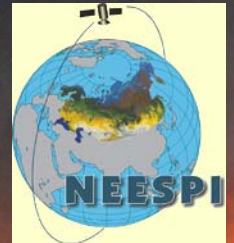


Fire and Climate Interactions in the Boreal Zone



Amber J. Soja with donations from Nadezda M. Tchebakova, Brian Stocks, Susan G. Conard, Anatoly I. Sukhinin, Douglas J. McRae, Paul W. Stackhouse Jr., Pavel Ya. Groisman, Tatiana V. Loboda, and Ivan A. Csiszar

Land Cover Land Use Change, 2007

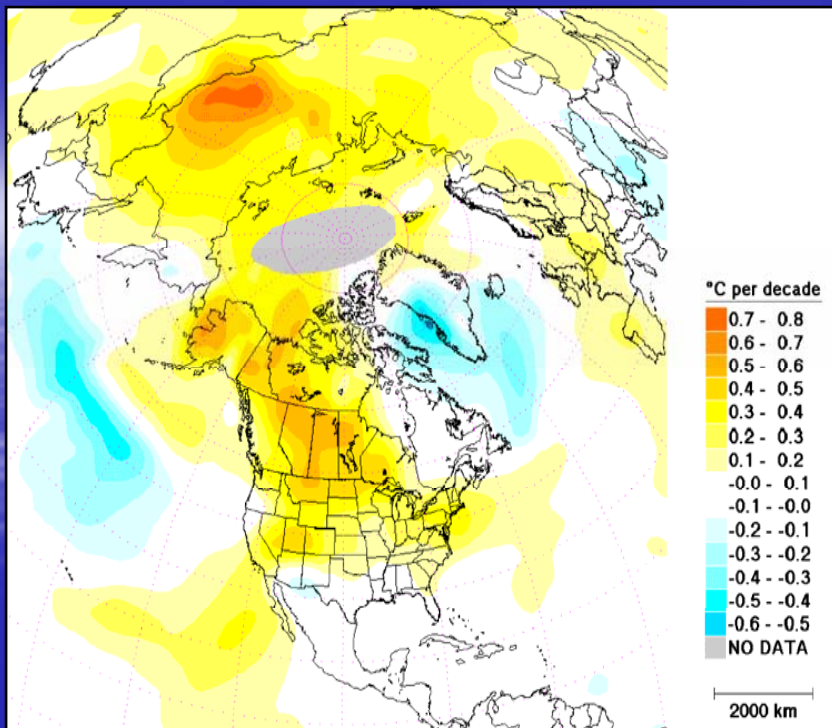
Photo courtesy of
Brian Stocks



Why are Russian boreal ecosystems important?

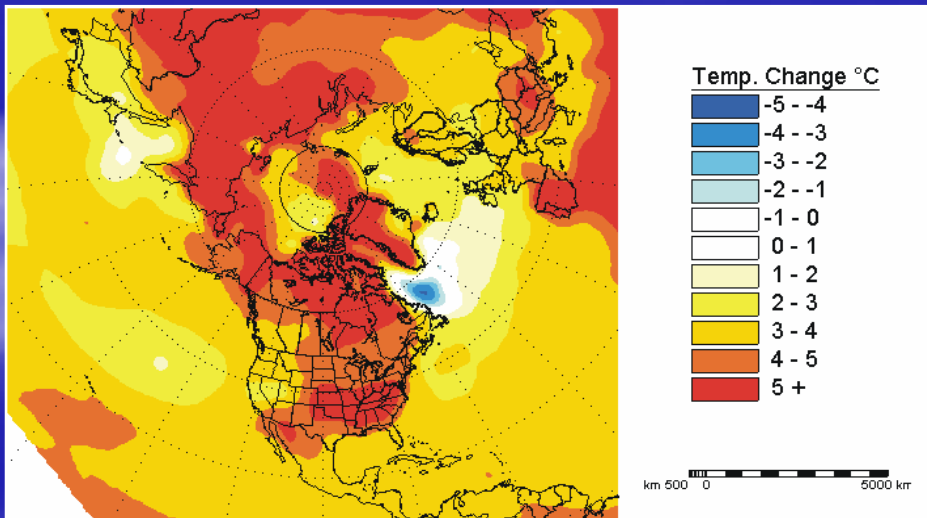
- ❖ The largest temperature increases are predicted to occur in northern hemisphere upper latitudes (Cubash et al., 2001).
- ❖ The greatest temperature increases are currently found in the cold, dry air masses over central Siberia (Balling et al., 1998).
- ❖ Boreal forests hold the largest reservoir of terrestrial carbon (Apps et al., 1993; Zoltai and Martikainen, 1996; Alexeyev and Birdey, 1998).
- ❖ Two-thirds of the boreal forest are located in Russia (25% of the world's forest).

Climate Change Realities and Projections

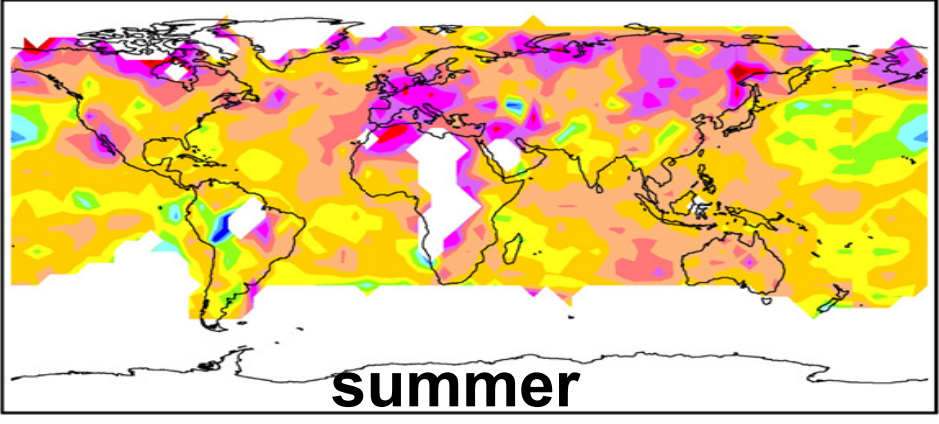
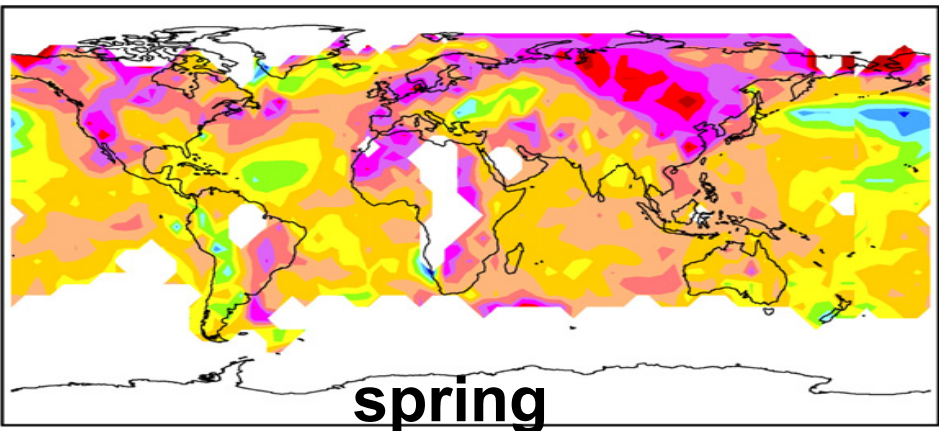
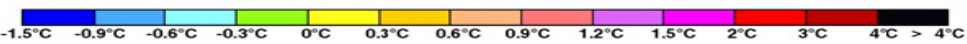
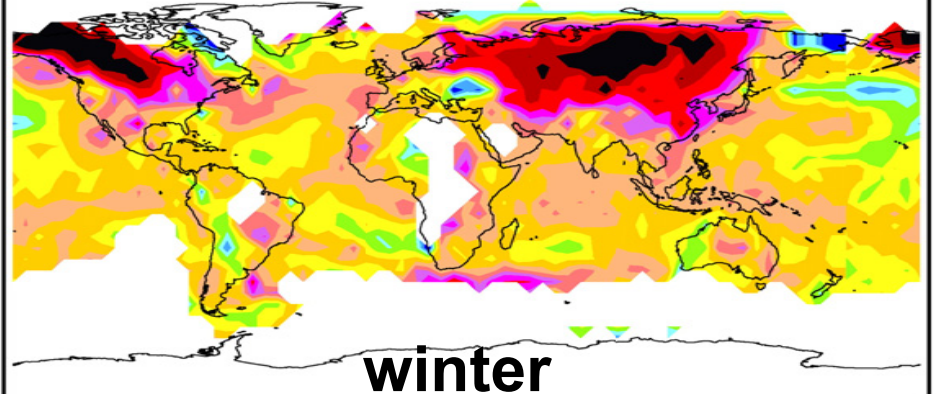


Observations above – summer temperature

- GCMs project 1.4 – 5.8^o C increase in global mean temperature by 2100
- Observed increases across west-central Canada and Siberia over past 40 years
- Greatest increases will be at high latitudes, over land and winter/spring
- Projected increases in extreme weather and extreme fire weather



Predicted changes 2080-2100



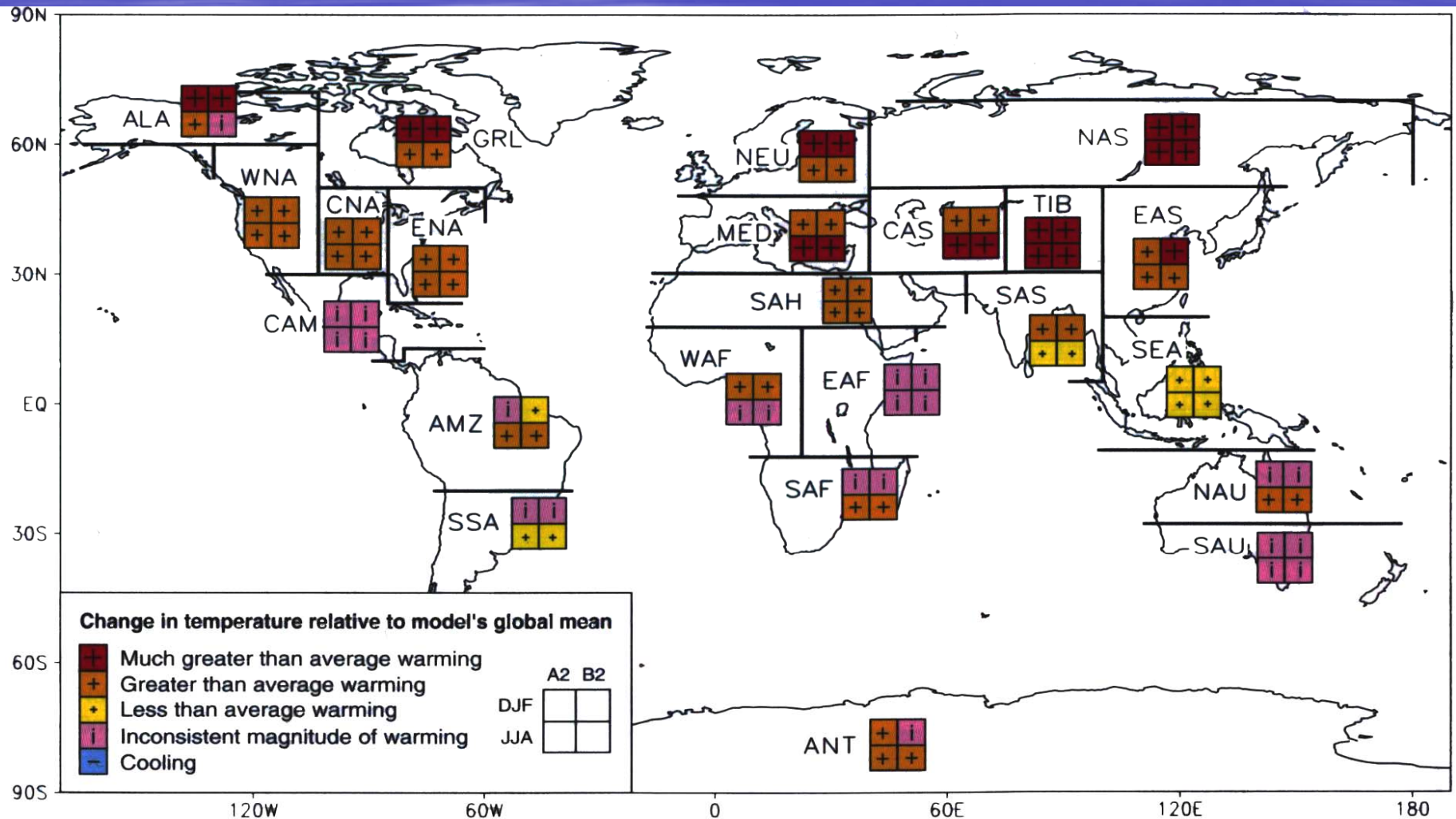
Mean seasonal temperature changes 1965 to 2004 .

Temperatures are increasing, particularly in the Northern Hemisphere winter and spring, which leads to longer growing seasons, increased potential evapotranspiration and extreme fire weather.

[Groisman et al., 2007; Jones and Moberg, 2003, updated]

Analysis of Inter-model Consistency in Regional Warming

Atmospheric-Ocean General Circulation Models (AOGCM) are in agreement that warming in Northern Eurasia could be in excess of 40% above the global average (at least 7 of 9 models) (IPCC, 2001).



Boreal forests and fire

Boreal forest communities are particularly responsive to climate change.

(Stocks and Street, 1982; Clark, 1988; Payette and Gagnon, 1985; Flannigan and Harrington, 1988; Sirois, 1992)

Synoptic weather patterns are the major regional factor controlling the occurrence of fire.

(Stocks and Street, 1982; Pastor and Mladenoff, 1992)





Wildfire is an integral component of boreal landscapes.

Dominant driver of ecological processes in boreal ecosystems

(Lutz, 1956; Rowe and Scotter, 1973; Van Cleve and Viereck, 1981; MacLean et al., 1983; Bonan and Shugart, 1989).

Wildfire maintains age structure, species composition, and the floristic diversity of boreal forests by resolving the beginning and end of successional processes

(Zackrisson, 1977; Van Wagner, 1978; Heinselman, 1981; Antonovski et al., 1992).

In a landscape-scale steady-state system, wildfire acts as a disturbing agent that maintains the current stability, diversity and mosaic structure of boreal ecosystems

(Loucks, 1970; Viereck and Schandelmeier, 1980; Romme, 1982; Shugart et al., 1991).



What is expected?

Under current climate change scenarios...

Boreal forest fire frequency and area burned are expected to increase (25 – 50%)

(Overpeck *et al.*, 1990; Flannigan and Van Wagner 1990, 1991; Wotton and Flannigan 1993; Stocks *et al.* 1998, 2000; Flannigan *et al.* 2001).

Increased ignition from lightning (20-40%)

(Fosberg *et al.* 1990, 1996; Price and Rind 1994)

What is expected?

Under current climate change scenarios...

**Increased fire season length
(up to 51 days, average 30 days)**

(Street 1989; Wotton and Flannigan 1993;
Stocks *et al.* 1998)

**Increased fire weather severity
(46% average)**

(Street 1989; Flannigan and Van Wagner 1991,
Stocks *et al.* 1998)

**Fire weather severity is predicted to be
greater in Russia than in North America**

(Stocks and Lynham 1996)





- I. Climate holds the ultimate key to altering boreal ecosystems (temperature and precipitation).**

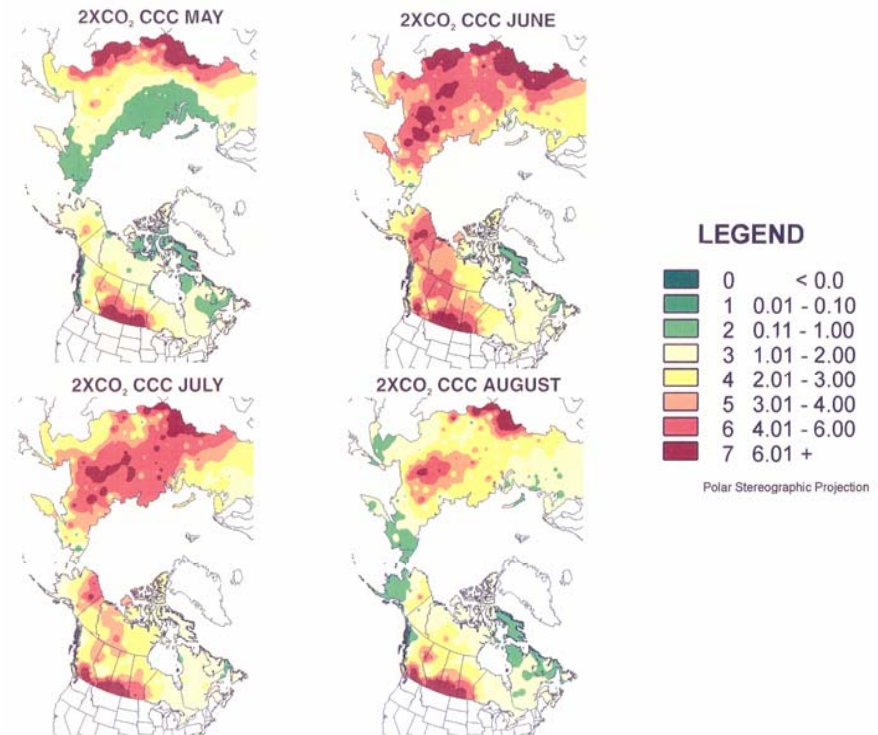
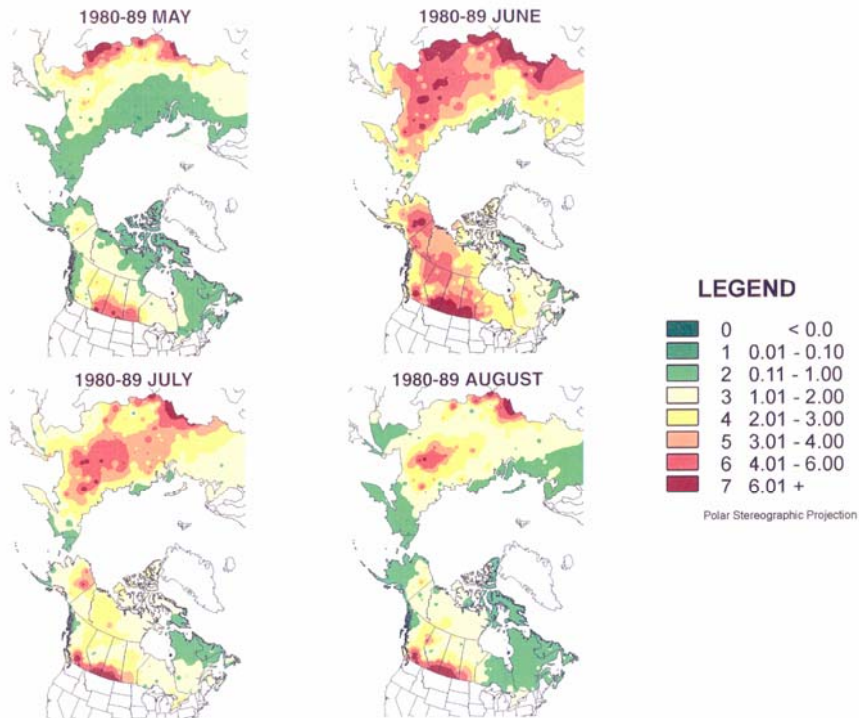
- II. Climate has the potential to affect boreal fire regimes by:**
 - (1) altering species composition;**

 - (2) altering fire ignitions from lightning and;**

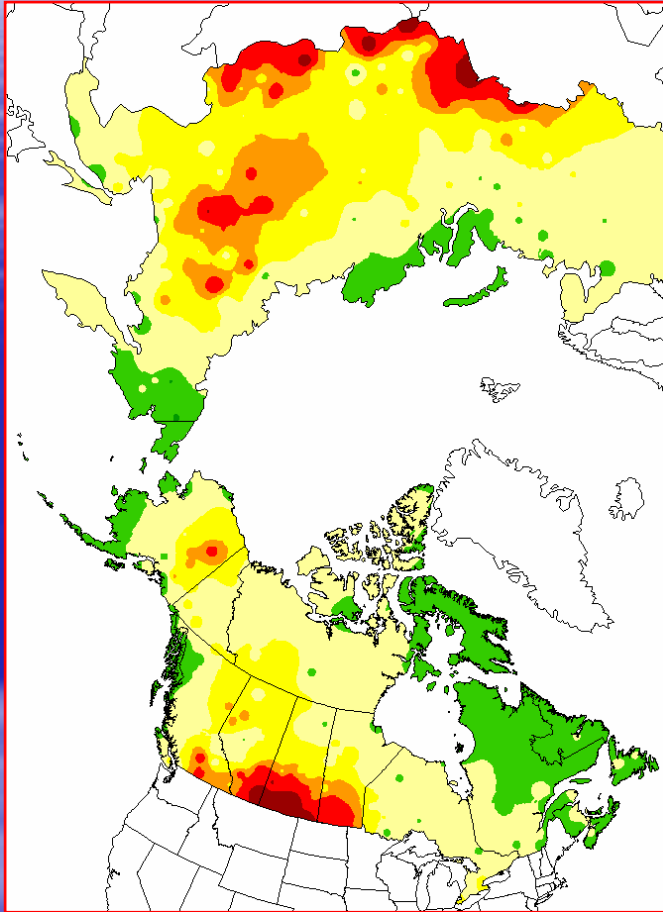
 - (3) altering weather conditions conducive to fire.**

Future Fire Danger Levels

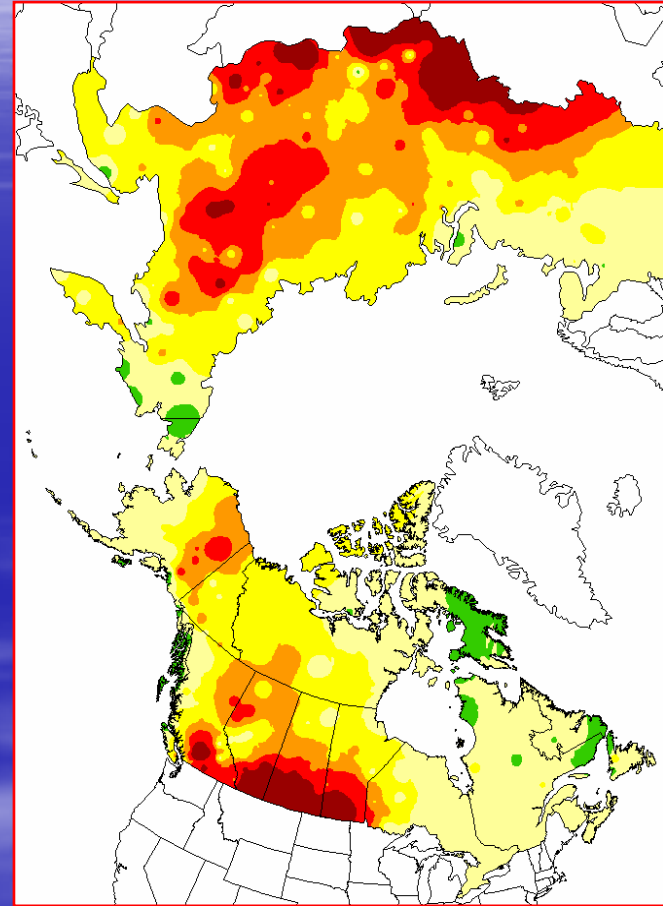
- All GCM and RCM projections show increase in strength and areal extent of extreme fire danger
- Increase in fire season length
- Increased weather variability and extremes at regional scale



Role of Future Climate Change



Historical Fire Weather

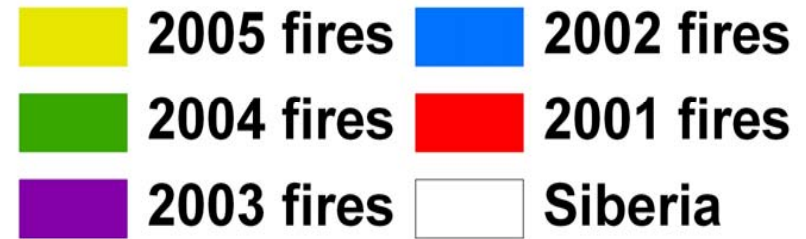
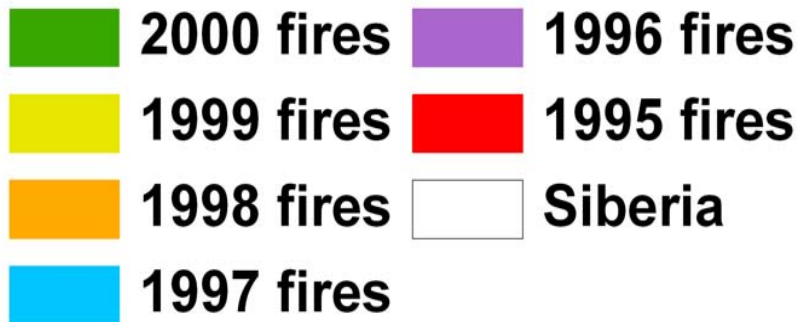
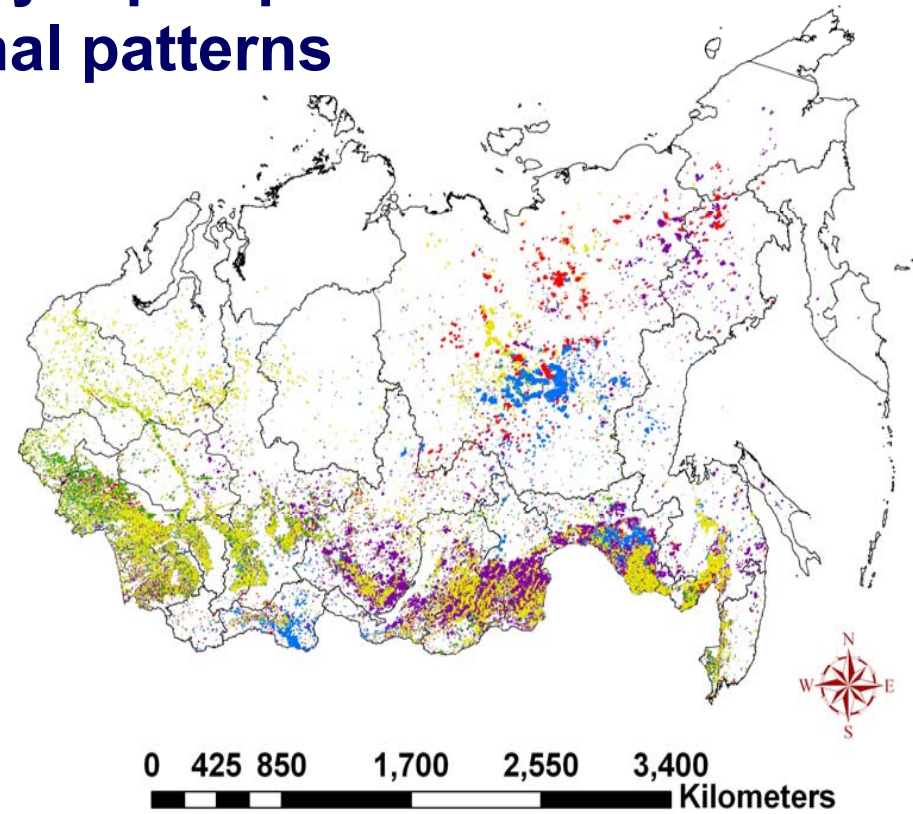
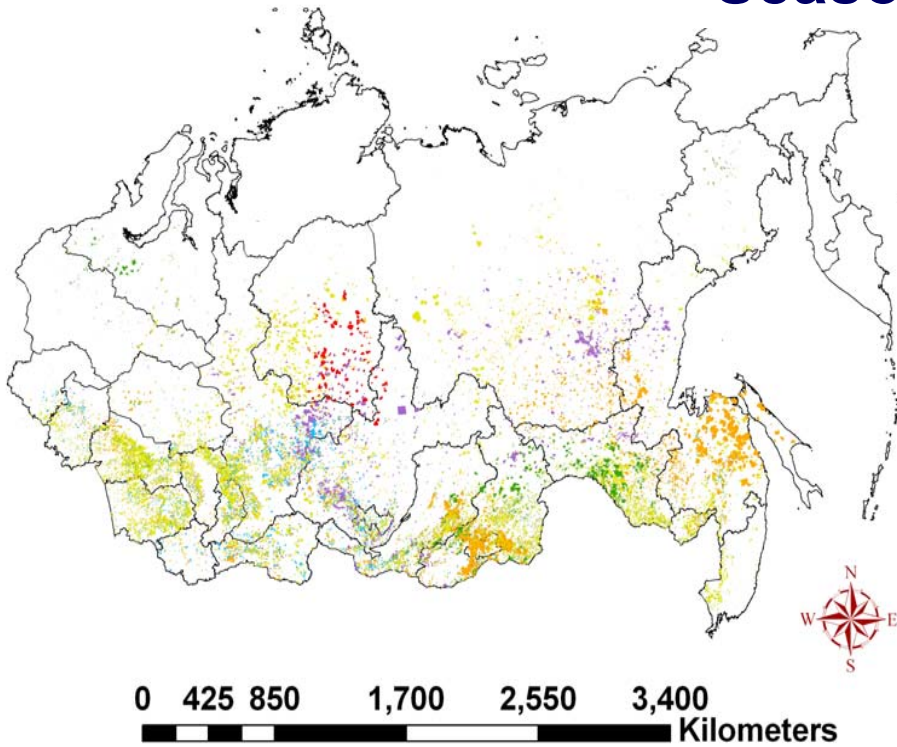


GCM: 2X CO₂

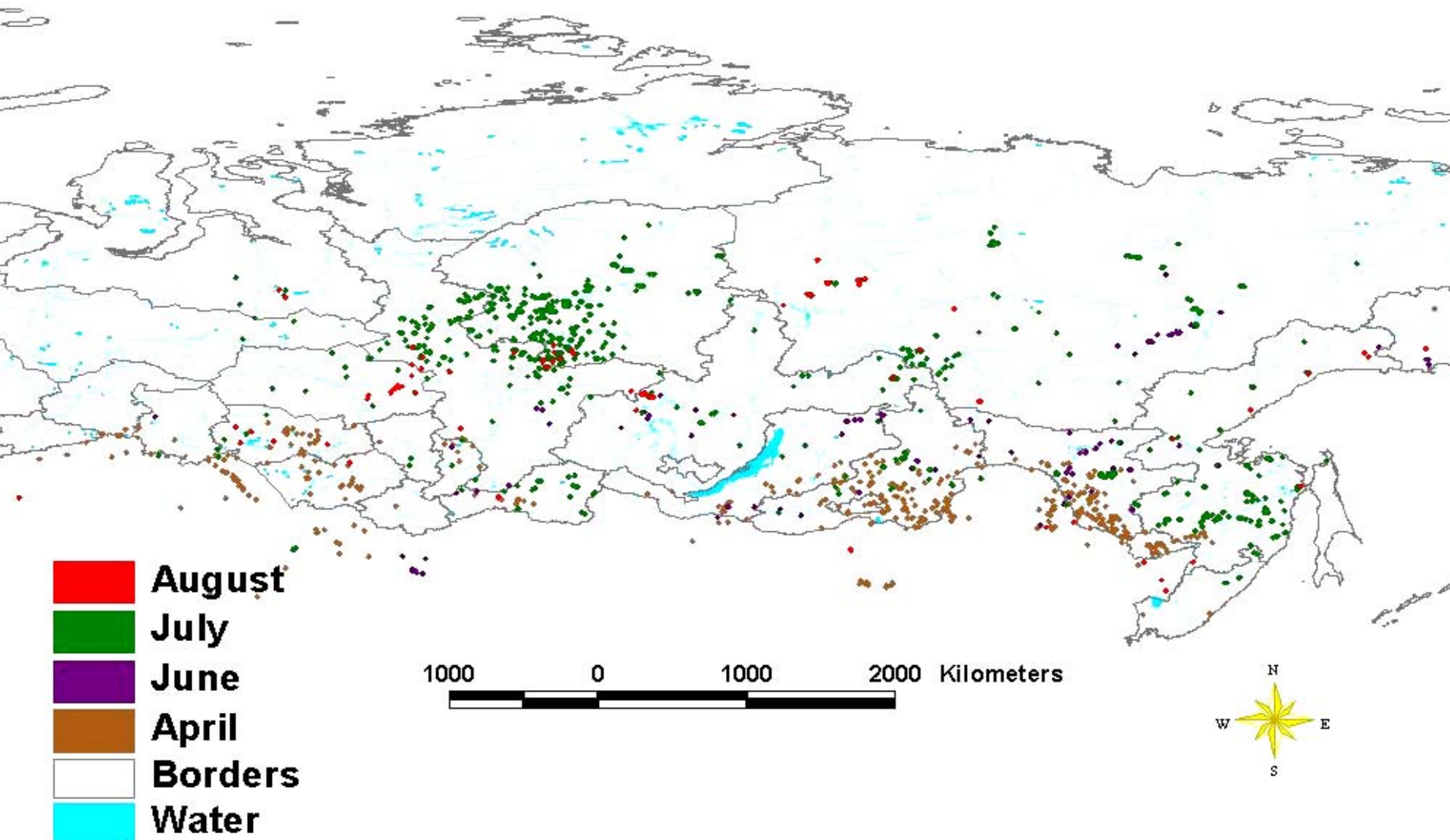
Fires across Siberia

- Large scale synoptic patterns

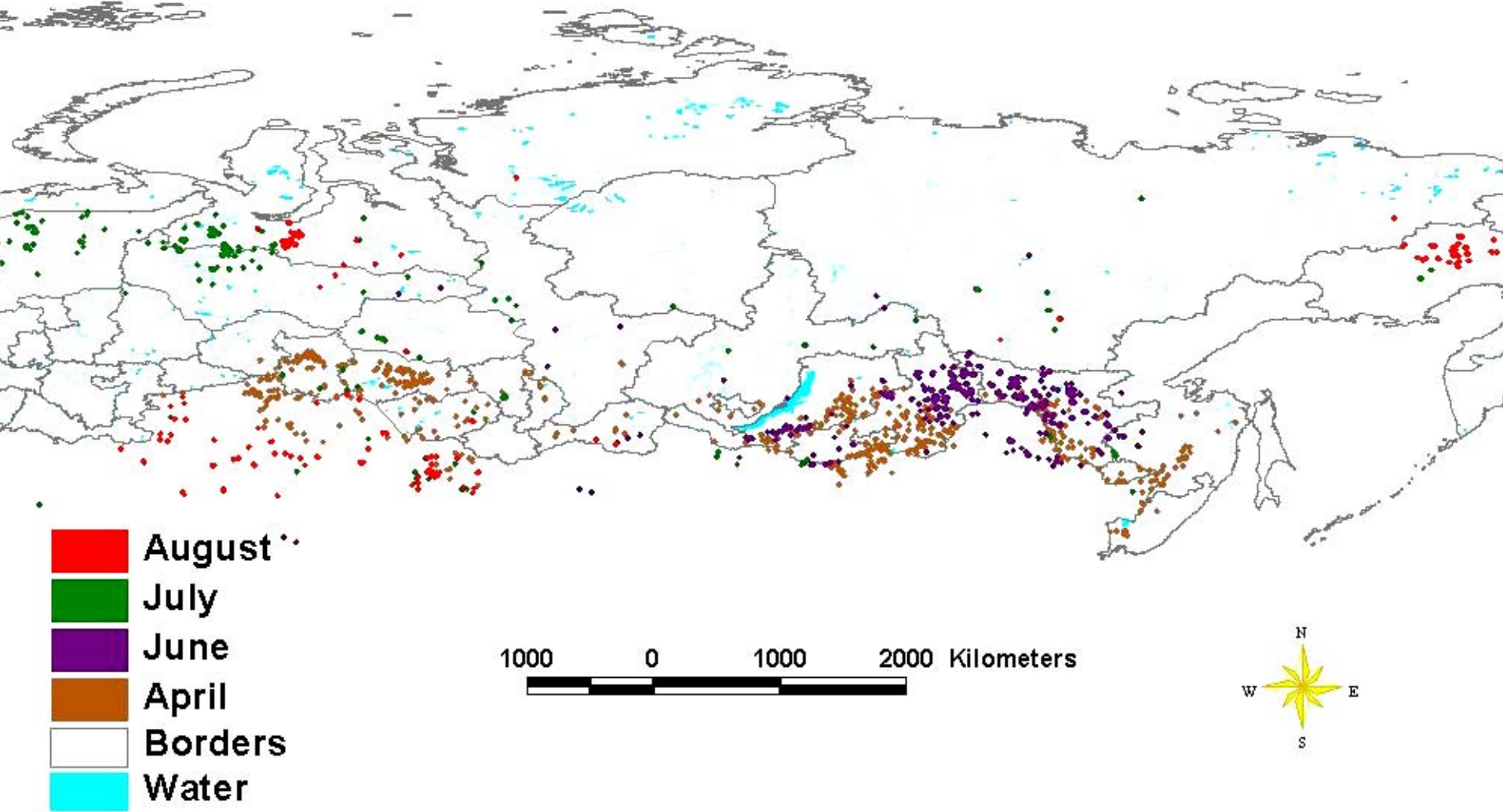
- Seasonal patterns

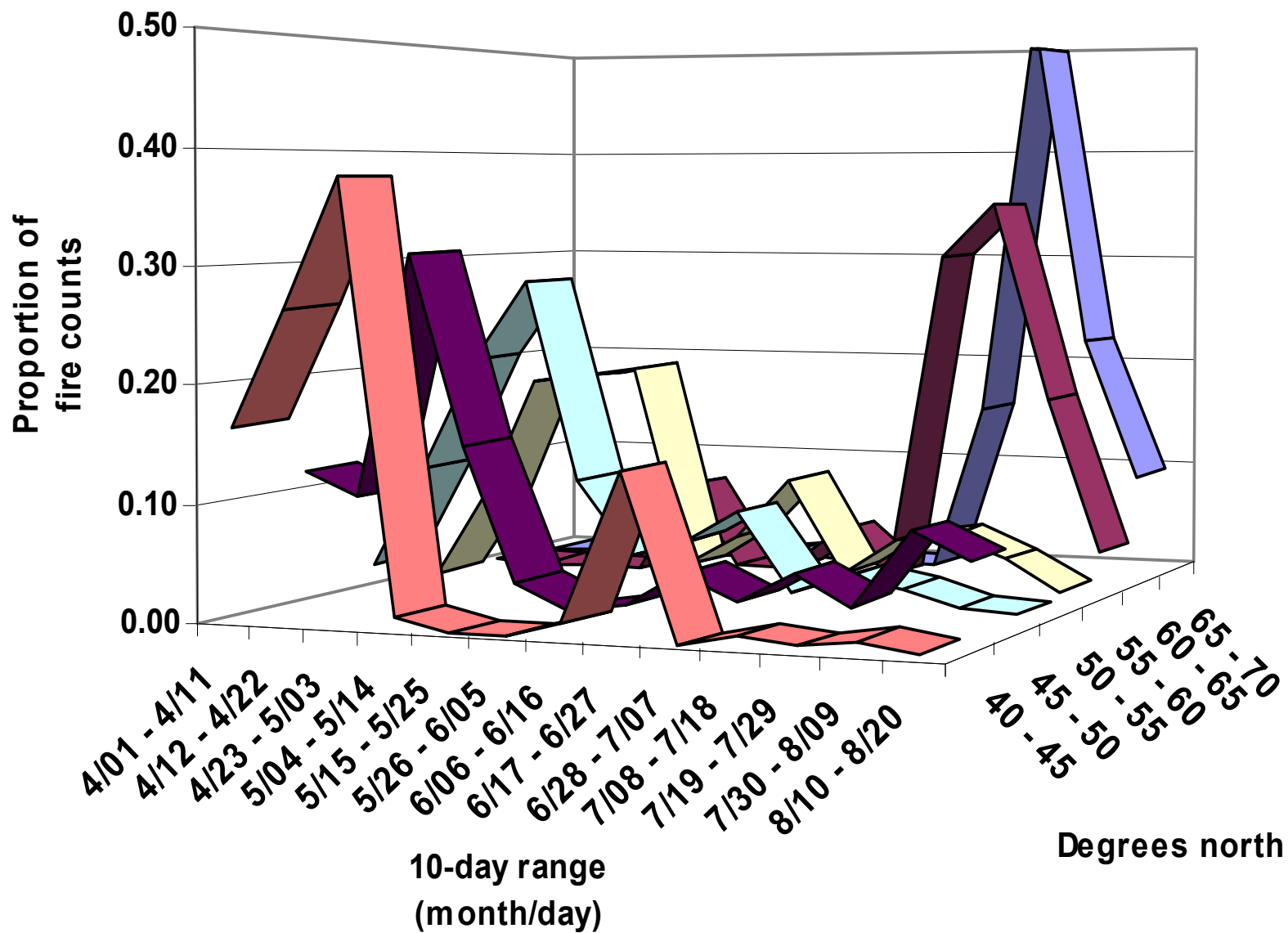


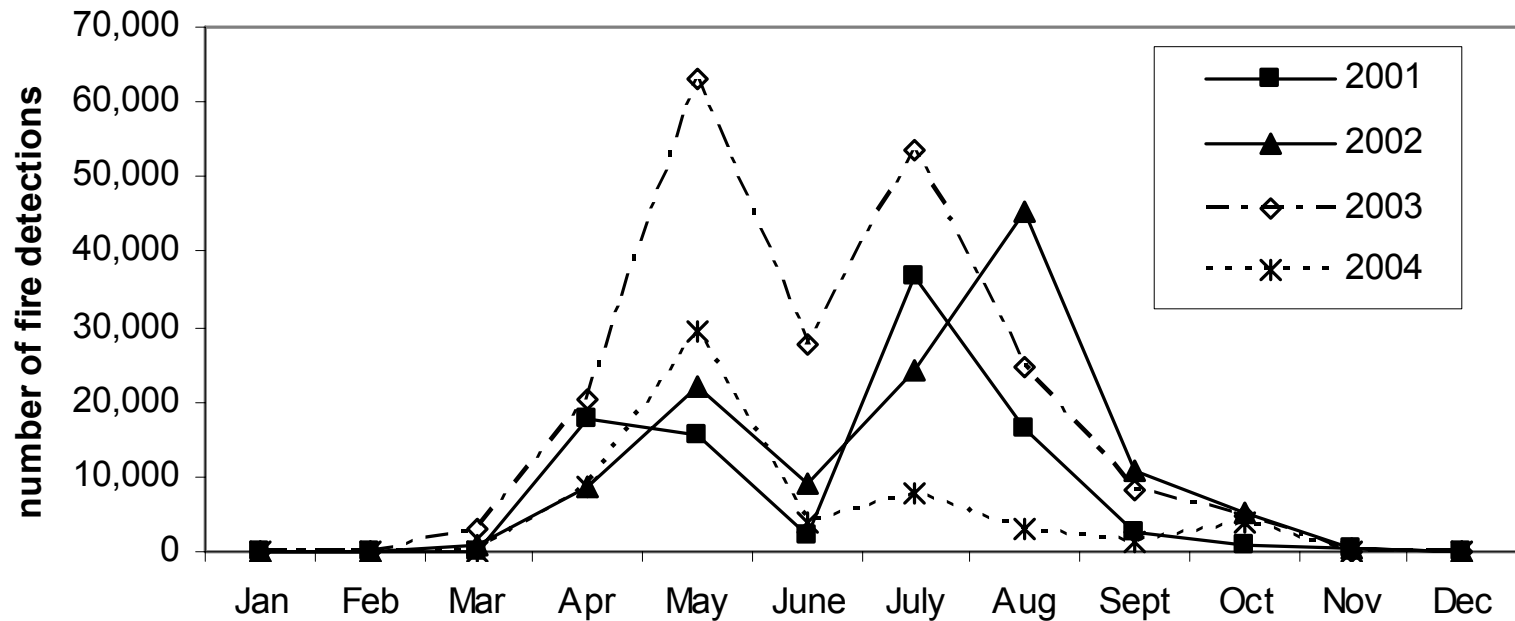
Distribution of fire in Siberia: 1999



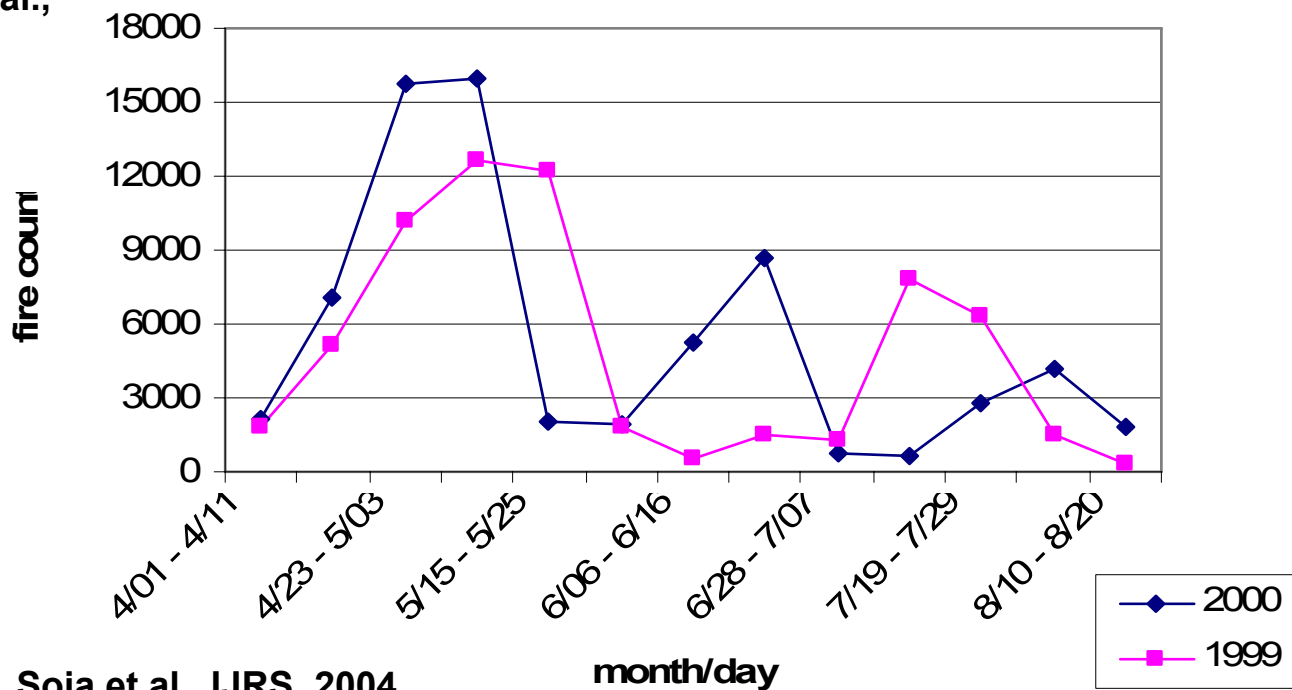
Distribution of fire in Siberia: 2000







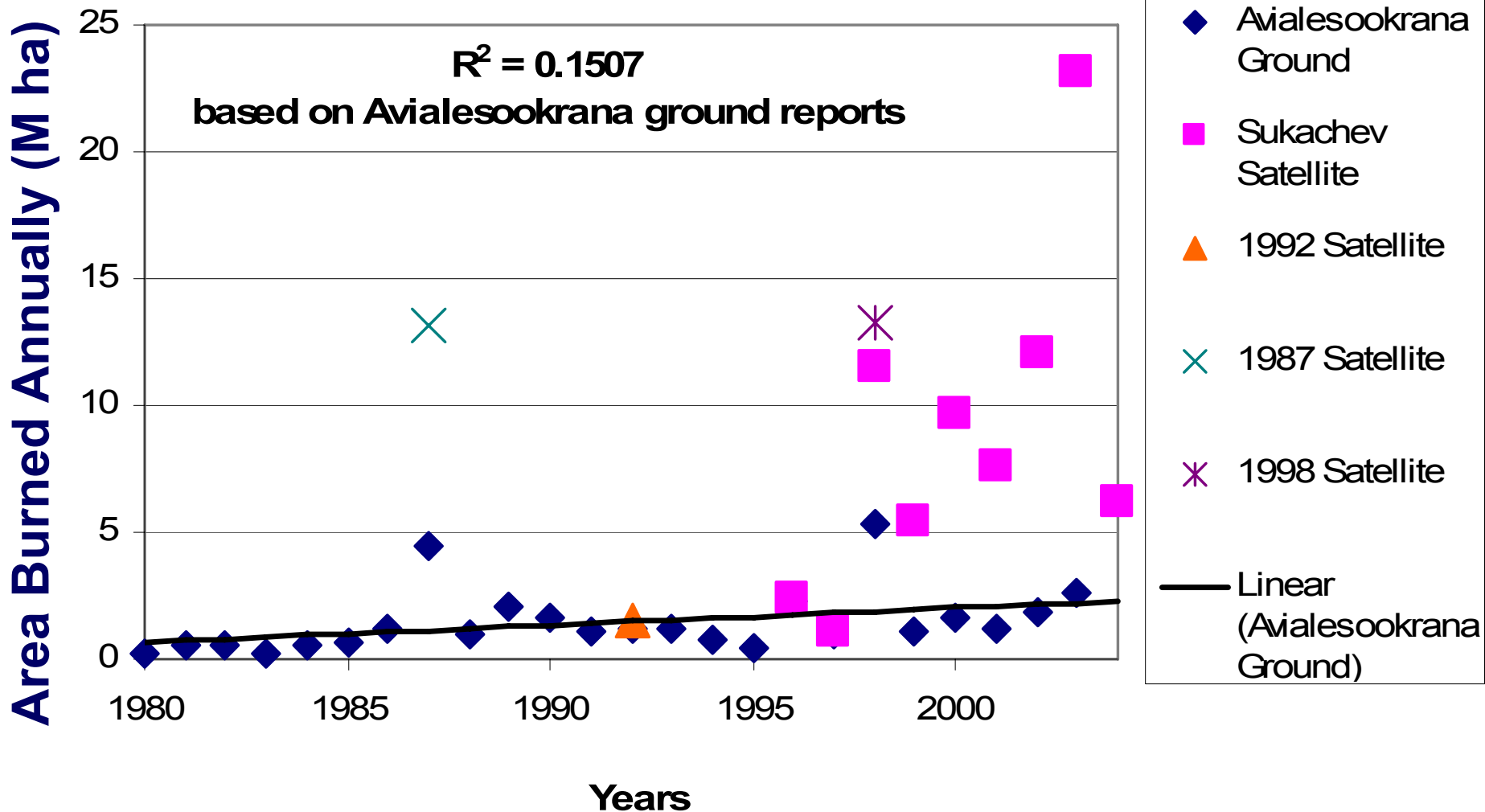
Loboda et al.,
2007



Soja et al., IJRS, 2004

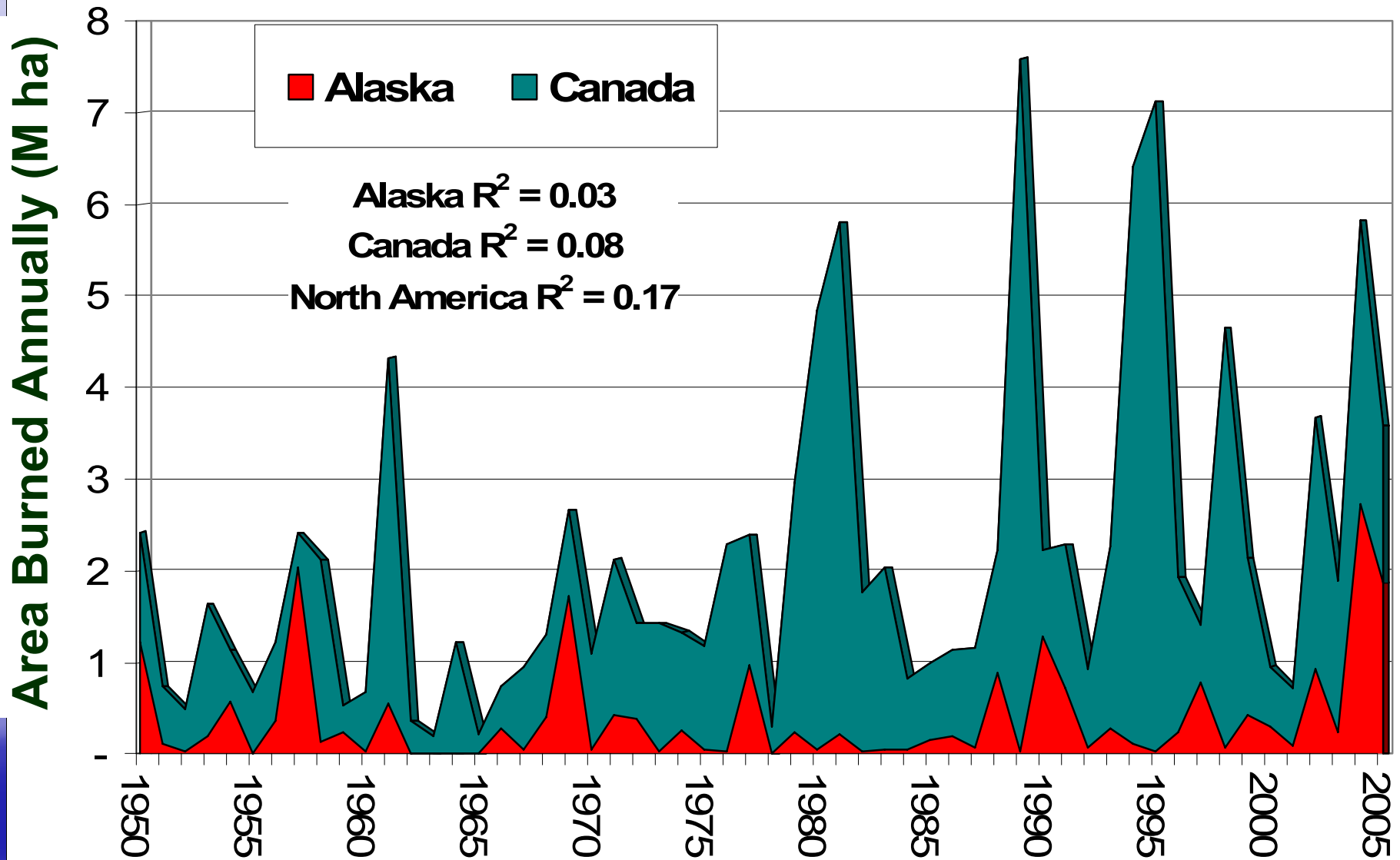
Seasonal
Patterns
of Fire in
Boreal
Siberia

Area burned in Siberia



In Siberia, 7 of the last 9 years have resulted in extreme fire seasons, and extreme fire years have also been more frequent in both Alaska and Canada.

Area burned in boreal North America



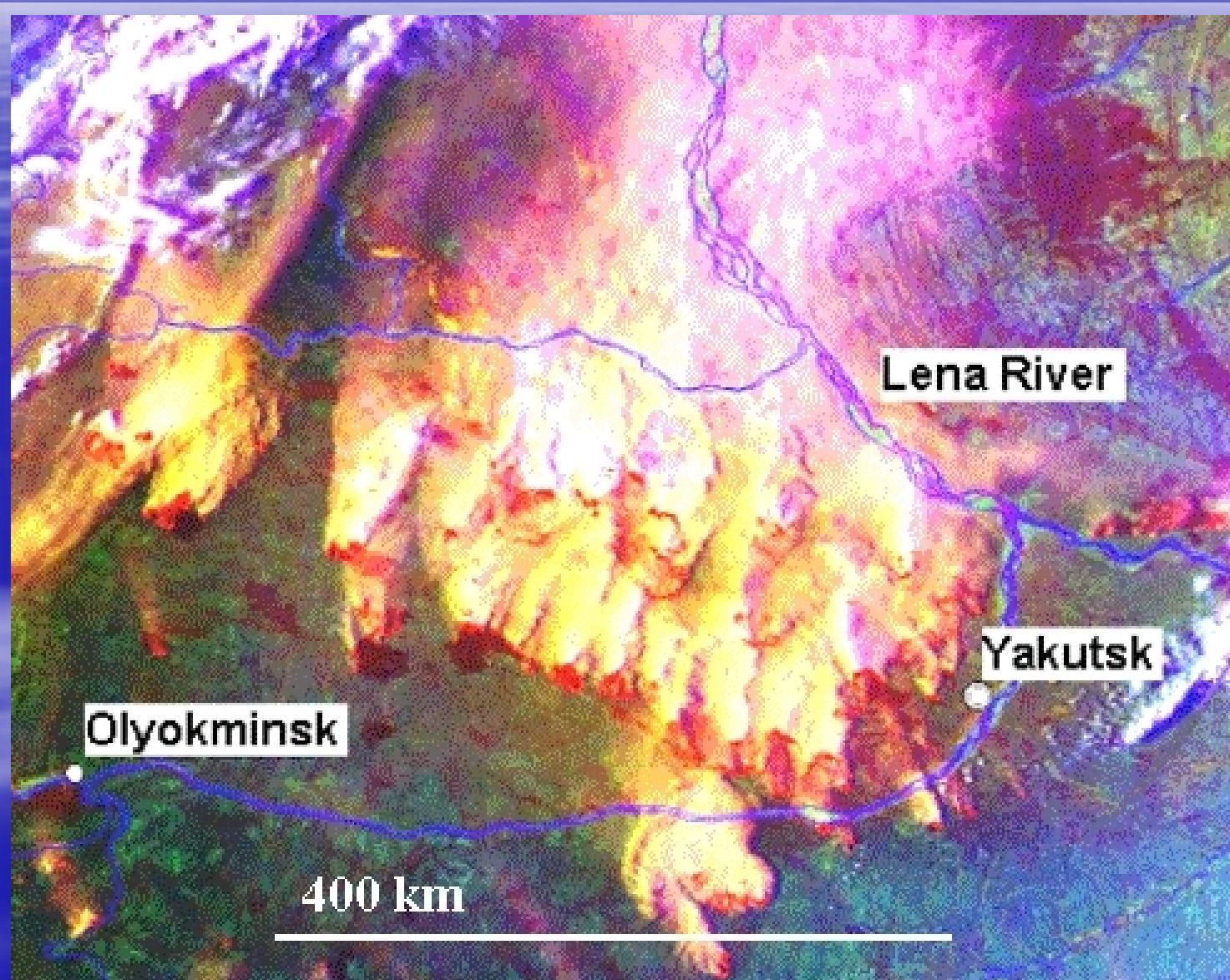
Fire Regimes Vary Widely





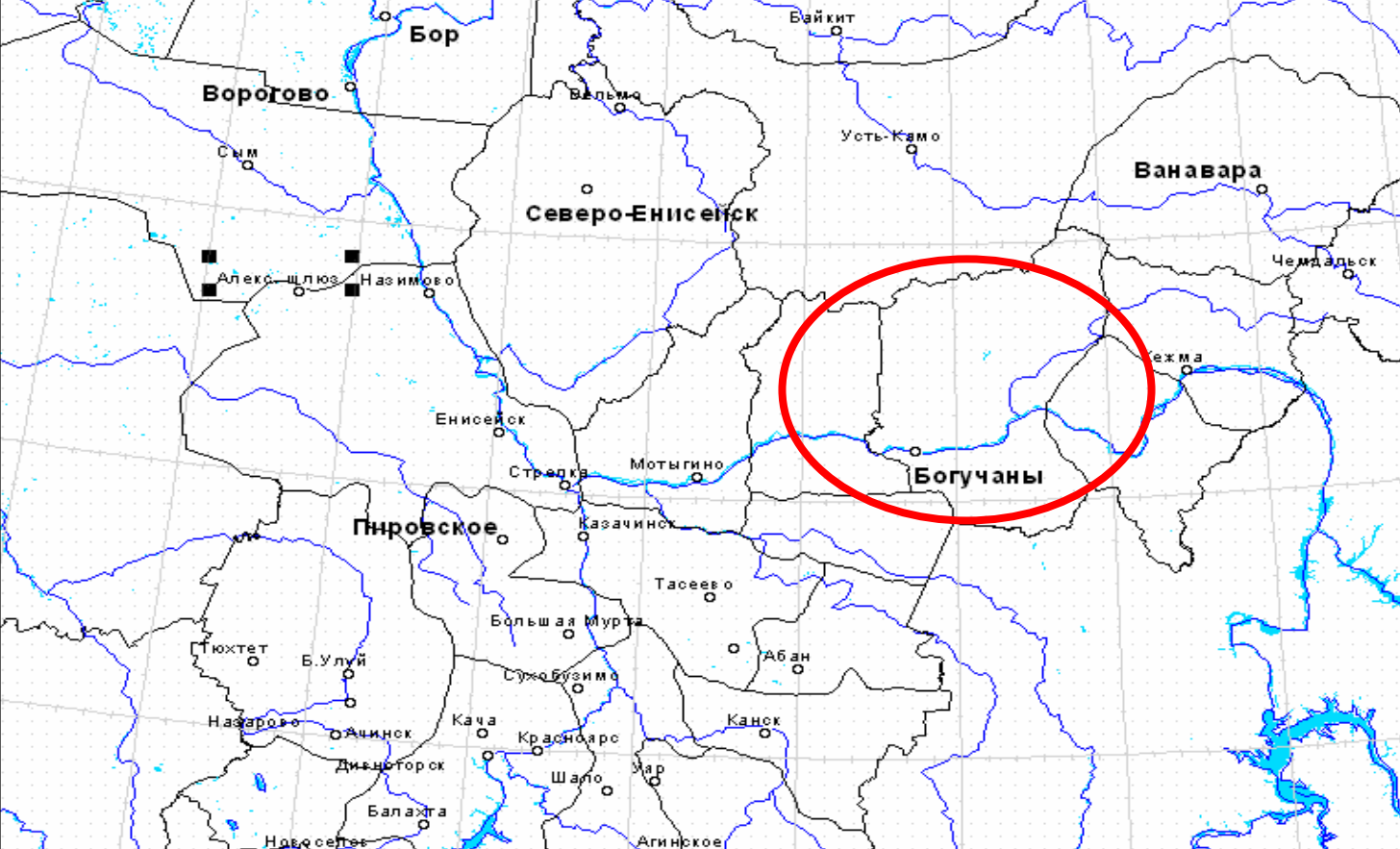
Fires burning in Sakha (Yakutia), August 2002

These fires burned from late April through early October

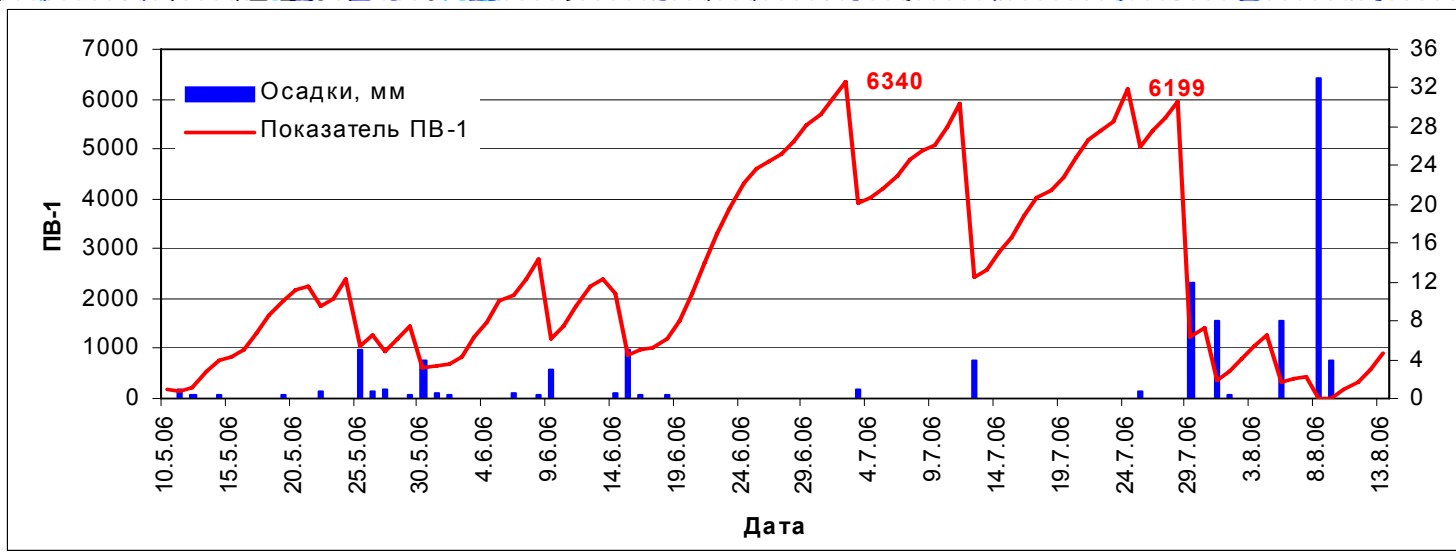


Over 5 M ha burned in Sakha, which accounts for almost half of the Siberian 2002 total carbon emissions, perhaps 10% of the total global carbon emissions from forest and grassland burning

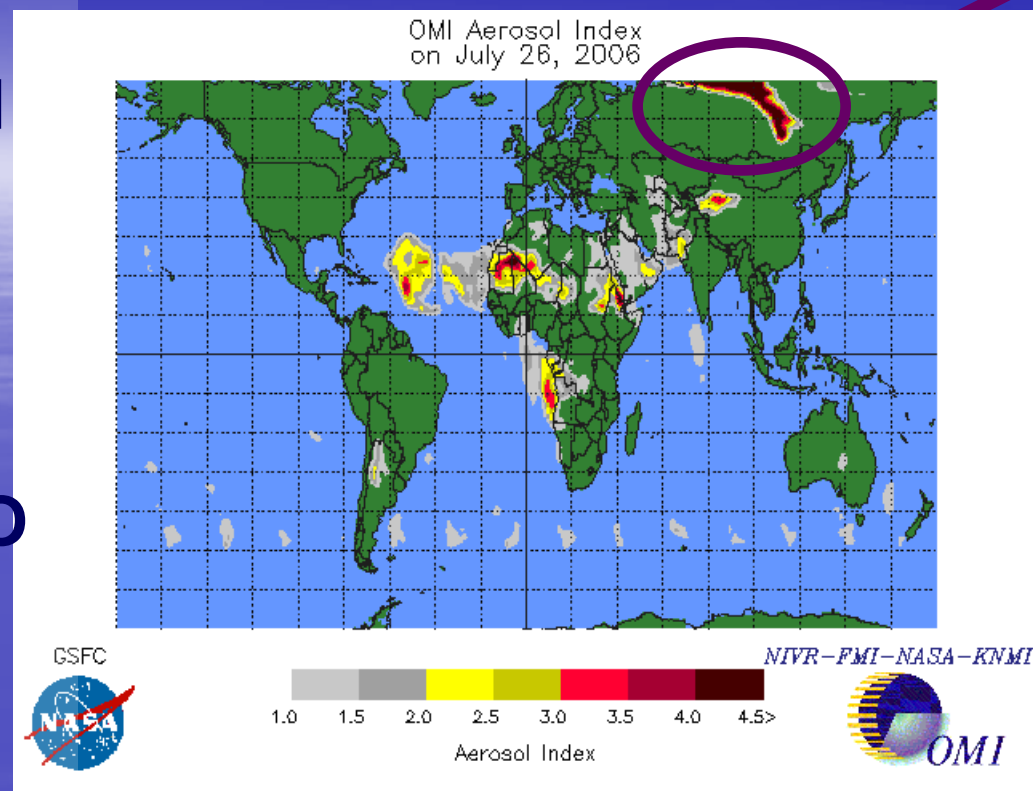
(Andreae and Merlet, 2001 Soja et al., JGR 2004).



Seasonal changes in the 2006 fire hazard index (red line), with rainfall (blue bars) for the Boguchany weather station .



On July 26, 2006, the Aerosol Index (AI) peaked in Siberia due to an extreme wildfire event, which traveled northwest over the North Pole. During this time, CALIPSO captured the vertical height and structure of the smoke plume.

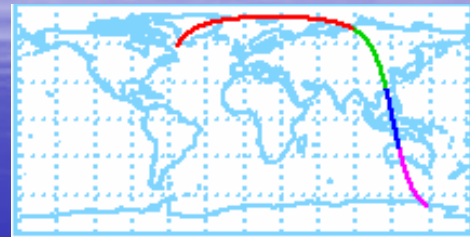
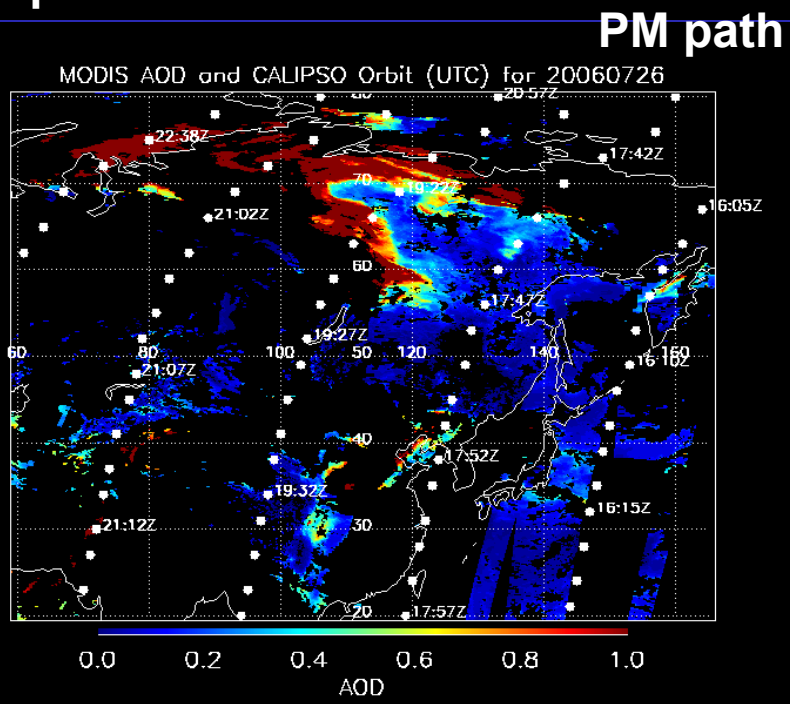
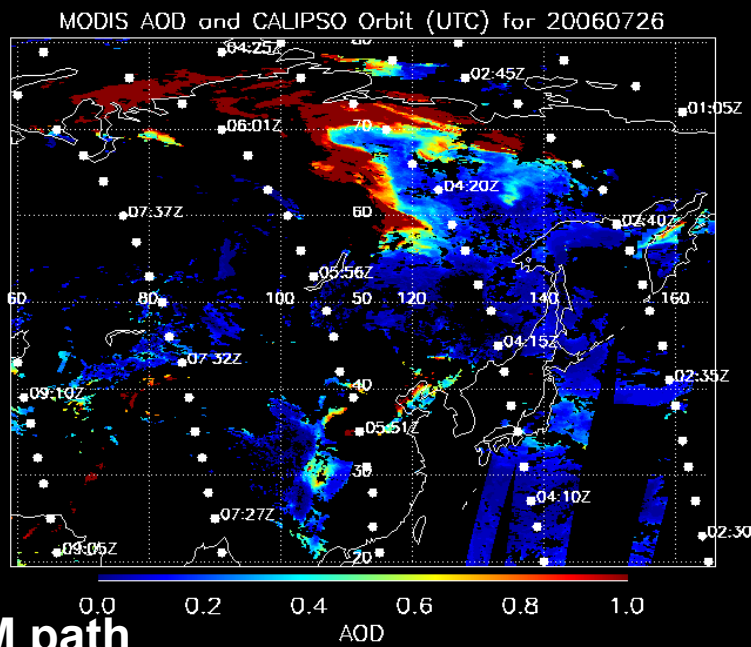


- CALIPSO combines an active lidar instrument with passive infrared and visible imagers to probe the vertical structure and properties of thin clouds and aerosols.
- 30 meter vertical resolution, 100 m swath.
- Data extends from sea level to 30 km.
- Launched on April 28, 2006 with CloudSat.

What is
CALIPSO?

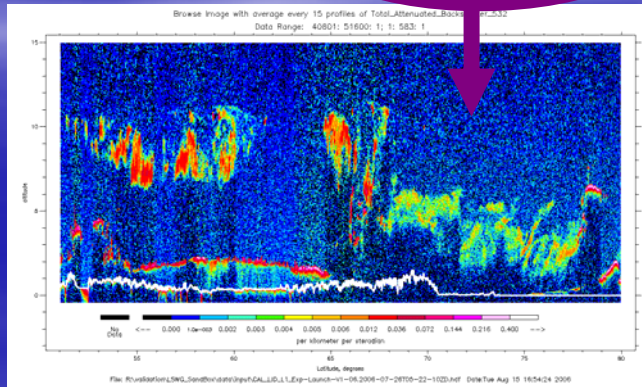
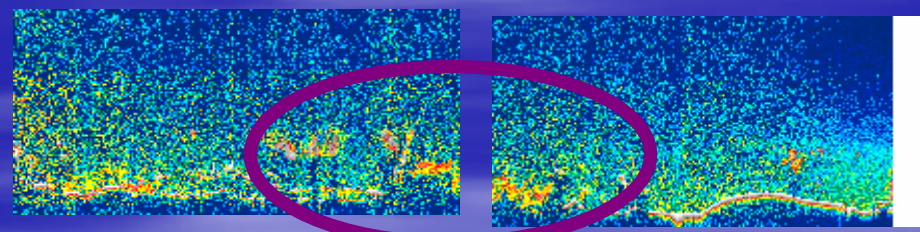
<http://www-calipso.larc.nasa.gov/>

Coincidence in Siberian wildfire, MODIS Aerosol Optical Depth (AOD) and the CALIPSO path.



CALIPSO flight track (green & red tracks shown below)

About 12:00 to 13:00 pm local time
 Begin: 2006/07/26 05:22:09.5520 UTC
 End: 2006/07/26 06:14:29.6124



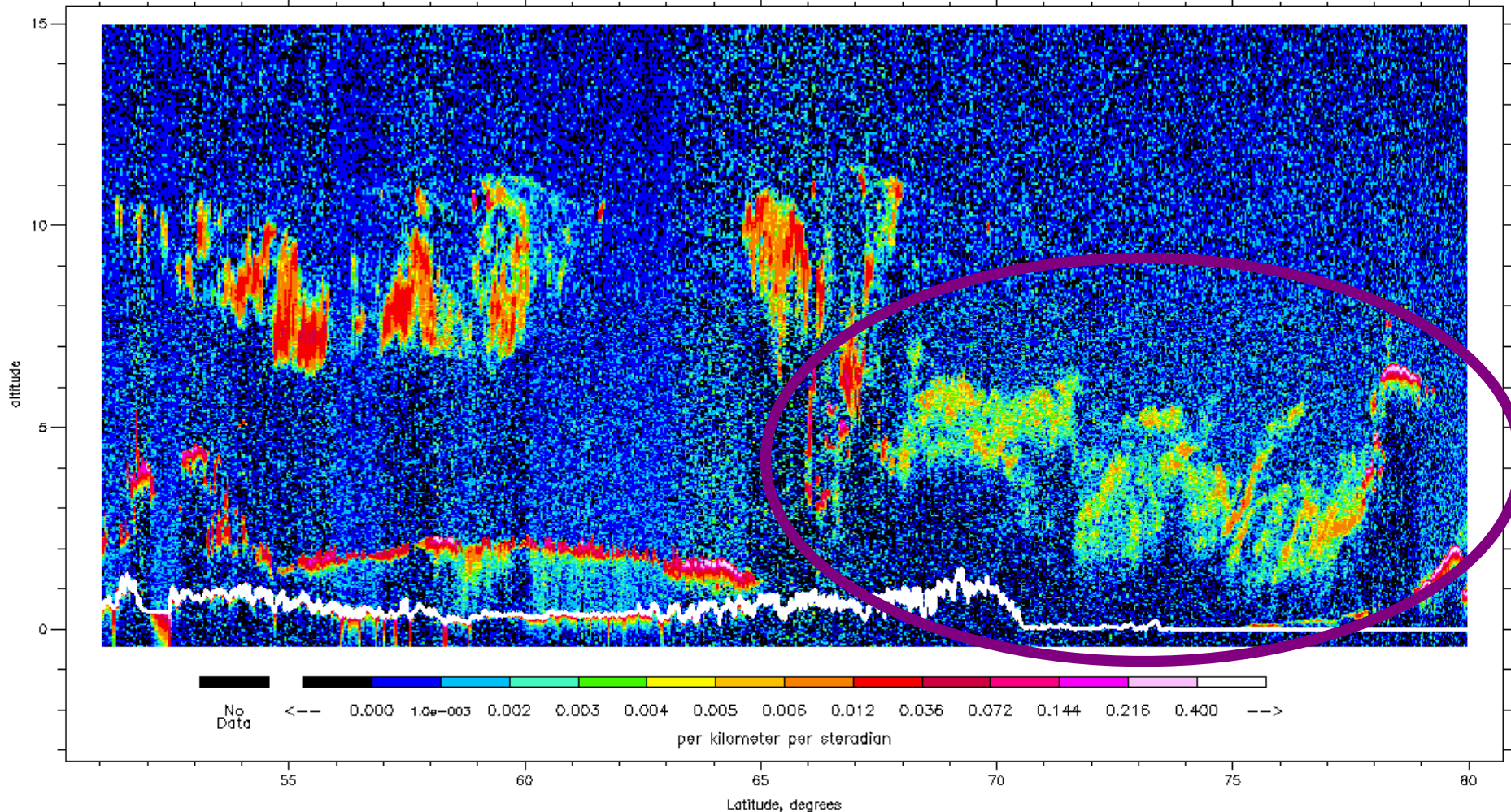
CALIPSO data

Expanded view, next slide

First Views of CALIPSO data

Browse Image with average every 15 profiles of Total_Attenuated_Backscatter_532

Data Range: 40801: 51600: 1; 1: 583: 1



File: R:\validation\LSWG_SandBox\data\input\CAL_LID_L1_Exp-Launch-V1-06.2006-07-26T05-22-10ZD.hdf Date: Tue Aug 15 16:54:24 2006

CALIPSO captures both the maximum altitude of the smoke plume at about 6 km and the vertical smoke structure, as it evolves over time.

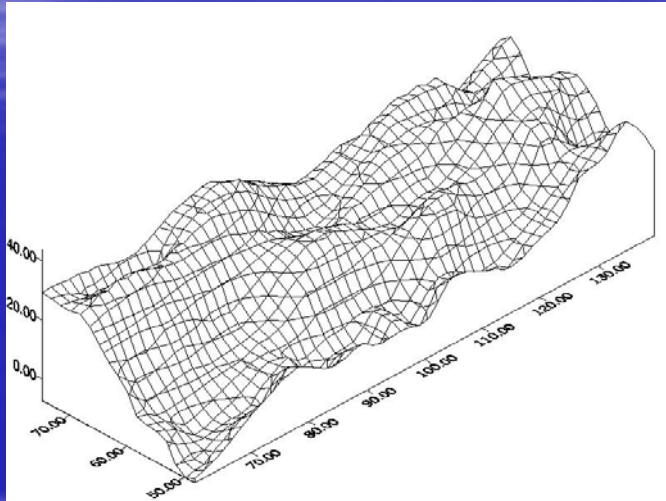
Initial albedo analysis from Sakha, Siberia shows decreased albedo for about 4 to 5 years, then it begins to increase.



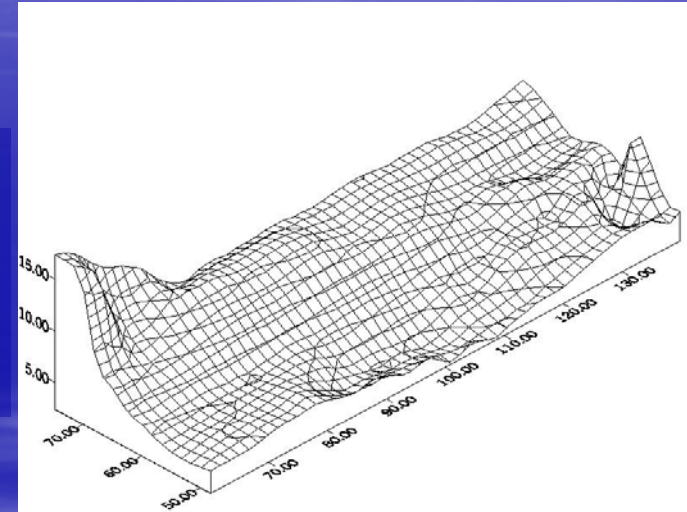
Gray-scale AVHRR image of band 2. This July, 17 2002 image shows dark fire scars (black) and active fires with smoke steaming from them (whitish). Remarkably, increased reflectance from the 1986 fire scars is still apparent, 16 years after the fire events.

Predicted changes in 2090 precipitation for Siberia (Hadley Center, HadCM₃GGa1)

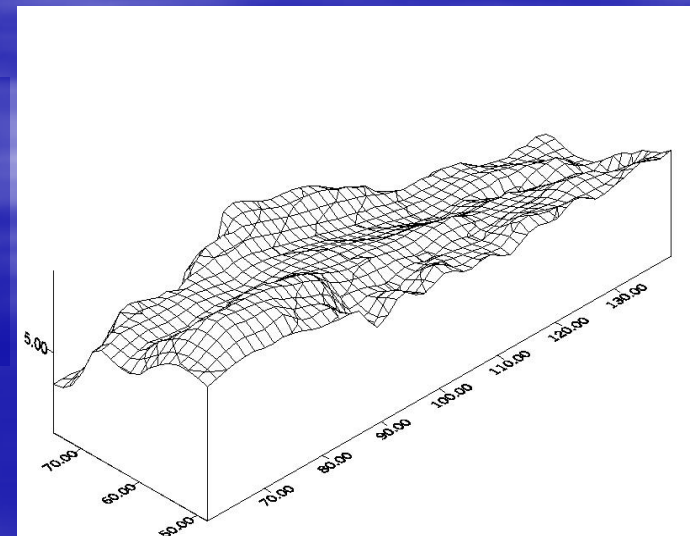
Precipitation (-4/+25%)



January temperature (+4/+9°C)



July temperature (+4/+6°C)



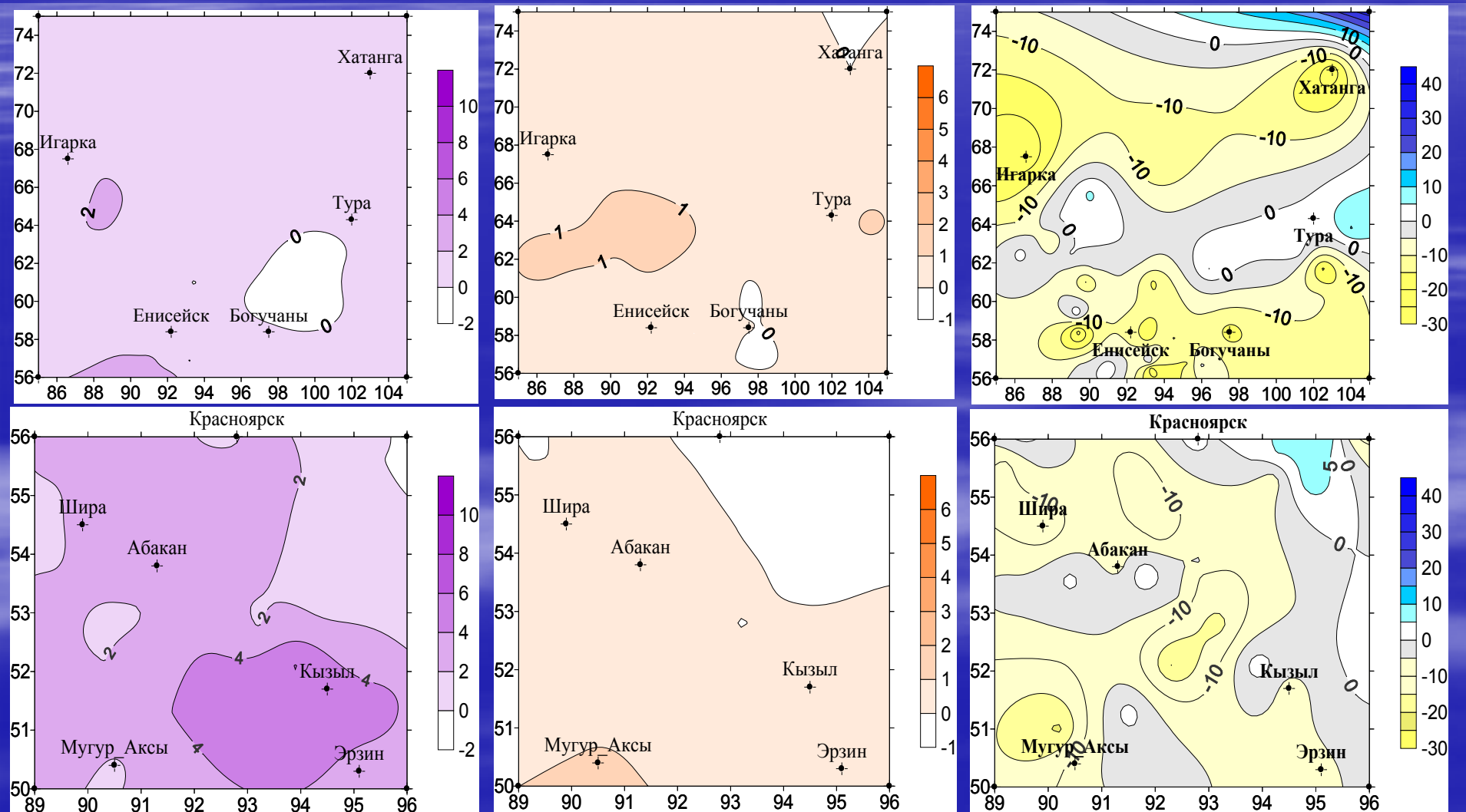
Tchbakova and Parfenova, 2000;
Parfenova and Tchbakova, 2001

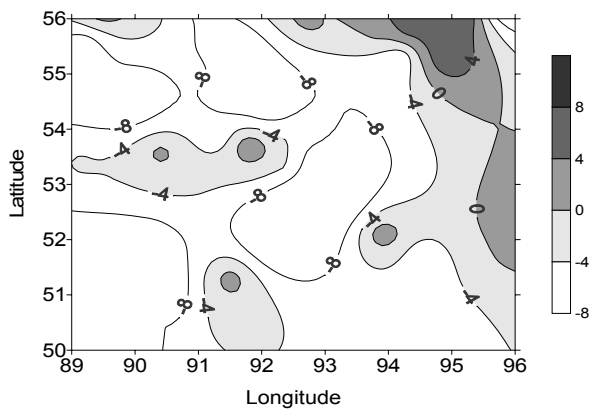
Climatic anomalies by 2000 in the north (upper) and in the south (lower) of Central Siberia.

T, °C, January

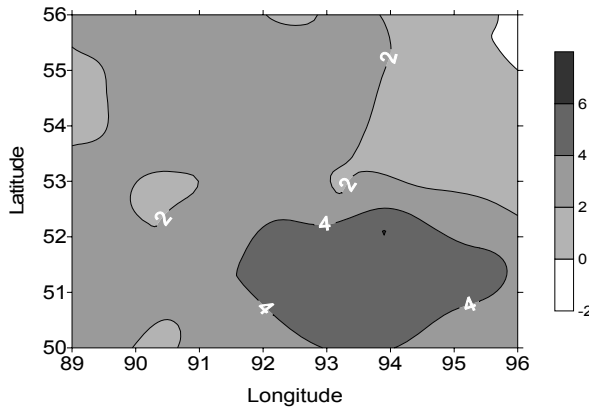
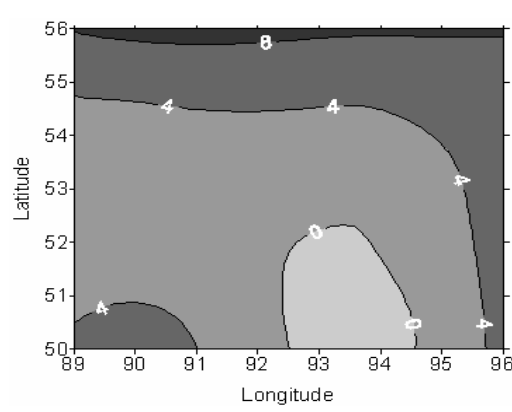
T, °C, July

Precipitation, mm

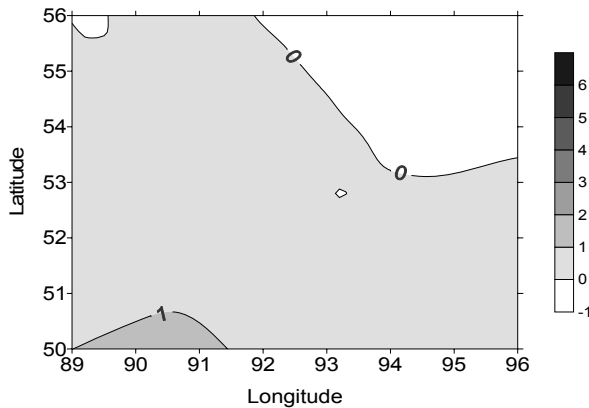
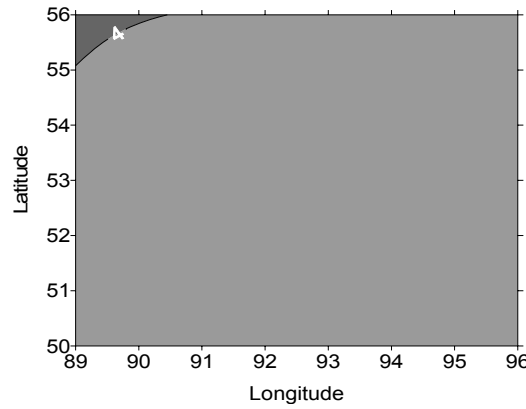




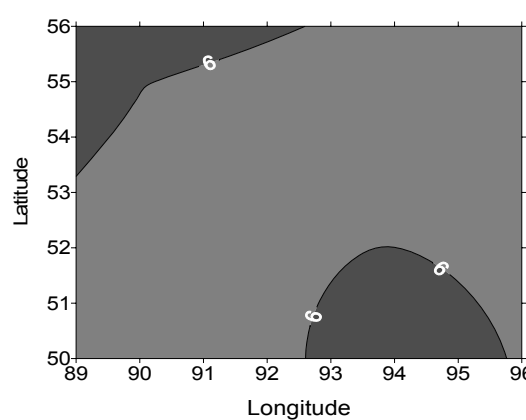
Annual precipitation (%)



January temperature (°C)



July temperature (°C)



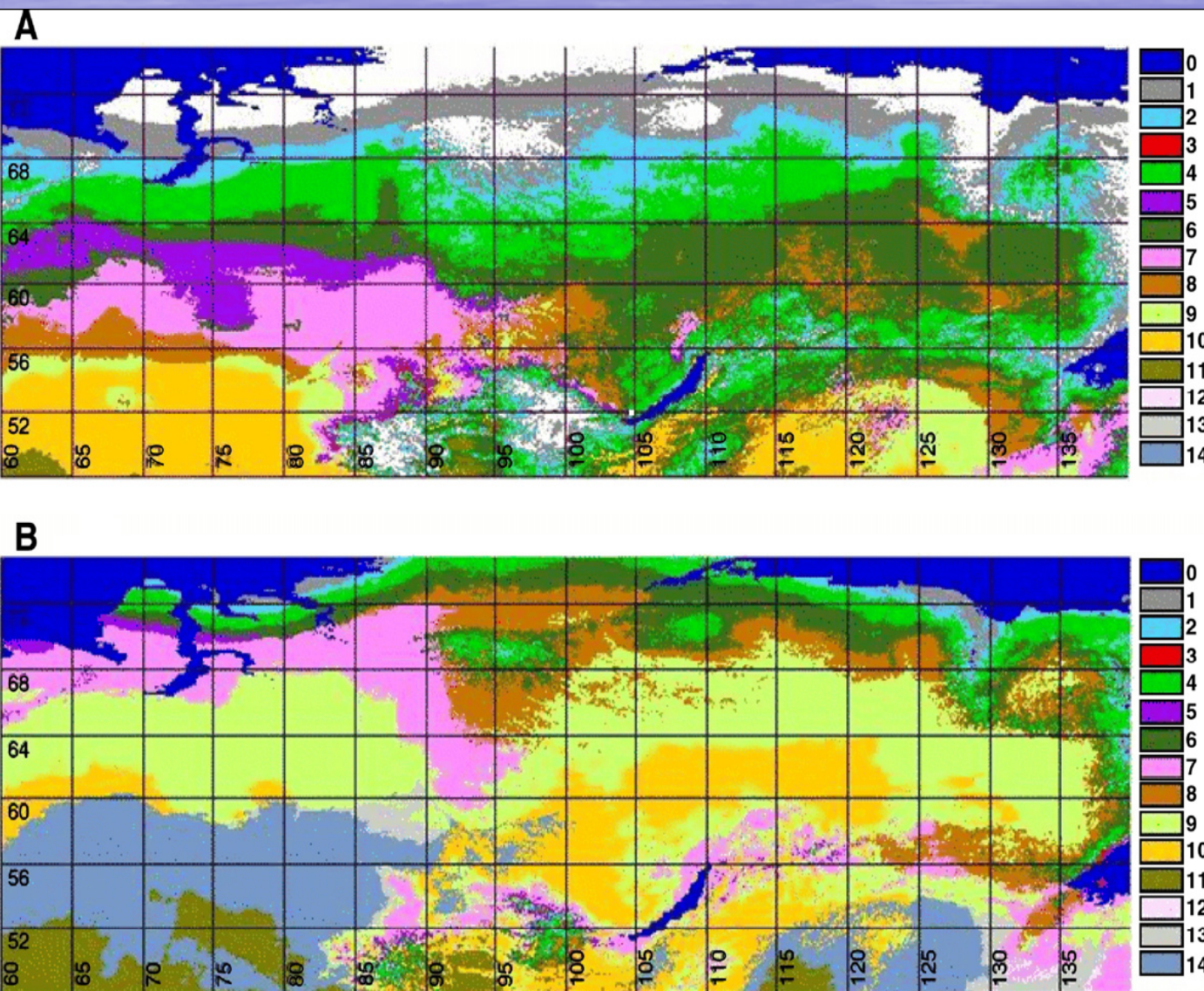
Climate change in the Sayan Mountains: observations, 1980-2000 (left) and predicted (right) by a Hadley Centre scenario (HadCM3GGa1) for 2090.

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, Tchebakova et al., 2007

Vegetation distribution in Siberia: (A) current and (B) future (2100)

based on Hadley scenario (HadCM3GGal) (IPCC, 1996).



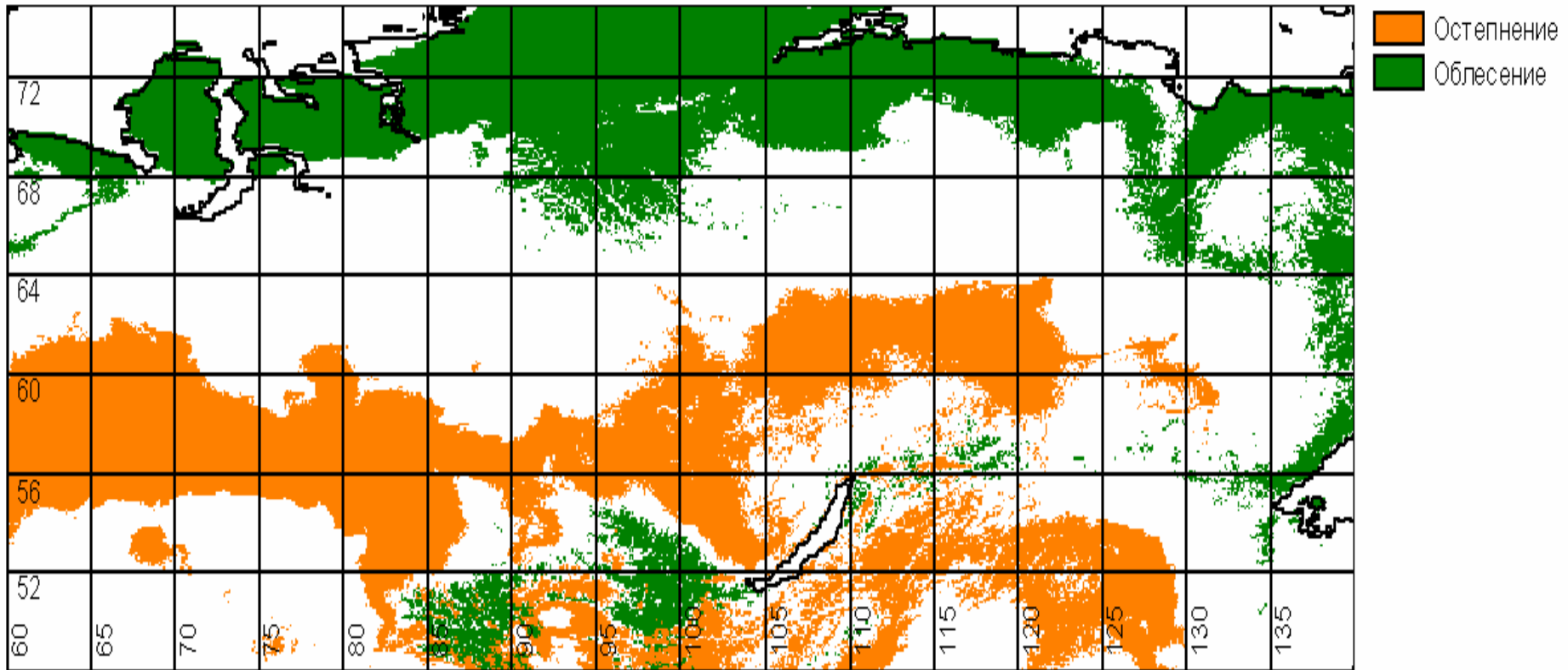
Water (0),
tundra (1),
forest-tundra (2),
N. dark taiga (3) and
N. light taiga (4),
middle dark taiga (5)
M. light taiga (6),
S. dark taiga (7) and
S. light taiga (8),
forest-steppe (9),
steppe (10),
semidesert (11),
broadleaved (12),
temperate forest-
steppe (13) and
temperate steppe
(14).

Tchebakova and
Parfenova, 2000, 2001

Modeled biome area change (2090)

Biome	Current Area, 10 ⁴ sq. km	Area change, 10 ⁴ sq. km (%)
Tundra	110.8	7.5 (- 93%)
Forest-Tundra	91.3	12.2 (- 87%)
Northern dark taiga	1.9	1.1 (- 42%)
Northern light taiga	191.1	48.6 (- 75%)
Middle dark taiga	52.7	10.2 (- 81%)
Middle light taiga	237.0	66.2 (- 72%)
Southern dark taiga	108.2	127.3 (+18%)
Southern light taiga	98.6	87.0 (- 12%)
Forest-steppe	62.6	328.1 (+5-fold)
Steppe	139.2	176.5 (+27%)
Temperate biomes	11.8	328 (+30-fold)

“Hot spots” of forest cover changes by 2090



Green – new forest habitats,

Orange – new steppe habitats,

– no change in forest vegetation

Outlook

North America

- Increasing fire activity and severity
- Increasing vulnerabilities
- Diminishing marginal returns on more expenditures

Russia

- Fire management program without funding
- Widespread forest exploitation of forests exacerbating fire problems
- No funding for forest protection despite fact that natural resources (mining/gas and oil) are a major driver of the Russian economy
- Increasing vulnerabilities
- Shift to regional fire control – will it happen? Will it be funded?
- Major uncertainties going forward



1 year after
severe crown fire

Conclusions (1 of 2)

Fire weather and fire danger has already increased across boreal North America and Siberia.

Boreal forests and fire are largely under the control of weather and climate, and they feedback to the climate system, in terms of fire emissions and changes in the Solar Radiation Budget (albedo).

There is currently evidence of climate- and fire-induced change across Siberia, particularly at treelines (northern, southern, and the upland and lowland mountainous treelines)

Conclusions (2 of 2)

Wildfire is a catalyst that serves two basic purposes in boreal forest:

- 1) a mechanism to maintain stability and diversity in equilibrium with the climate and;**
- 2) a mechanism by which forests move more rapidly towards equilibrium with climate.**

“An altered fire regime may be more important than the direct effects of climate change in forcing or facilitating species distribution changes, migration, substitution, and extinction.”

Weber and Flannigan (1997)



Thank-you!