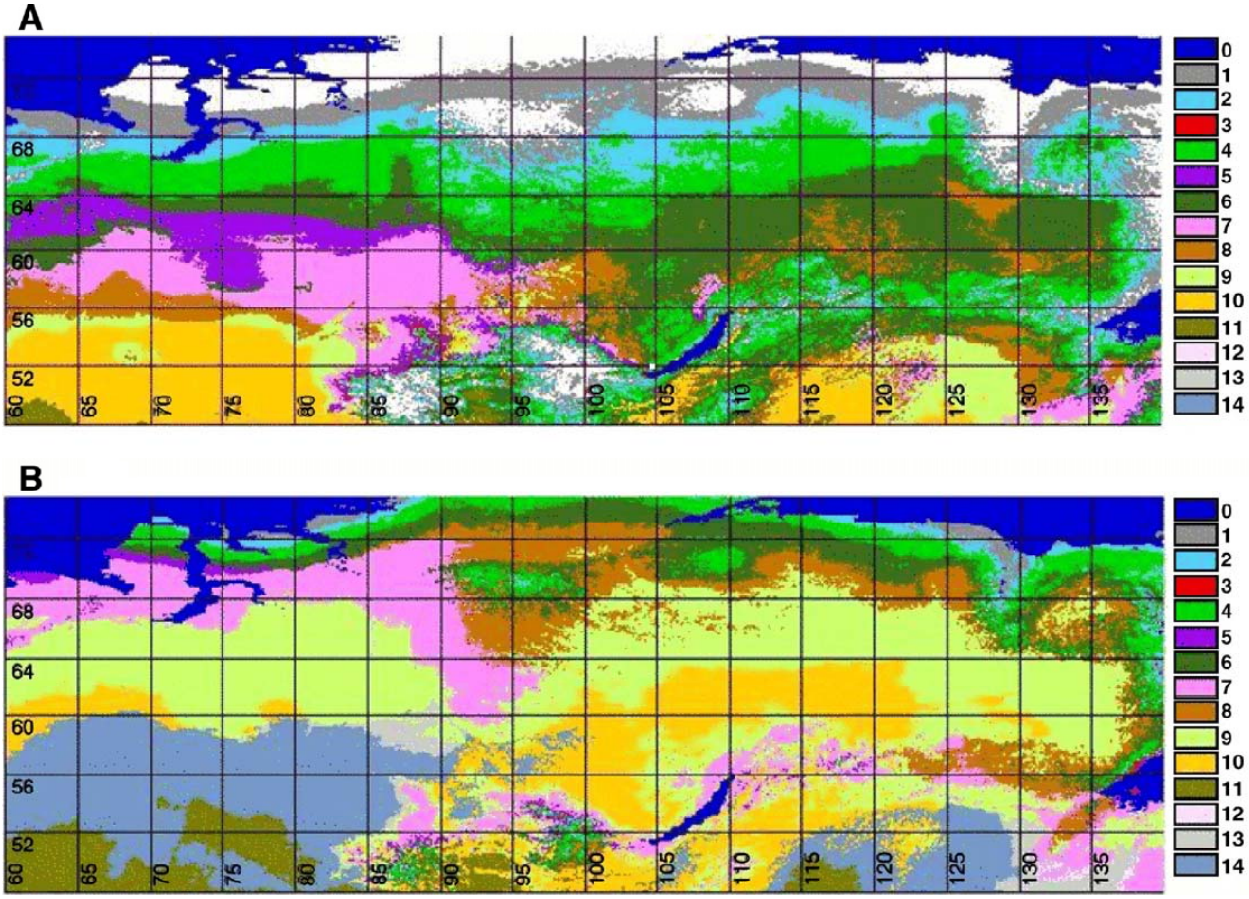
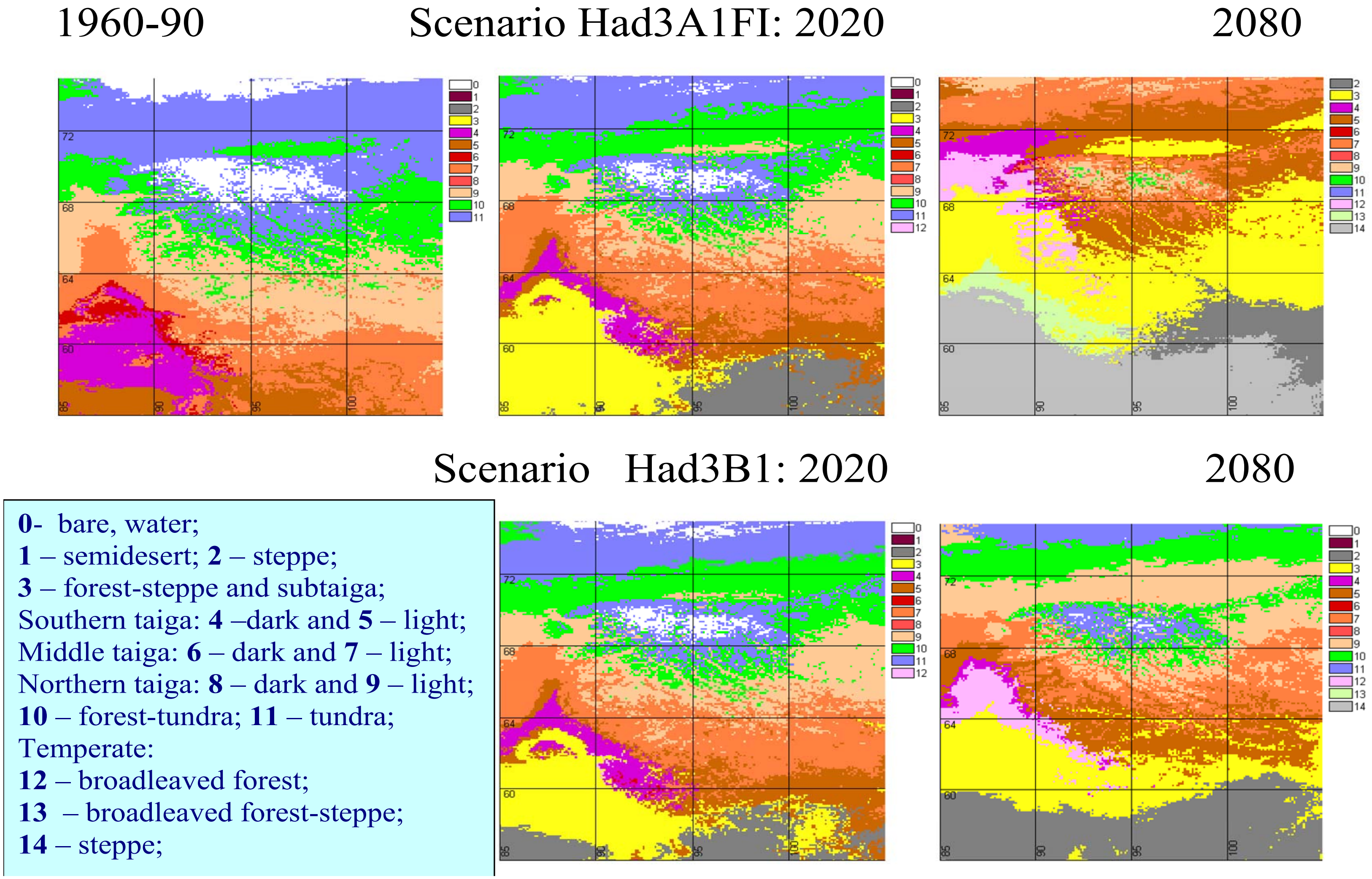


Figure 21. Vegetation distribution in Siberia: (A) current and (B) future (2100) based on a Hadley scenario (HadCM3GGal) (IPCC, 1996). Water (0); tundra (1); forest–tundra (2); northern dark taiga (3) and light taiga (4); middle dark taiga (5) and light taiga (6); southern dark taiga (7) and light taiga (8); forest–steppe (9); steppe (10); semi-desert (11); broadleaved (12); temperate forest steppe (13) and temperate steppe (14).

These data first demonstrate the models capability by modeling “current” vegetation distribution and then potential vegetation change under climate change scenarios. The largest potential decrease in particular ecosystems were estimated in the tundra (-93%) and forest tundra (-87%), and the largest potential ecosystem increases were estimated in the steppe (27%) forest steppe (5 fold) and temperate biomes (30 fold) (Soja et al., 2007)..

On the following page (Figure 22), we focus on central Siberia using 2 distinct Special Report on Emissions Scenarios (SRES). We modeled the A1 and B1 scenarios, because they reflect opposite ends of the SRES range. The largest temperature increase was simulated from the A1FI scenario (rapid economic growth, no CO_2 stabilization and a mean global temperatures increase of 4.5°C) and the smallest temperature increase was simulated using the B1 scenario (CO_2 stabilization at 550 ppm and a mean global temperature increase of 2.0 °C).

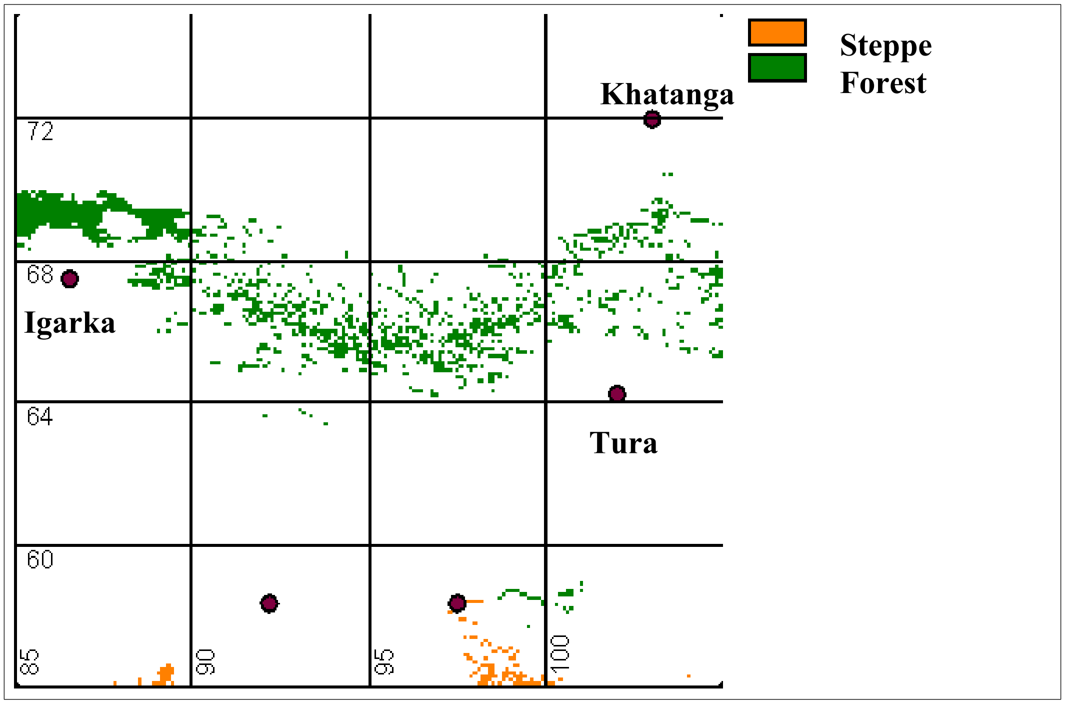

1960-90 Scenario Had3A1FI: 2020 2080

Scenario Had3B1: 2020 2080

0- bare, water;
1 – semidesert; **2** – steppe;
3 – forest-steppe and subtaiga;
Southern taiga: **4** –dark and **5** – light;
Middle taiga: **6** – dark and **7** – light;
Northern taiga: **8** – dark and **9** – light;
10 – forest-tundra; **11** – tundra;
Temperate:
12 – broadleaved forest;
13 – broadleaved forest-steppe;
14 – steppe;

Figure 22. Vegetation distribution modeled using two unique Hadley Centre scenarios (see bottom page 10). With these vegetation distribution maps, we focused on the regions that were likely to experience the first effects of climate change.

Northern Plateaus



Southern Mountains

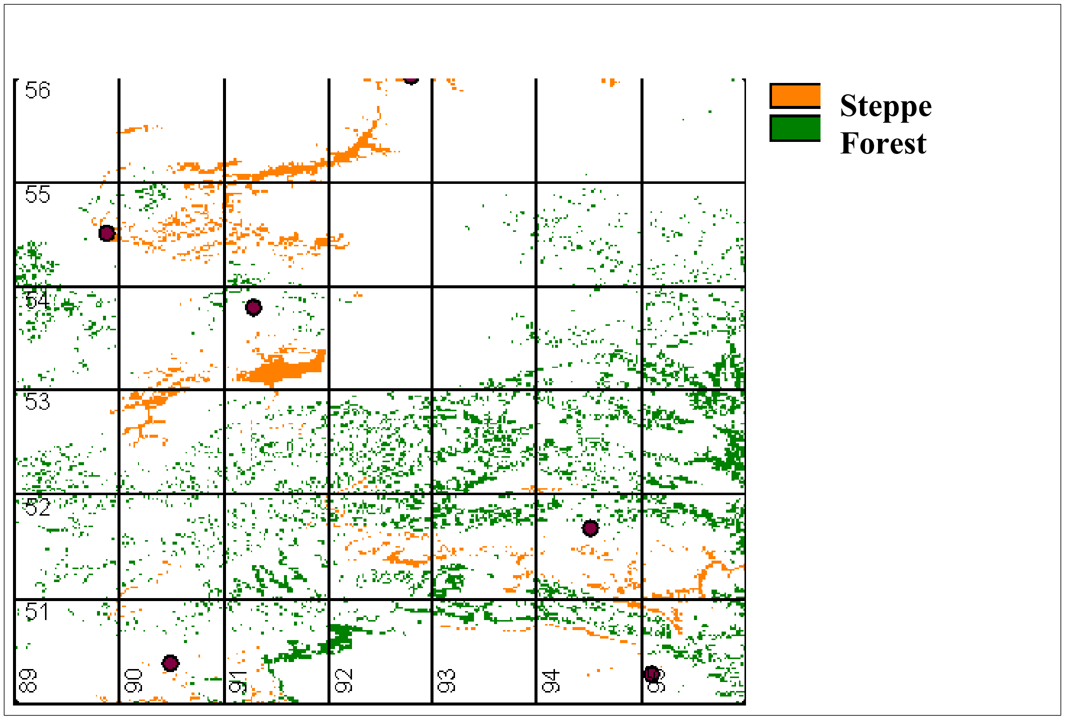


Figure 23. Modeled “Hot Spots” of potential steppe and forest change in central Siberia. These are the regions where climate-, fire-induced land cover change is expected to be first evident.

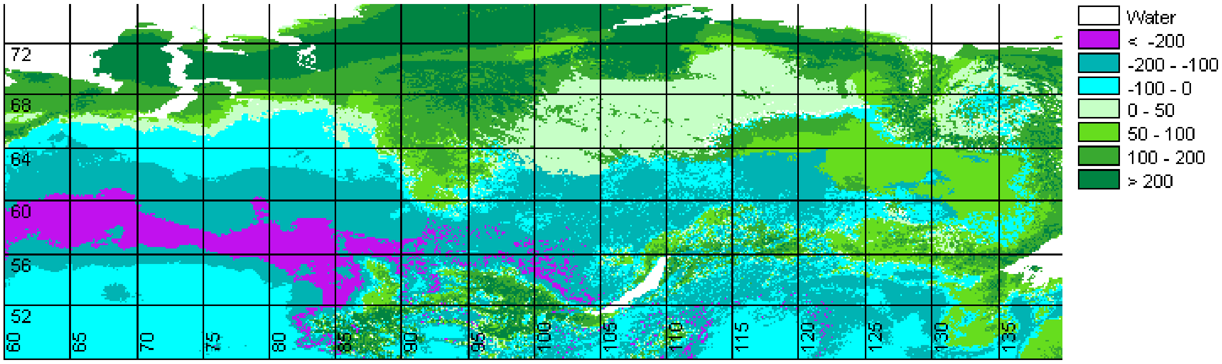


Figure 24. Results from the Siberian bioclimatic model that estimate potential phytomass (biomass) change in tons per hectare caused by fire- and climate-induced land cover change by 2090.

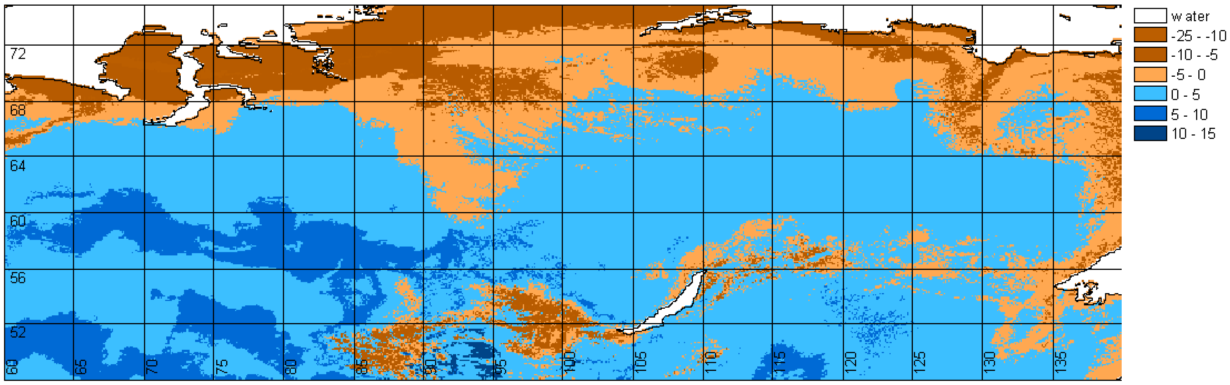
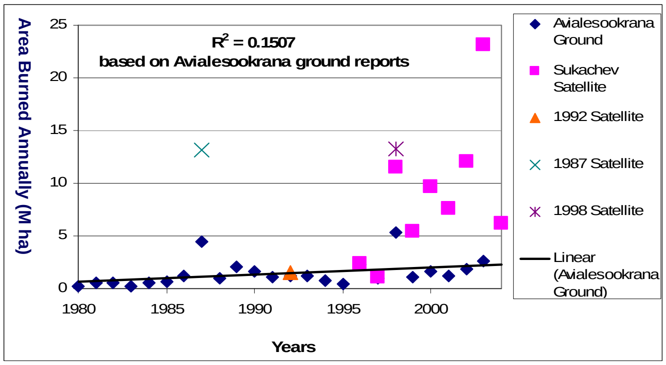
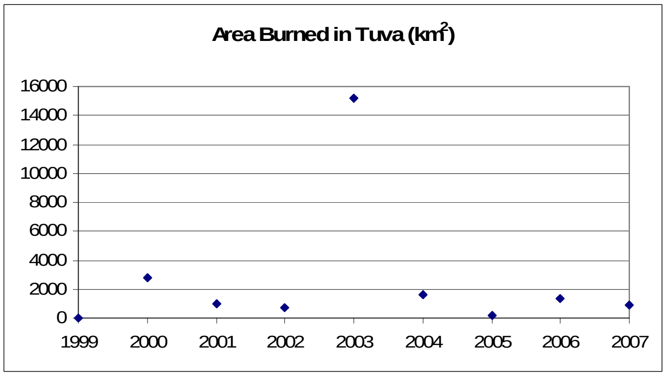


Figure 25. Albedo change (2090) due to vegetation change estimated by the Siberian bioclimatic model. According to this modeled scenario, overall summer albedo would increase in Siberia by 1.2%, resulting in a net cooling effect. Summer albedo would increase over 72% of the area in southern and middle latitudes due to dark forest retreat and species shifts. In the northern latitudes and highlands, tundra would be replaced by forest, which results in a decrease in albedo of 28% of the area contained in these regions.

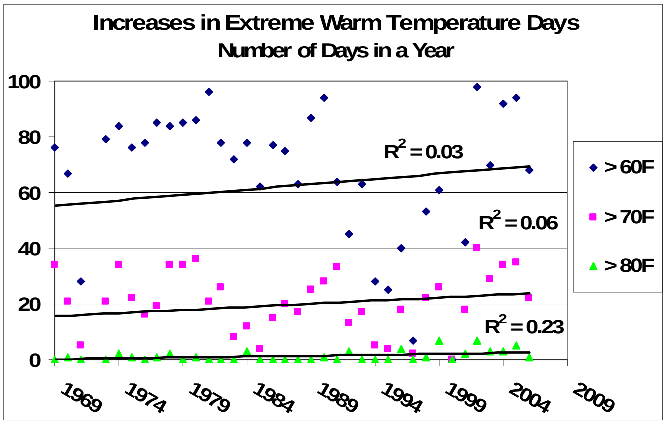


26a. Area burned in Siberia.

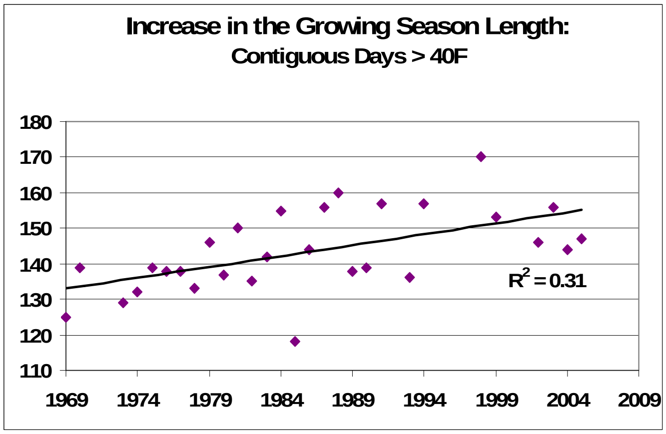


26b. Area burned in Tyva.

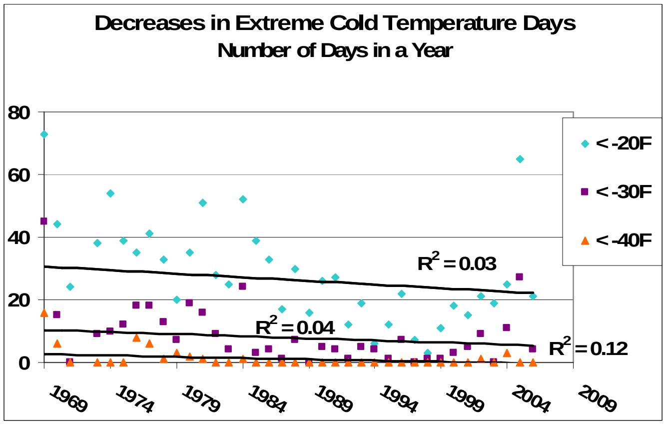
Even though extreme fire events were increasing across Siberia, it was not evident that they were increasing in the Tuvan Republic. However, it has been reported that the relic *P. sylvestris* forests that have existed since the last ice age (~5000-8000 years BCE) were burning and not regenerating in Tuva.



26c. Increase in extreme warm temperatures.



26d. Increase in Growing Season days.



26e. Decrease in extreme cold temperatures.

Figure 26. Figures 26c though 26f were based on weather data taken from a ground station in Kyzyl, Tyva, however these relationships were consistent with other stations across Tyva. It appears the forests were getting a one-two punch, first from the fire and then weather, which was increasingly warmer and dryer and not conducive for seedling/sapling regeneration.

Publication History

Citations in the Press

August 2009, Nadezda Tchebakova and Amber Soja were interviewed by phone in Krasnojarsk Russia by AP news, which resulted in an on-line publication.

November 2007, Amber Soja was interviewed for an article that was published in the Christian Science Monitor: http://www.csmonitor.com/2007/1101/p13s02-usgn.html?page=1

January 2007, Nadezda Tchebakova was interviewed by a local Siberian radio station on global climate warming and consequences for the biosphere.

Fall 2006, A. Soja interviewed on National Public Radio's Earth and Sky, hosted by Deborah Byrd, Joel Block and Jorge Salazar, *Expert says northern forests affected by warming.* The show aired on several occasions, beginning on September 11, 2006. The show is available upon request.

July, 2006, Amber Soja and Nadezda Tchebakova were cited in an Associated Press article, *World Wildfires*, written by Charles Hanley that appeared in at least 200 newspapers worldwide (released for Saturday and Sunday news). Article available upon request.

September 27, 2006, Nadezda Tchebakova was cited in a New Scientist Print Edition article, *One degree and we're done for,* written by Fred Pearce after attending the "International Symposium: Environmental change in Siberia" conference held in Leicester, United Kingdom. http://www.newscientist.com/article.ns?id=mg19125713.300

September 2006, Nadezda Tchebakova was invited to appear on local television to discuss issues of climate change in Krasnojarsk, Siberia.

Awards

We won the National Institute of Aerospace Best Research Publication award for the Global and Planetary Change manuscript *Climate-induced boreal forest change: Predictions versus current observations*, Soja, Tchebakova et al. 2007, listed below.

Professional Service

Soja reviewed an average of 2 manuscripts per month and Tchebakova several per year.

Soja Guest Editor for the Northern Eurasian Earth Science Partnership Initiative special issue in Environmental Research Letters (http://iopscience.iop.org/1748-9326/4/4/045002) 2009/2010.

Soja co-chair with Pavel Groisman; Ongoing climatic changes in Northern Eurasia: Why they force us to be expedient in our research; EGU General Assembly 2010

Soja Participated in the Copenhagen negotiations (Dec. 7-18, 2009) on-line by answering questions about the science of climate change, which were submitted by hundreds of journalists.

Soja Chair ARCTAS session A41E. Composition of the Arctic Atmosphere: Sources, Transport, Chemistry, and Impacts on Clouds and Climate V, Oral session AGU Fall 2009

Soja Chair, A42D Wildland Fire Emissions in Chemical Transport Models: Improving Input Resolution, Poster and Oral sessions AGU Fall 2009.

Soja spoke and served on a 'Women in Science and Engineering' panel at Hampton University July 2009.

Soja Guest Editor for the Northern Eurasian Earth Science Partnership Initiative special issue in Environmental Research Letters (http://www.iop.org/EJ/journal/erl) 2007.

Soja participated in My NASA Data Workshop for Teachers, NASA LaRC, June 26, 2008, Presentation - Fire, Weather, Climate and Vegetation Change, Stackhouse and Soja.

Soja invited speaker at the President's Bay Ridge Club Annual Meeting; Northern Neck Insurance Company.

Manuscript Publications

Ivanova G.A., Ivanov V.A., Kukavskaya E.A., Soja A.J., 2010. Forest Fire Frequency in Scots Pine Stands of Tuva, Russia. *Environmental Research Letters.* №5: 015002 doi:10.1088/1748-9326/5/1/015002.

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Presentations at Conferences and Meetings

Invited Plenary and Session Talks

May 11-14 2009, Tchebakova N.M, *Seed zoning to mitigate effects of a drying climate*. Intl workshop "Forests at the limit – selective environment at the receding (xeric) edge of distribution and consequences". Sopron, Hungary.

July 14-15 2009, Tchebakova N.M., Parfenova EI, Shkolnik IM. *The use of a MGO regional climate model for assessing vegetation change in Siberia in the 21st century*. NEESPI Research Workshop devoted to Climatic, Environmental, Land Cover - Land Use Change Studies in Siberia.. Krasnoyarsk, Russia.

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