Analysis of the Ability of Large-Scale Reanalysis Data to Define Siberian Fire Danger in Preparation for Future Fire Weather

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Abstract – Wildfire is the dominant natural disturbance in boreal regions, which acts as a catalyst for regulating successional processes, under the control of weather and climate. Large-scale reanalysis and ground-station interpolated meteorological data are used to estimate local- and regional-scale fire weather for a normal and an extreme fire year. Despite the difference in spatial scales, fire weather indices compare well spatially, temporally and quantitatively (1999 r^2=0.93; 2002 r^2=0.90; 2004 r^2=0.96). The daily data are one fire weather index category or less in 74% of the cases. Cumulative and daily fire weather indices also reveal a strong relationship with the daily and seasonal amount of area burned. The ability of large-scale weather data to estimate fire weather provides confidence in the relevance of large-scale data to be used to enhance fire weather prediction in remote regions where station data are sparse and also its potential use in estimating large-scale future fire danger.

Keywords: fire weather danger, satellite, GEOS-4, Russia, climate, NCDC, biomass burning emissions.

1. INTRODUCTION

1.1 Background and Motivation

Fire is the dominant natural disturbance that maintains balance or precipitates ecosystem change in boreal regions, and fire is largely under the control of weather and climate (Van Wagner, 1978; Heinselman, 1981; Van Cleve and Viereck, 1981). Boreal regions store the largest reservoir of terrestrial carbon (Apps et al., 1993; Zoltai and Martikainen, 1996; Alexeyev and Birdsey, 1998), making their carbon cycle and related gas and aerosol contributions particularly significant. Two-thirds of the boreal forests (25% of the worlds forest) are located in Russia (Hare and Ritchie, 1972). Additionally, some of the greatest temperature increases are currently found in the Northern Eurasian winter and spring, which has led to longer growing seasons, increased potential evapotranspiration and extreme fire weather (Groisman et al., 2007). In the Siberian Sayan, winter temperatures have already exceeded 2090 Hadley Centre estimates (Soja et al., 2007).

Fire regimes (frequency, severity, area burned, season length) are predicted to increase in boreal regions under current climate change scenarios (Overpeck et al., 1990; Flannigan and Van Wagner, 1991; Wotton and Flannigan, 1993; Stocks et al., 1998; Flannigan et al., 2001). There is evidence of climate-induced change across the circumboreal in terms of increased infestations, alterations in vegetation and increased fire regimes (area burned, severity and number of extreme fire seasons) (Dale et al., 2001; Flannigan et al., 2001; Turetsky et al., 2002; Kharuk et al., 2005; Chapin et al., 2006; Soja et al., 2007). Therefore, changes in fire regimes have the potential to compel ecological change, moving ecosystems more quickly towards a new equilibrium with the climate.

Siberia is large enough that changes in fires regimes and ecosystems could feedback to the climate system by affecting the carbon balance, altering hydrologic regimes, modifying patterns of clouds and precipitation, modifying permafrost structure, altering direct and indirect emissions, and altering radiative forcings by changing albedo, both directly (i.e. land cover change) and indirectly (i.e. black carbon deposition to the Arctic) (Radke et al., 1991; Konzelmann et al., 1996; Sokolik, 2003; Kaufman and Koren, 2006; Randerson et al., 2006). We endeavor to establish relationships between historic fire weather, ecosystems and fire regimes in Siberia as necessary background training information to be used for estimating future ecosystem-specific direct fire emissions under future fire weather conditions.

1.2 Objectives

The ultimate goal of this work is to demonstrate the viability of large-scale (1°) meteorological data to define fire weather danger and fire regimes, so future fire regimes can be predicted using large-scale fire weather data, like that available from current Intergovernmental Panel on Climate Change (IPCC) climate change scenarios. In this talk, we intend to: (1) evaluate fire weather indices derived using reanalysis and interpolated-station data; (2) discuss the advantages and disadvantages of using these distinct data sources; and (3) highlight established relationships between large-scale fire weather data, area burned, active fires and ecosystems burned.

2. METHODS, RESULTS AND DISCUSSION

2.1 Methodology

Fire weather indices, which relate fuel conditions to the potential for fire, are derived using metrological variables at a large-scale (1°) and at the local-station scale. Specifically, the Canadian Forestry Service (CFS) Forest Fire Weather Index (FWI) System is derived using: NASA Goddard Earth Observing System version 4 (GEOS-4) large-scale reanalysis and NASA Global Precipitation Climatology Project (GPCP) data; and National Climatic Data Center (NCDC) surface station-interpolated data (NCDC, 2005; 2008).

The FWI System was developed over the last century by the CFS to assess daily forest conditions and the potential for forest fires (Van Wagner, 1987). The FWI system has proven its utility in numerous ecosystems and has been officially used in Alaska since 1992, although non-forested ecosystems (i.e. grasslands) offer unique challenges (Stocks and Street, 1982; Harrington et al., 1983; Alexander and Groot, 1988; Flannigan and Harrington, 1988; Fogarty and Alexander, 1999; Alexander and Cole., 2001; Amiro et al., 2004). Requirements of the FWI are local noon surface-level air temperature, relative humidity, wind speed, and daily (noon-noon) rainfall. The fire danger class scale is shown in Table A.

Table A

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

FWI results are compared both spatially and temporally at a district (Jakutia), territory (Republic of Sakha) and regional scale for two fire seasons, one representing a normal fire year (1999) and the other an extreme fire year (2002). Each of these datasets is compared over time to a satellite-derived large fire dataset (Soja et al., 2004b; Sukhinin et al., 2004).

2.1 Jakutian and Sakhan Assessment

The area that was burned during the 1999 and 2002 fire seasons in Sakha is shown in Figure 1. Area burned in Sakha in 1999 is just less than 0.8 million hectares (Mha) and greater than 5.0 Mha in 2002 (10-year mean 1998-2007 1.2 M ha). In 2002, the fires burned the entire fire season, and they burned deeply into the soils of this continuous permafrost zone, releasing large amounts of biomass burning emissions, particularly when combustion was less efficient due to the moist permafrost-lain surface (Soja et al., 2004a).

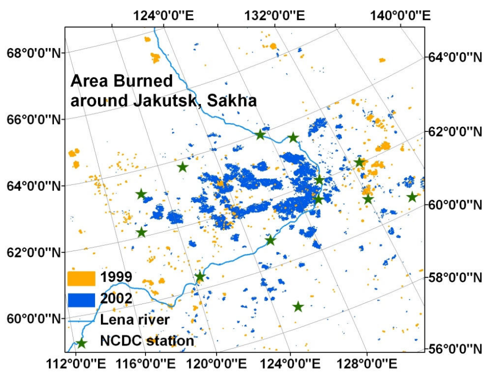

Figure 1. Area burned in Sakha in 1999 and 2002 demonstrating the difference in a normal and an extreme fire year.

Cumulative FWI for one station (Jakutsk) are compared in Figure 2, and the NCDC FWI are consistently higher at this station in both 1999 and 2002. However, overall the NCDC and GEOS FWI compare well.

FWI for the Republic of Sakha are compared in Figure 3. The meteorological stations used for this comparison are shown in Figure 1. The NCDC- and GEOS-derived FWI track well (r^2 = 0.69 in 1999 and 0.80 in 2002) over time in Sakha in both the normal and extreme fire years (Figures 2 and 30 even though the total accumulated precipitation at Jakutsk from March-October differs substantially (1999: GPCP 275.2 mm, station 316.738 mm; 2002: GPCP 178.42 mm, station 130.302 mm). The duration of rainfall events and temperature strongly control FWI. The regional-scale NCDC data tend to be slightly larger than the GEOS FWI in the early and late season, however the GEOS data tends to be larger during most of the fire season.

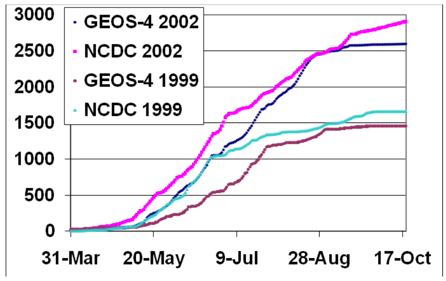

Figure 2. Cumulative FWI for the Jakutsk NCDC station and the coincident GEOS-4 1-degree cell.

Increased daily area burned also tracks well with the FWI shown in Figure 3. In general, the fires do not become large (> 1400 km^2) until FWI values are above 20 and typically sustained above 20. Area burned daily continues to increase as FWI values increase, particularly when they reach above 30 and are sustained above 30. The fires continue to burn and smoulder throughout the 2002 fire season, acting to dry nearby and underlying soils; these smouldering fires are primed to flare as FWI increase.

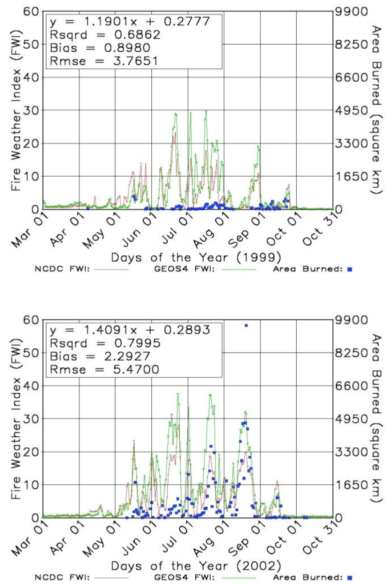

Figure 3. FWI time series for the Republic of Sakha for 1999 (a) and 2002 (b), highlighting the similarity between regional NCDC station- and GEOS/GPCP-derived FWI.

Regional mean FWI values do not register above 30 in 1999 and are not sustained above 20. In contrast, FWI values above 20 are sustained in 2002 and are often greater than 30. FWI are overlaid with daily area burned in 1999 and 2002.

2.1 Northern Eurasian Assessment

In general, the daily patterns of GEOS-4 reanalysis and NCDC interpolated FWI are remarkably similar, as shown in Figure 4. Complete daily and monthly data and movies are available for viewing on-line at http://www.nianet.org/soja/. Increasing FWI values coincide well with increasing fire activity. The influence of weather and climate on the fire season is apparent as the larger FWI categories move north and south in sync with summertime seasonal warming and cooling.

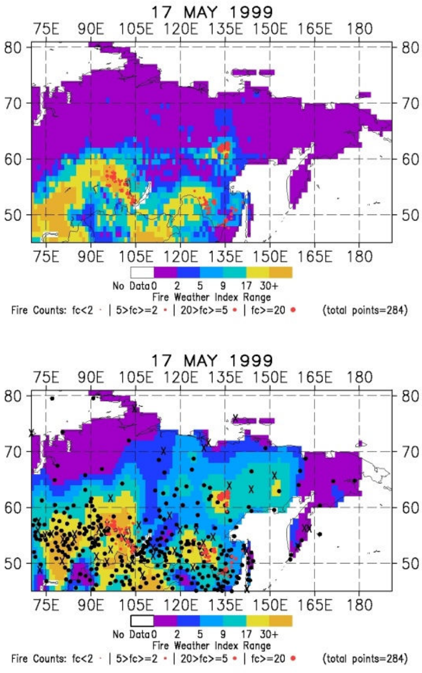

Figure 4. Spatial comparison of GEOS4/GPCP- and NCDC station-interpolated FWI in the upper and lower panels, respectively. The black dots are station locations, and the Xs represent stations that did not meet the reporting criteria (75% of observations per day; and 60% of the days per month). In the domain shown here, there are 648 stations and 232 do not meet the criteria. Fires are shown in red.

Daily FWI values are in broad agreement spatially over time and the data are also in general quantitative agreement. The overall mean daily datasets compare well in every year analyzed, however mean daily NCDC-derived FWI are typically larger than GEOS-4 FWI, as shown in figure 5. This relationship is consistent in 2002 and 2004, as well. The greatest differences between the GEOS-4- and NCDC-based products are found during the peak of the fire season (~June 1st–August 15th). Even then, approximately 74% of the cells contain 1 FWI category difference or less (~18% of the cells contain 2 categories difference; ~7% contain 3 categories difference); examples are shown in Figure 6. The largest differences are generally found at the transition zones between large regions of agreement, at southern boundaries and in regions where surface stations are sparse.

The NCDC FWI register a greater number of low, moderate and high fire danger classes (categories 1-3), while the GEOS-4 FWI remain very low (category 0). These larger NCDC-interpolated FWI are spatially expansive and are typically driven by the limited number of northern stations, some of which do not meet the75/60% reporting criteria. On the other hand, the GEOS-4 FWI register a greater number of very high and extreme fire danger classes, which are often located at the southern boundary where temperatures are typically high and there are a large number of ground-based stations. The FWI System was developed for the cooler boreal forest, as opposed to hot steppe ecosystems, so accuracy should be optimized in regions similar to those where the index was developed. On the majority of days, both FWI capture the large patterns of fire.

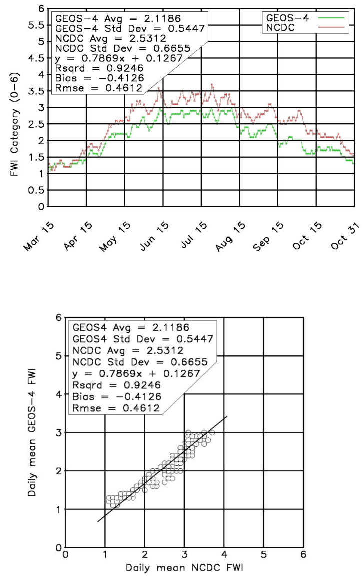

Figure 5. Daily time series of the mean domain GEOS-4-reanalysis and NCDC-interpolated FWI for 1999 (upper panel): and a scatter plot from 1999 comparing the data (lower panel). The GEOS-4 and NCDC FWI correlate well spatially and temporally resulting in overall R^2 values of 0.93 in 1999, 0.90 in 2002 and 0.96 in 2004.

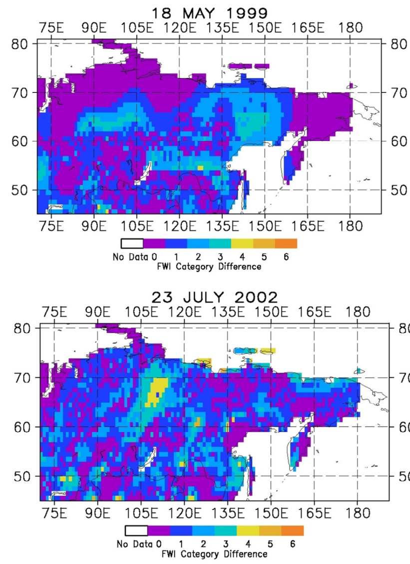

Figure 6. Difference between GEOS-4-reanalysis and NCDC-interpolated FWI for 18 May 1999 and 23 July 2002 (category absolute error).

Small FWI values dominate at the beginning and end of the fire seasons, and the larger FWI values dominate in the middle of the fire season. However, very high and extreme fire danger values dominate and persist during extreme fire seasons, which highlights the relationship between presistently stable high pressure weather conditions and extreme fire seasons. Figure 7 shows mean daily area burned increases with increasing FWI values.

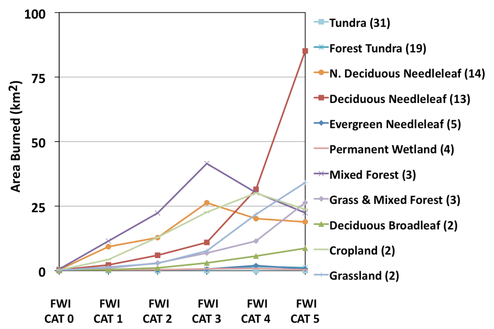

Figure 7. Mean area burned per 1° cell for all years (1999, 2002 and 2004) based on GEOS-4 data. In general, in both normal and extreme fires seasons, area burned increases with increasing FWI, although there are annual, regional and ecosystem differences.

Consistent patterns of burning in unique ecosystems exist between the GEOS-4 and NCDC data, however the actual percent of active fires within each ecosystem and FWI category differs depending on the base data (Figure 8). For instance, grasslands occupy 2% of the geographic domain, and according to the GEOS-4 data, 8.8% of the grassland cells in FWI category 5 contain fire (NCDC 9.8%). The reason for this is the total number of FWI categories differ. For instance, there are more FWI category 5 contained in the GEOS-4 domain, hence a smaller fraction active, and these are primarily located at the southern boundary of Siberia. This emphasizes the necessity of: using the same foundation of "baseline" data to establish the relationships that will be used in future assessments; and more detailed assessment of distinct geographic regions.

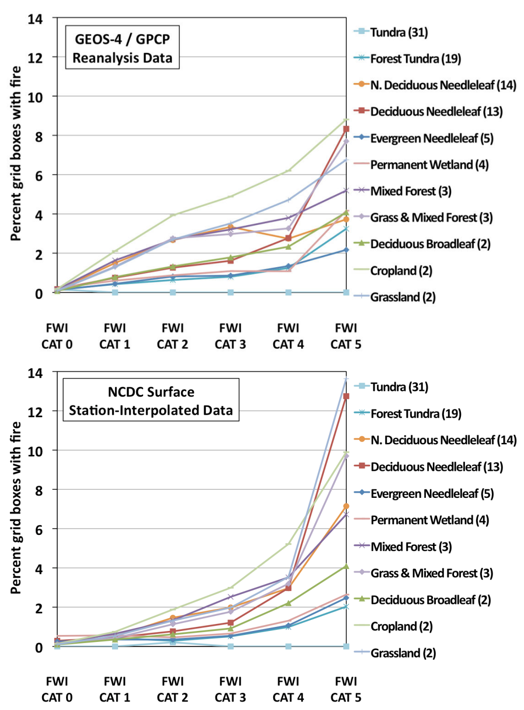

Figure 8. Mean percent grid cells that contain fire in each ecosystem for all years (1999, 2002 and 2004). The percent each ecosystem occupies within the domain is found in parentheses; the tundra holds 31% of the domain.

3. CONCLUSIONS

Daily and cumulative weather variables control relative fire danger by providing the environment necessary for converting potential fuel to available fuel. At a local scale, there is an historic understanding of the relationship between meteorological variables and the potential for increased fire danger, however the capacity for using large-scale meteorological variables to estimate specific fire weather indices, fire regimes and fire danger has not been fully explored or quantified.

Station data are better able to estimate fire weather and danger at a local scale. However, in remote Siberia, stations are spatially distant, so the reanalysis data could be used to enhance the current prediction of fire danger potential in remote locations. Additionally, Northern Eurasian station data are often inaccurate or missing, and the missing data are not likely to be random in space and time. Moreover, there has been a declining number of Russian surface observation stations from 1990 through the present. Reanalysis data are spatially and temporally consistent making it easily portable to multiple data applications or models. However, reanalysis data, which relies on assimilation of satellite and other datasets, are maturing, while the surface station data are historically available (some stations as early as 1920).

GEOS-4 reanalysis and NCDC station-interpolated fire weather indices are generally consistent spatially, temporally and quantitatively. Despite the 1-degree spatial scale, the GEOS-4 reanalysis data are able to accurately assess fire weather and danger at district, territory and regional scales.

Increased fire activity coincides with increased FWIs in both data products, but there are interannual, regional and ecosystem-dependent differences that require consideration in future applications. Relationships can be established that link large-scale fire weather to fire frequency, the fraction of cells burned and the amount of area burned in individual ecosystems, and these can be use to estimate historic and future fire regimes.

Most importantly, large-scale weather data can be used to accurately assess fire weather at local and regional scales, which has implications for its ability to quantify future fire potential. The capability of GEOS-4 weather parameters to accurately estimate fire weather provides support for the potential ability of larger-scale data to predict future fire weather using large-scale predictions, such as those from IPCC weather and climate change scenarios.

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