Insights on the statistical variability of experimental fire behavior data using airborne-infrared

Douglas J. McRae, Susan G. Conard, Ji-zhong Jin, Anatoly I. Sukhinin, Tom W. Blake, and Galina A. Ivanova

Natural Resources Canada
Canadian Forest Service

Wildland Fire Canada 2010, 6 October 2010, Kitchener, ON.

The problem

TABLE 4. Fire impact on forest fuels and fire behavior characteristics of the Sharpsand Creek experimental fires in immature jack pine.

Fire No.	Fuel consumed (kg/m²)				Depth of burn (cm)	Rate of spread (m/min)	Frontal fire intensity (kW/m)
	Total surface	Ground fuels	Crown fuels	Total fuel			
2	0.22	0.44	0.89	1.55	2.01	10.74	4717
5	0.39	0.94	1.27	2.60	3.74	14.64	10785
7	0.53	0.42	0.00	0.95	1.91	2.10	599
11b	0.55	0.97	1.40	2.92	3.84	49.44	40903
12	0.66	1.30	1.04	3.00	4.63	20.16	17136
14	0.94	1.31	1.11	3.36	4.64	27.30	25990
18	0.74	0.73	0.00	1.47	3.01	0.66	291

Adapted from: Stocks, B.J. 1987. Fire behavior in immature jack pine. Can. J. For. Res. 17: 80–86.

The problem

Assumption:

Values for fire behavior databases are given as though they are a 'magical' constant for a particular fuel type and burning condition rather than an average with statistical ranges associated with it.

Obvious questions:

1. **How accurate are these averages?**
2. **What is the standard deviation/standard error level of each average?**
3. **What is the absolute range in these values?**

The problem

Reason for questions:

1. **Suppression activities – Concerns regarding rate of spread/intensity values: is it safe to send fire crews to work on a firefront?**

Rate of spread average of 6.5 m/min

5.0 - 8.0 versus 5.0 – 15.0 m/min

The problem

Fire behavior is difficult to quantify in the past because of:

- The lack of adequate sampling due to field expenses and expense of monitoring equipment.
- Equipment failures.
- Reliance on visual observations based on fixed-point measurements.
- Research personnel safety concerns.
- Mother nature never cooperates (e.g., wind lulls and gusts, wind direction changes, etc.).

FIRE BEAR Project
(Fire Effects in the Boreal Eurasia Region)

- To better understand fire in central Siberia, the FIRE BEAR Project was created as a forest fire research study to provide answers to basic questions on fire management.
- Replicated 200 x 200-m experimental burn plots on Scots pine (*Pinus sylvestris)* / lichen (*Cladonia* sp.) / feather moss (*Pleurozeum schreberi*) forest sites.
- Fuel and fire behavior on these fires was quantified.

FIRE BEAR Project

(Fire Effects in the Boreal Eurasia Region)

Rate of spread: 2.5 m/min
Fireline intensity: 620 kW/m

Rate of spread: 4.9 m/min
Fireline intensity: 2259 kW/m

Rate of spread: 5.6 m/min
Fireline intensity: 5220 kW/m

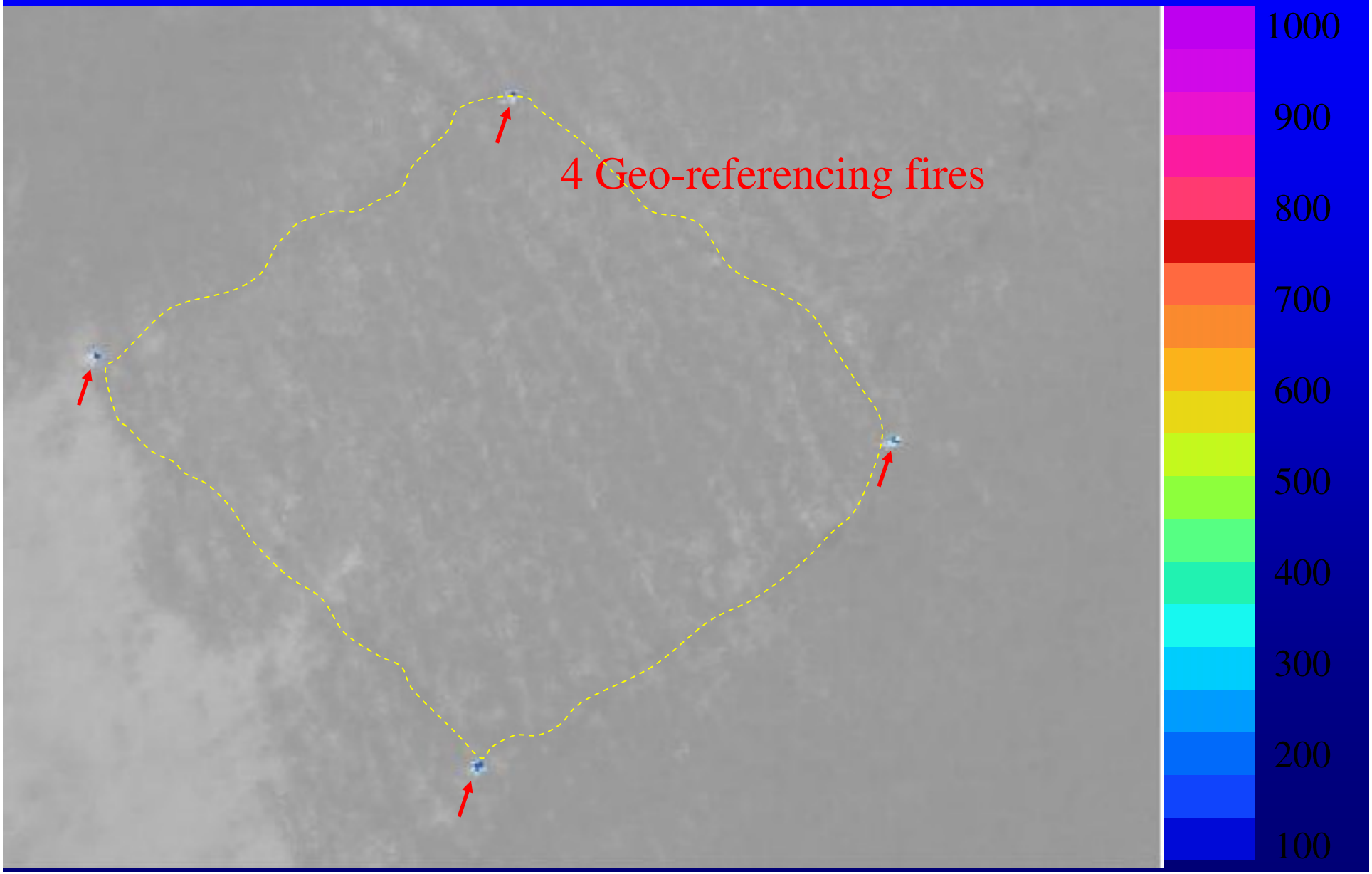
Boguchany, Russian, June 18, 2002

Plot 1 3:29:11 PM

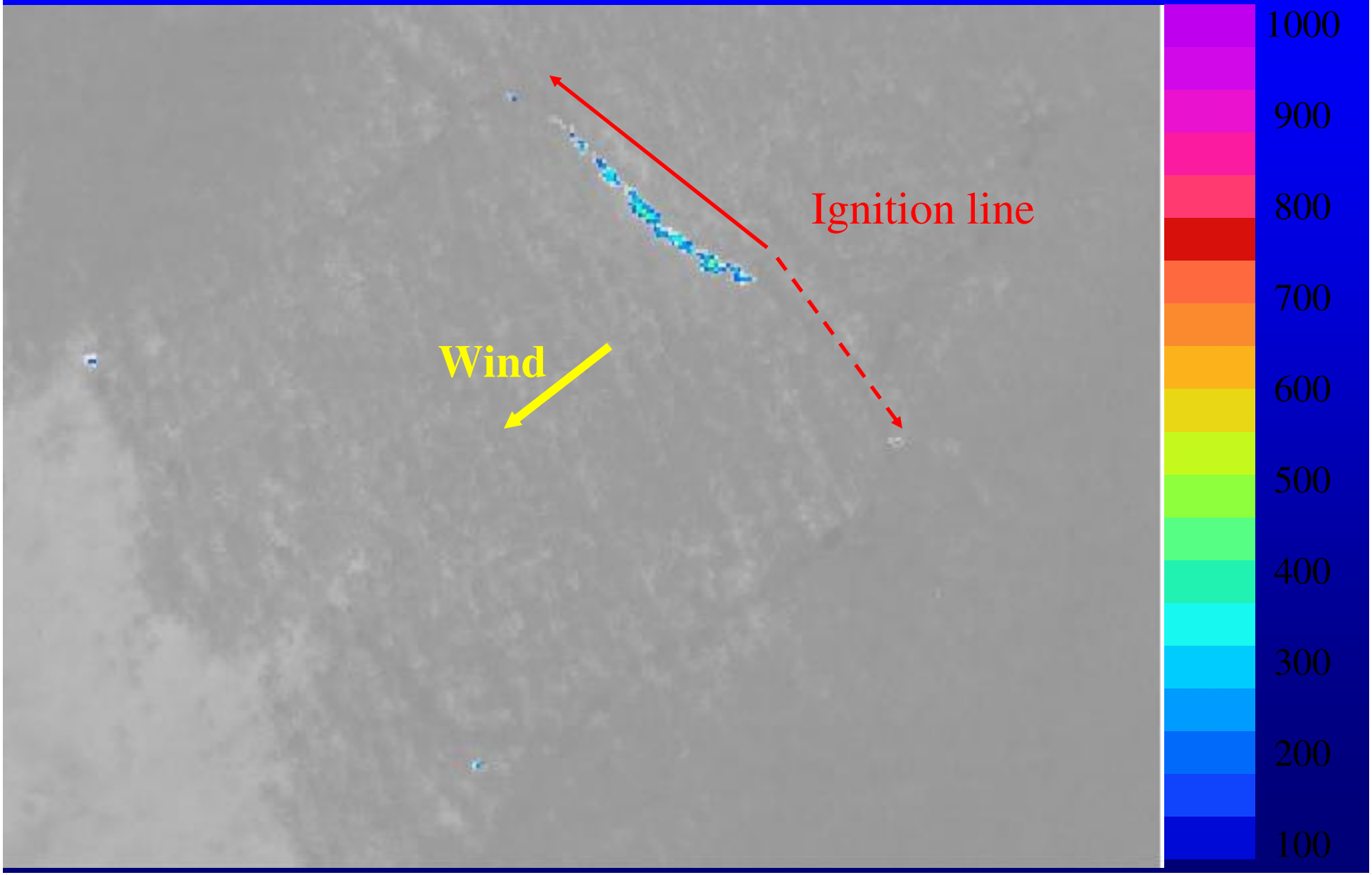
4 Geo-referencing fires

1000
900
800
700
600
500
400
300
200
100

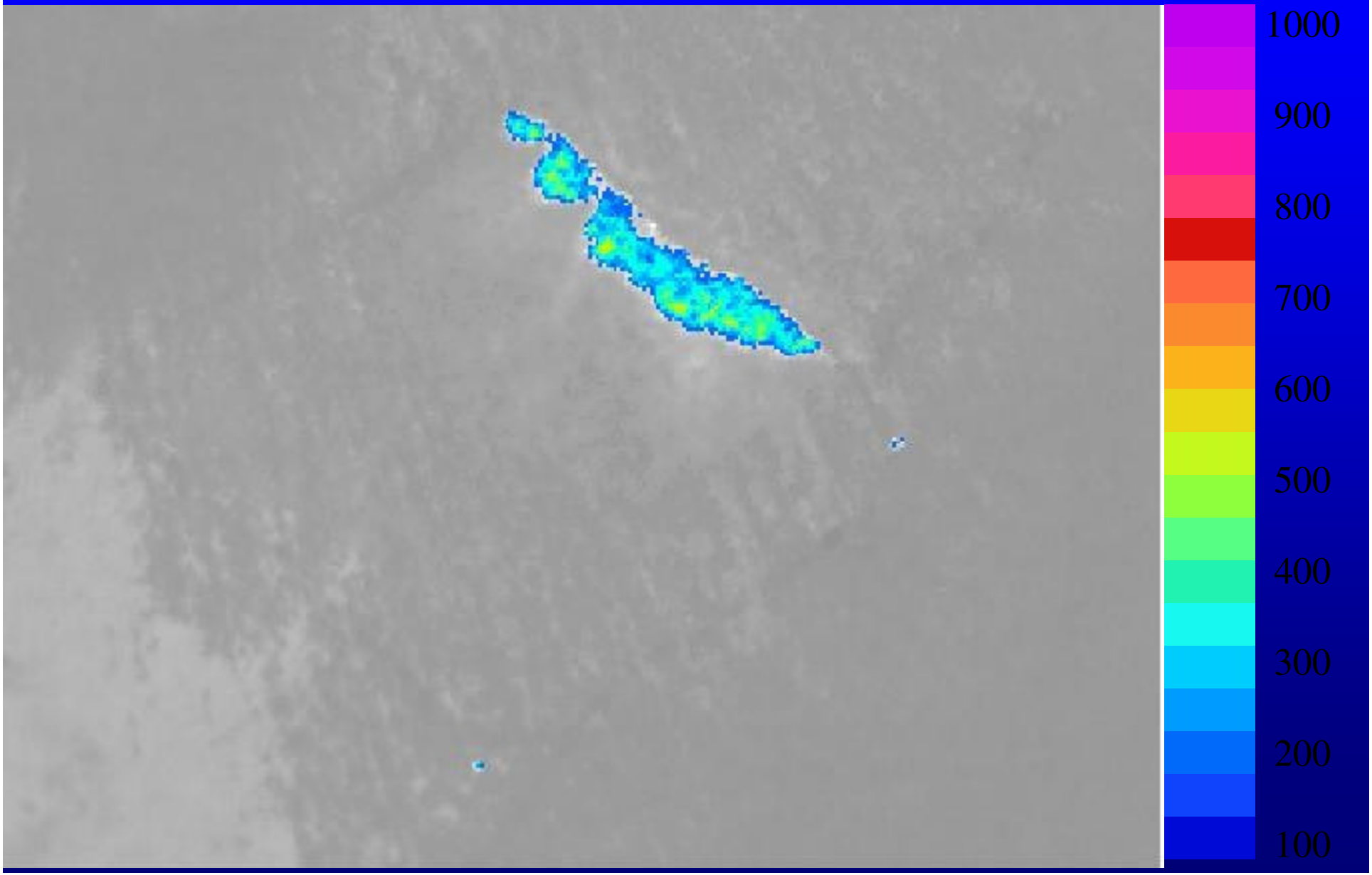
Boguchany, Russian, June 18, 2002



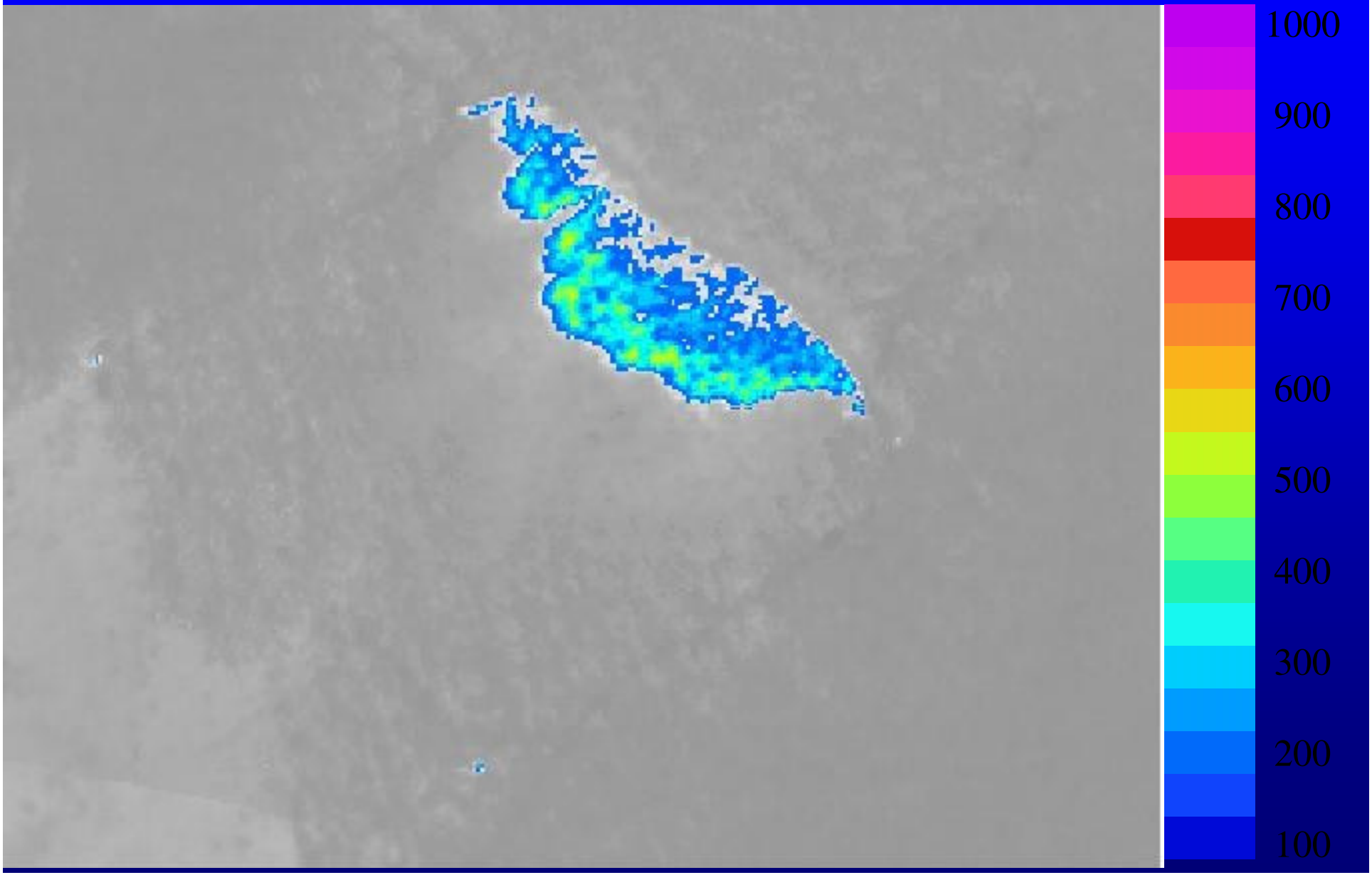
Boguchany, Russian, June 18, 2002



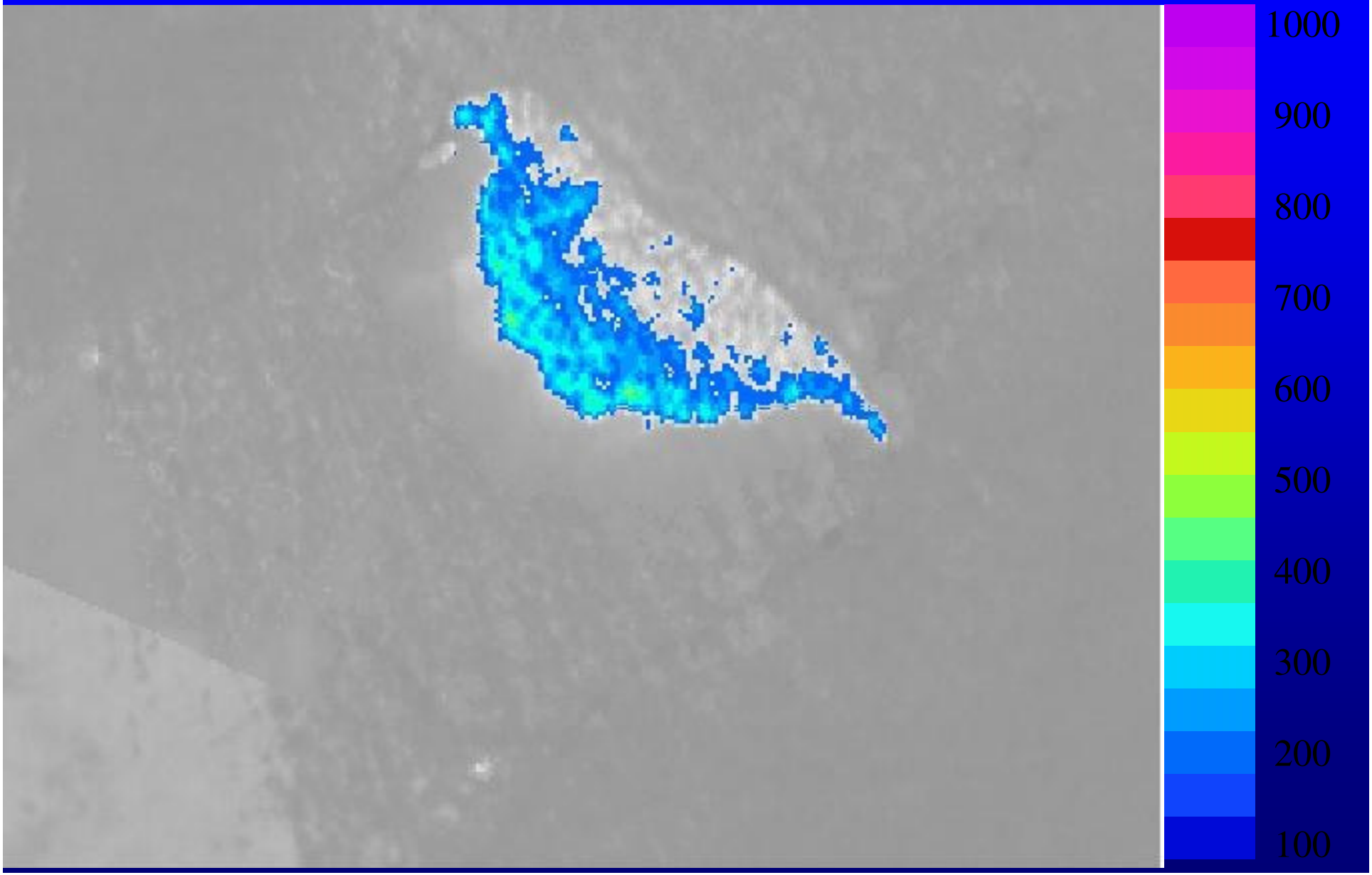
Boguchany, Russian, June 18, 2002



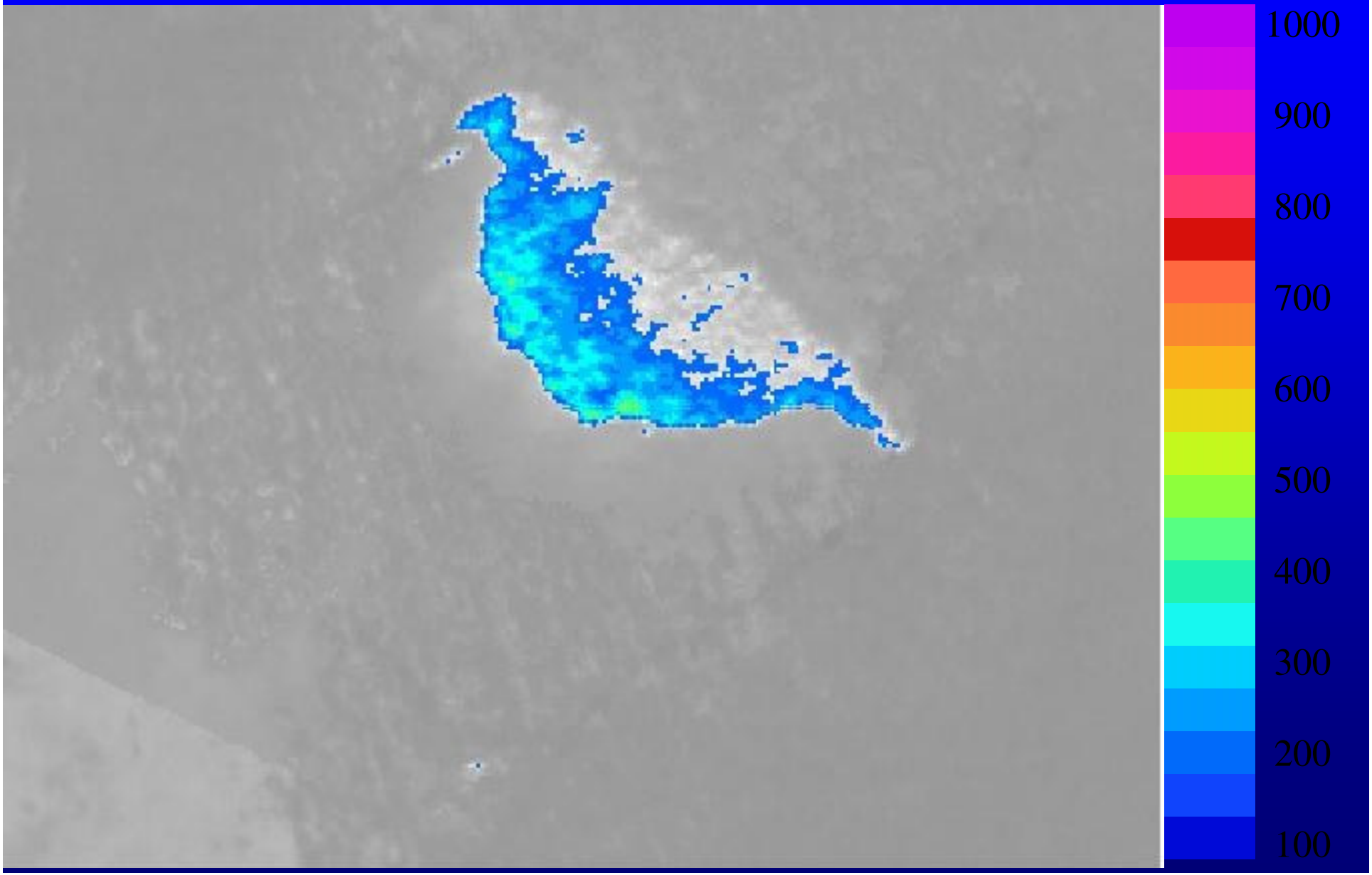
Boguchany, Russian, June 18, 2002



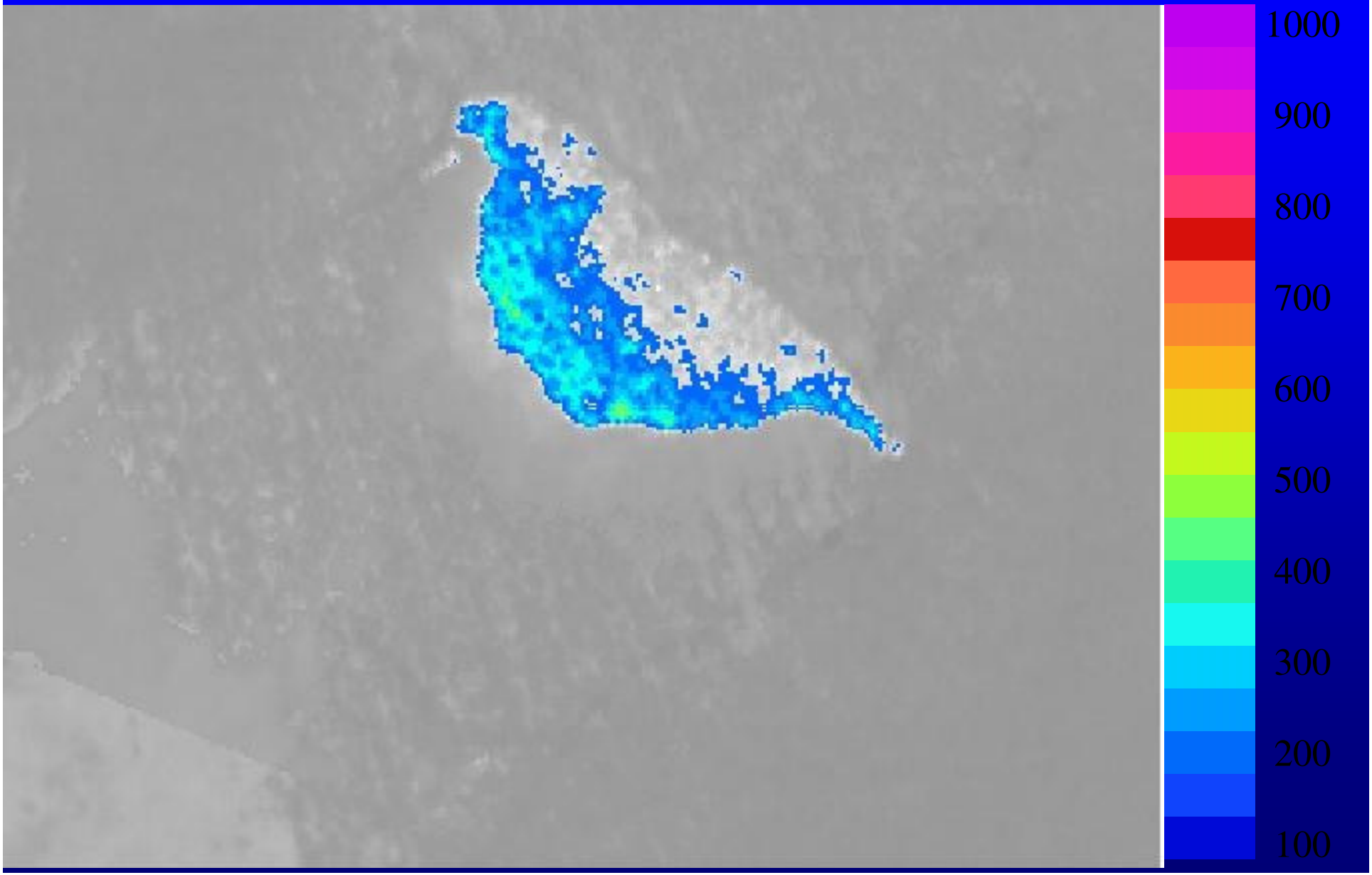
Boguchany, Russian, June 18, 2002



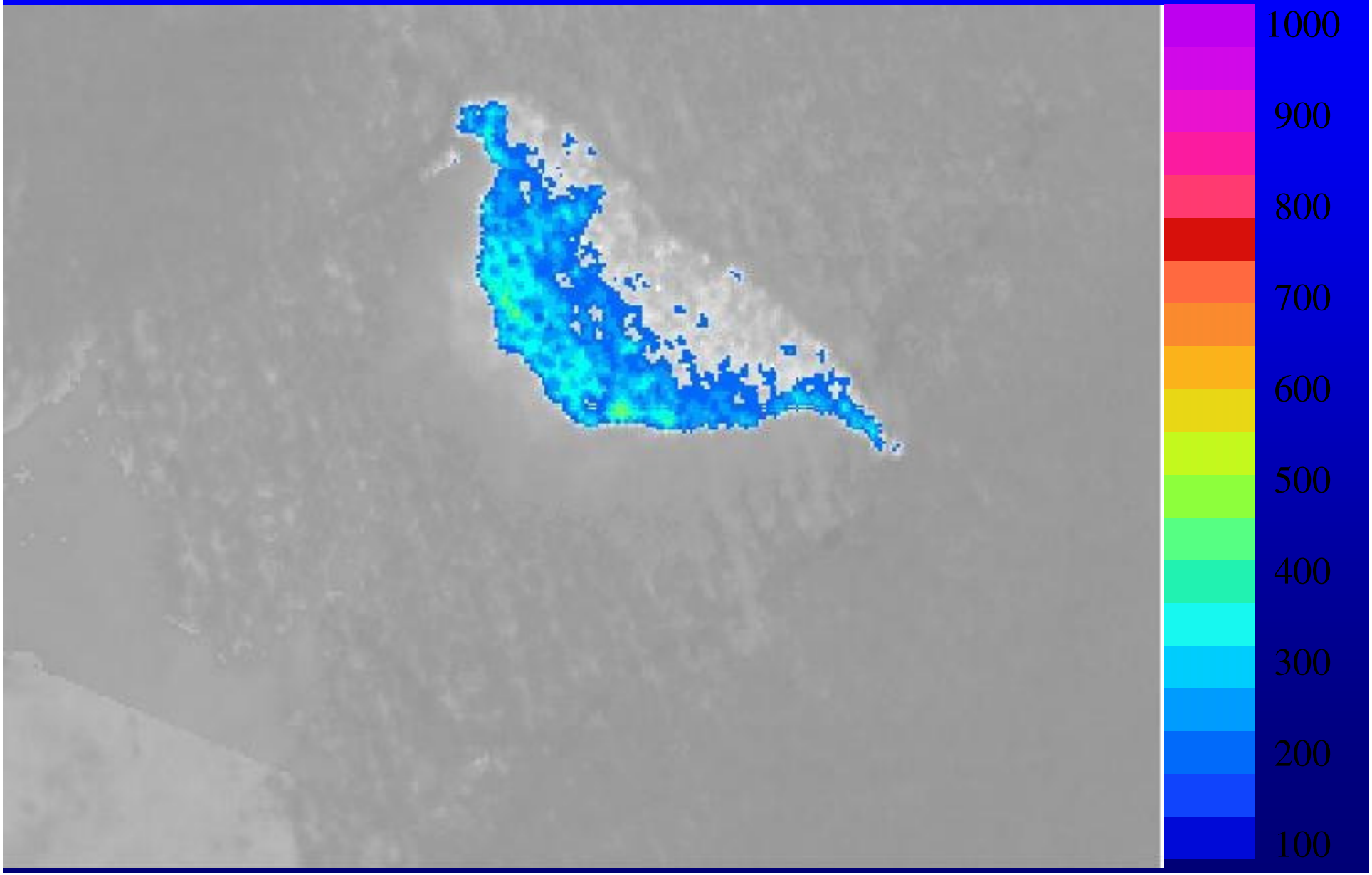
Boguchany, Russian, June 18, 2002



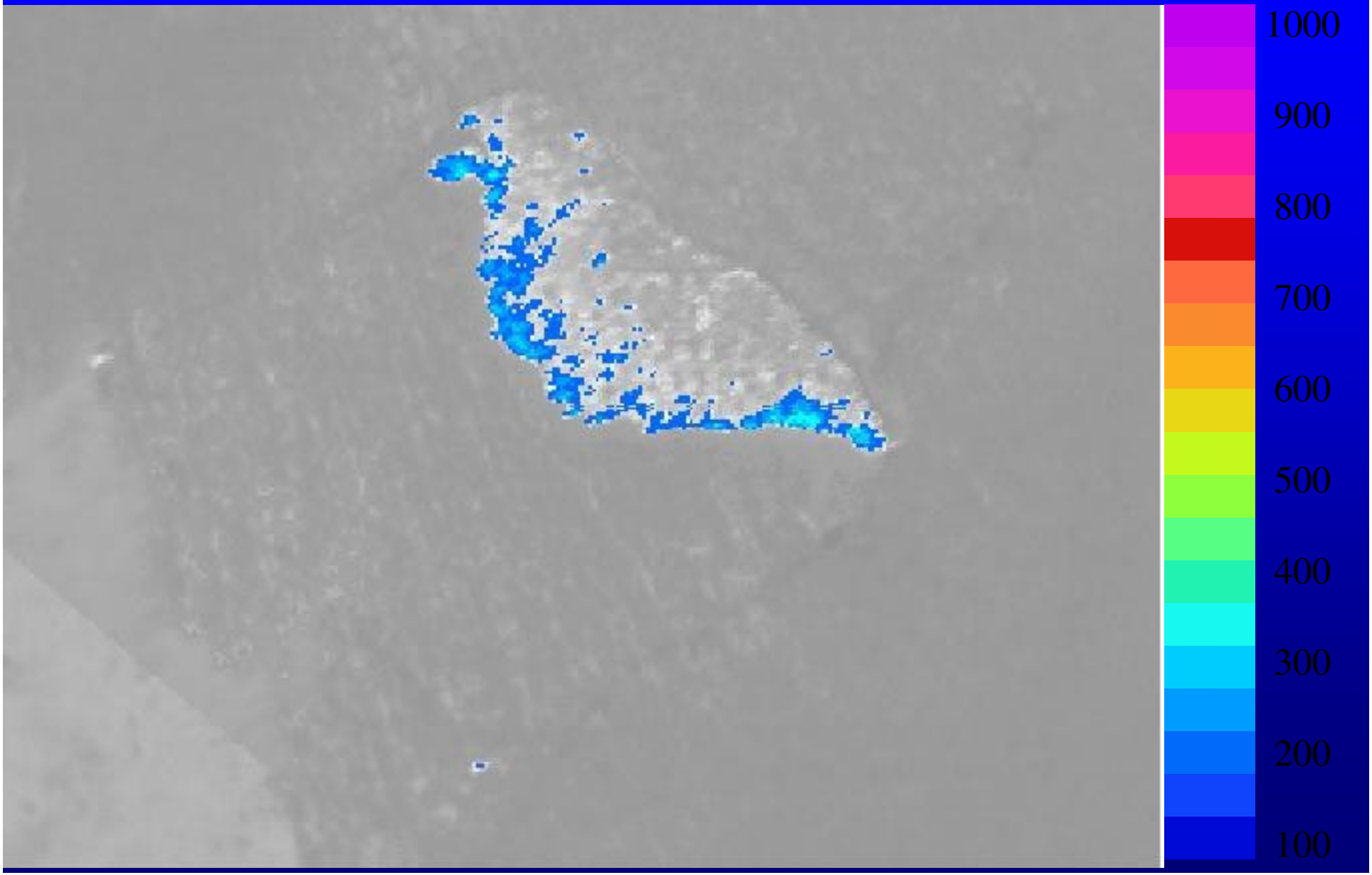
Boguchany, Russian, June 18, 2002



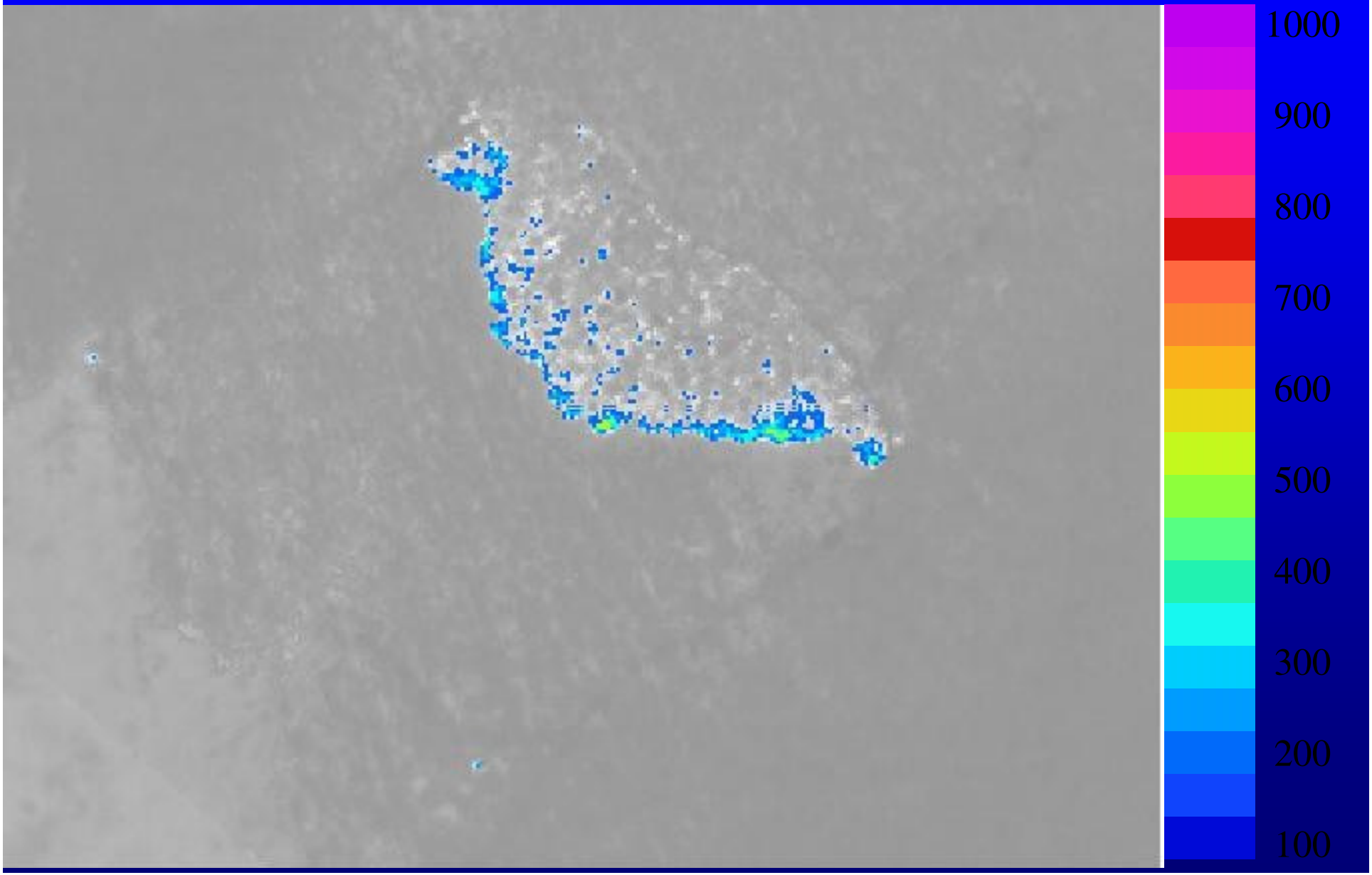
Boguchany, Russian, June 18, 2002



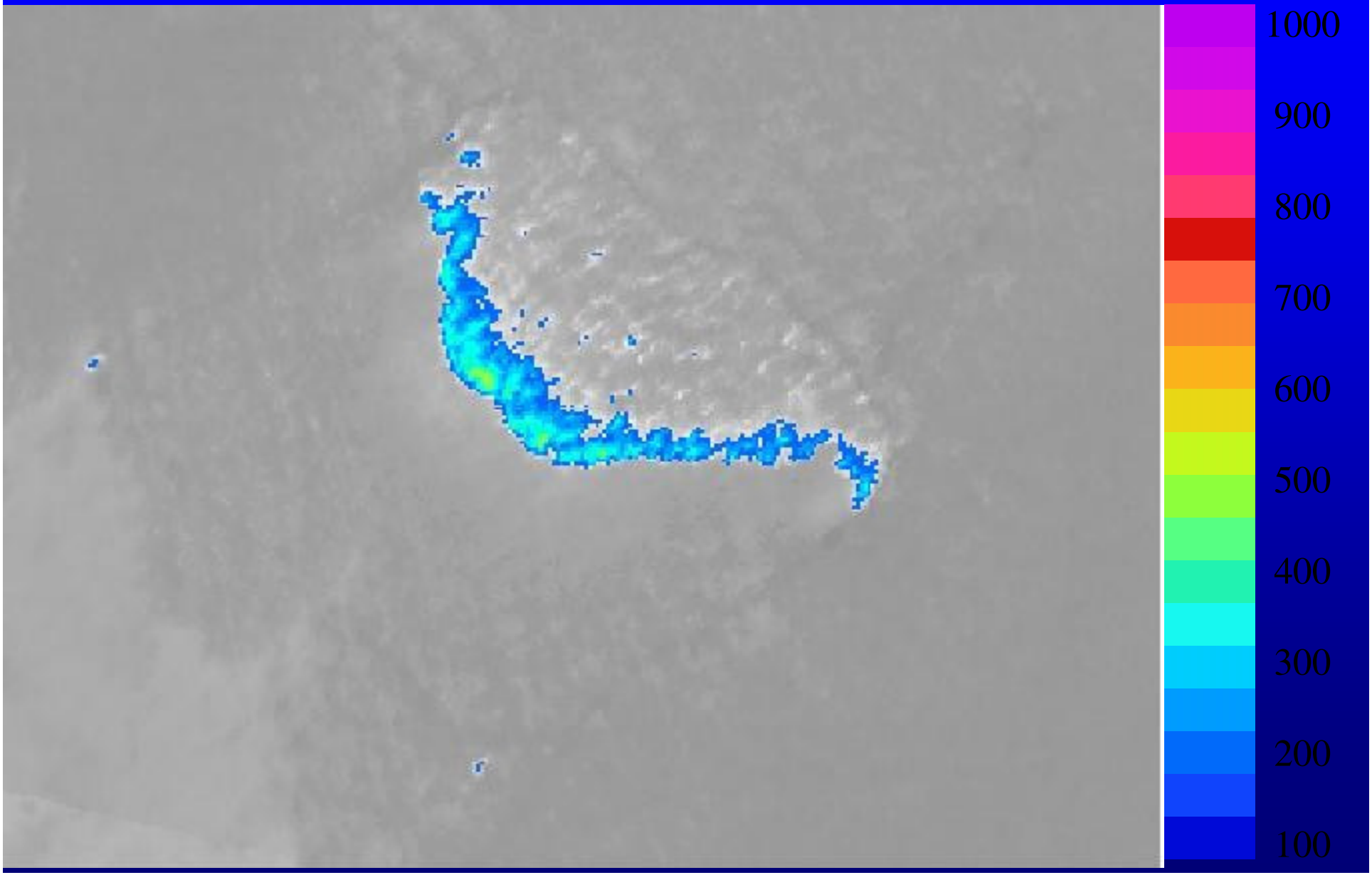
Boguchany, Russian, June 18, 2002



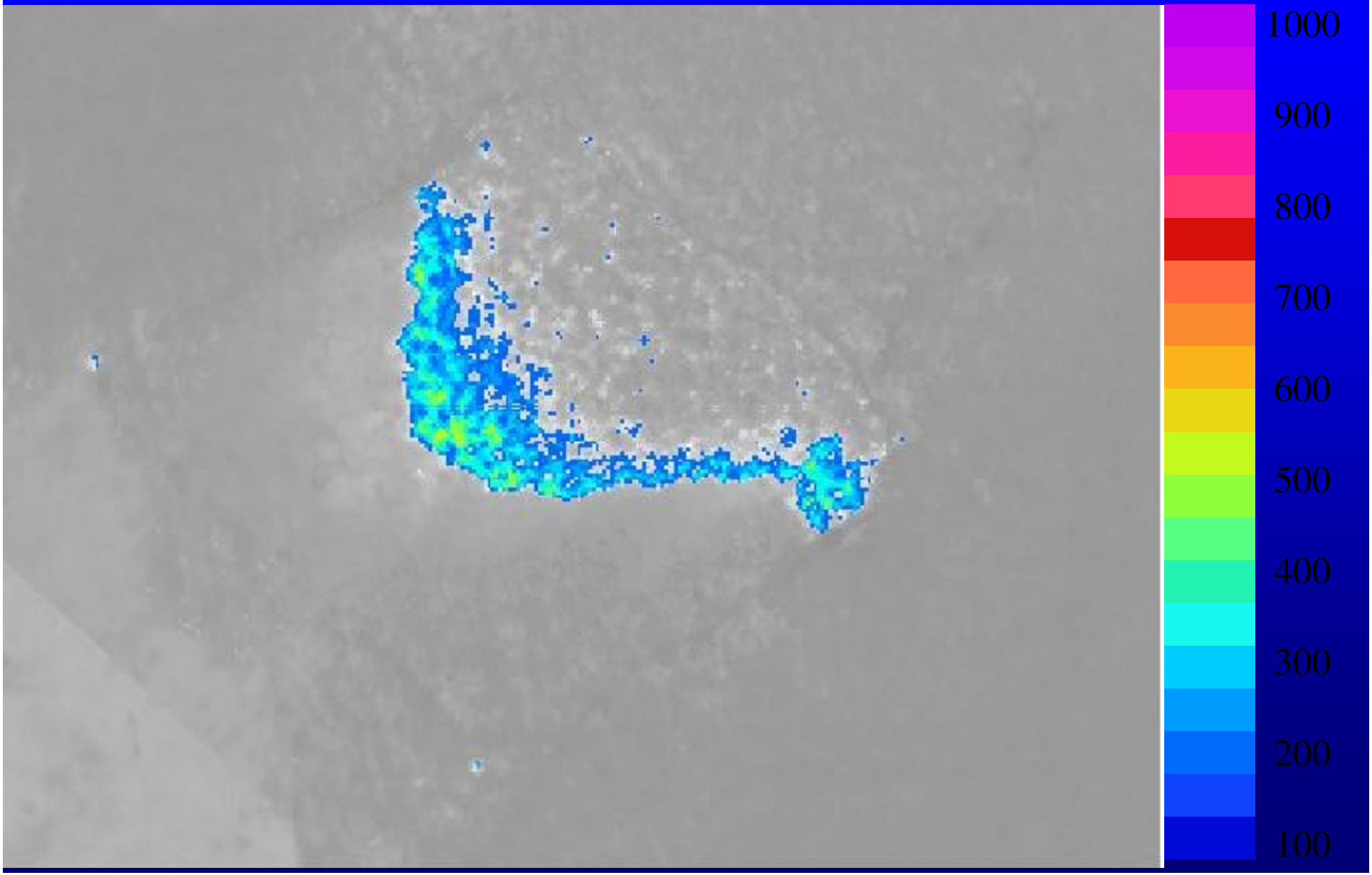
Boguchany, Russian, June 18, 2002



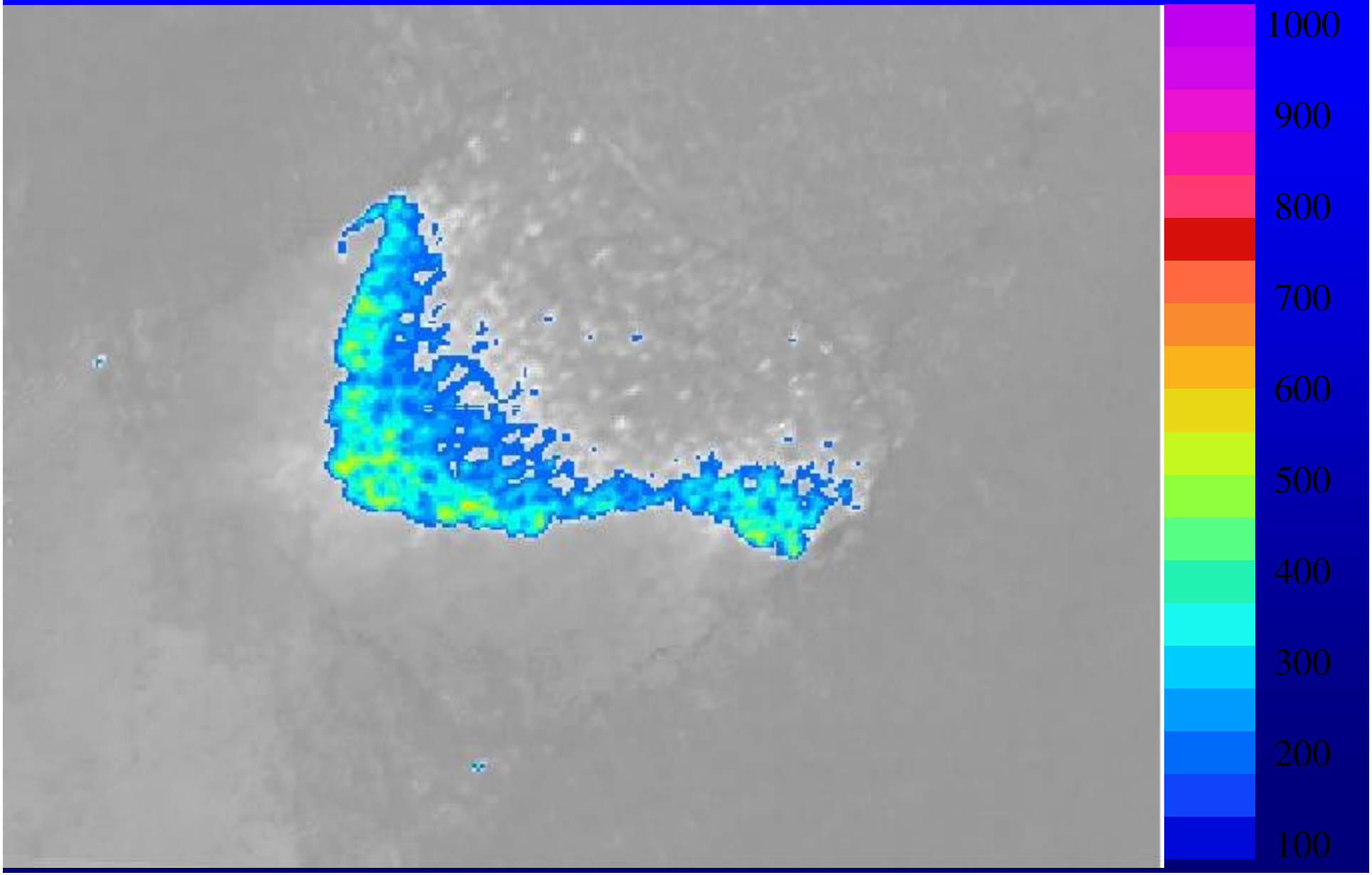
Boguchany, Russian, June 18, 2002



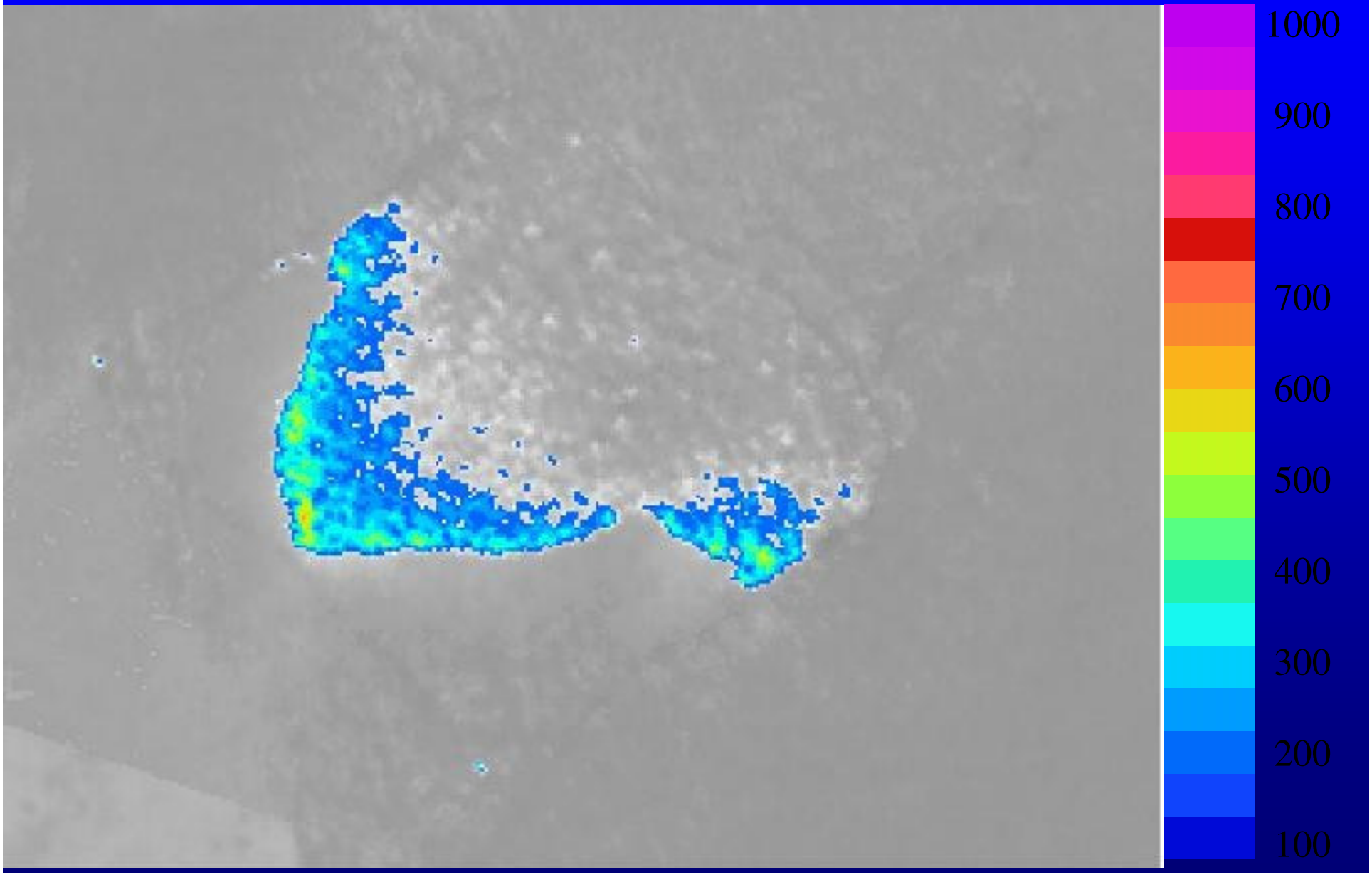
Boguchany, Russian, June 18, 2002



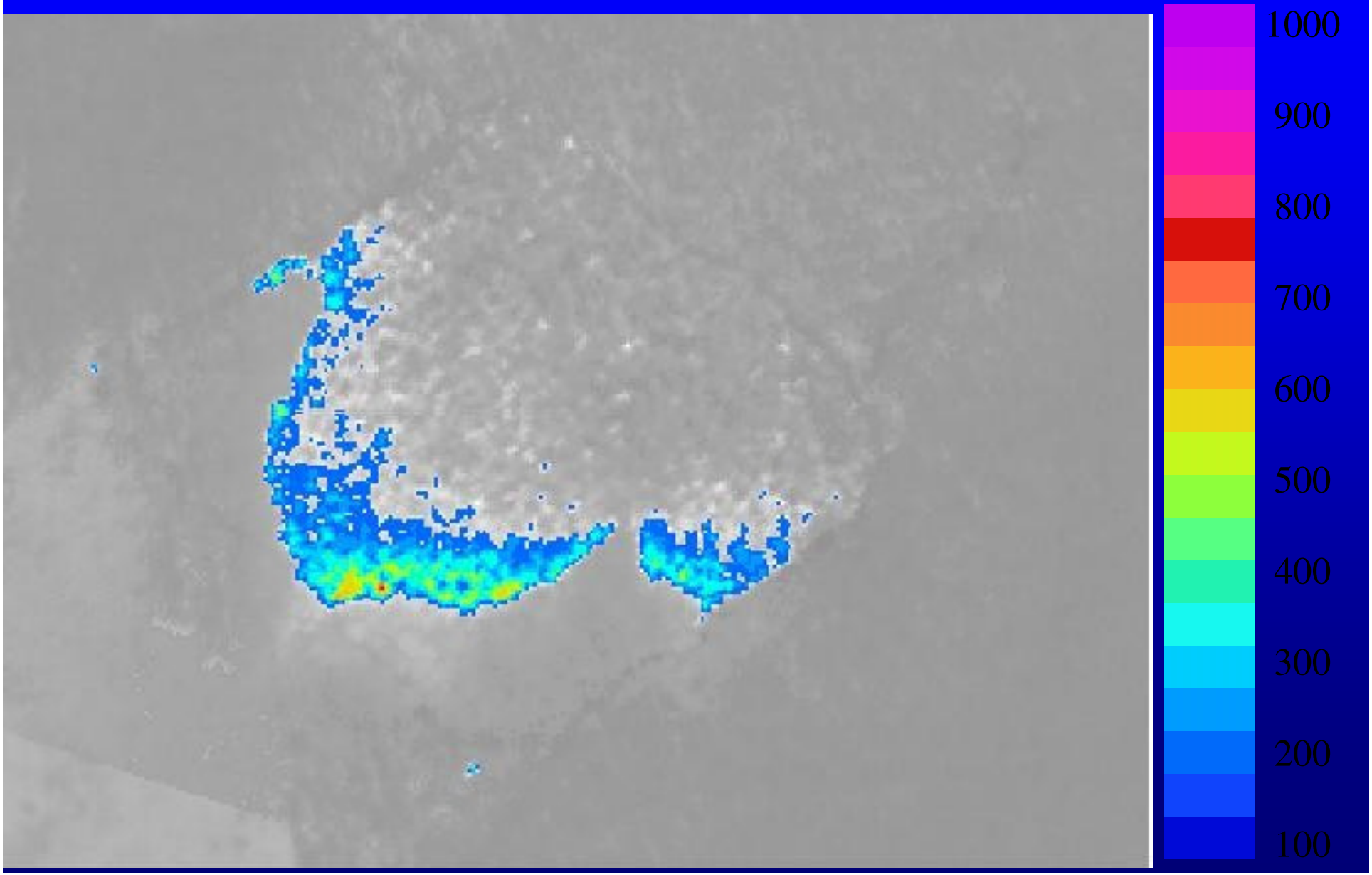
Boguchany, Russian, June 18, 2002



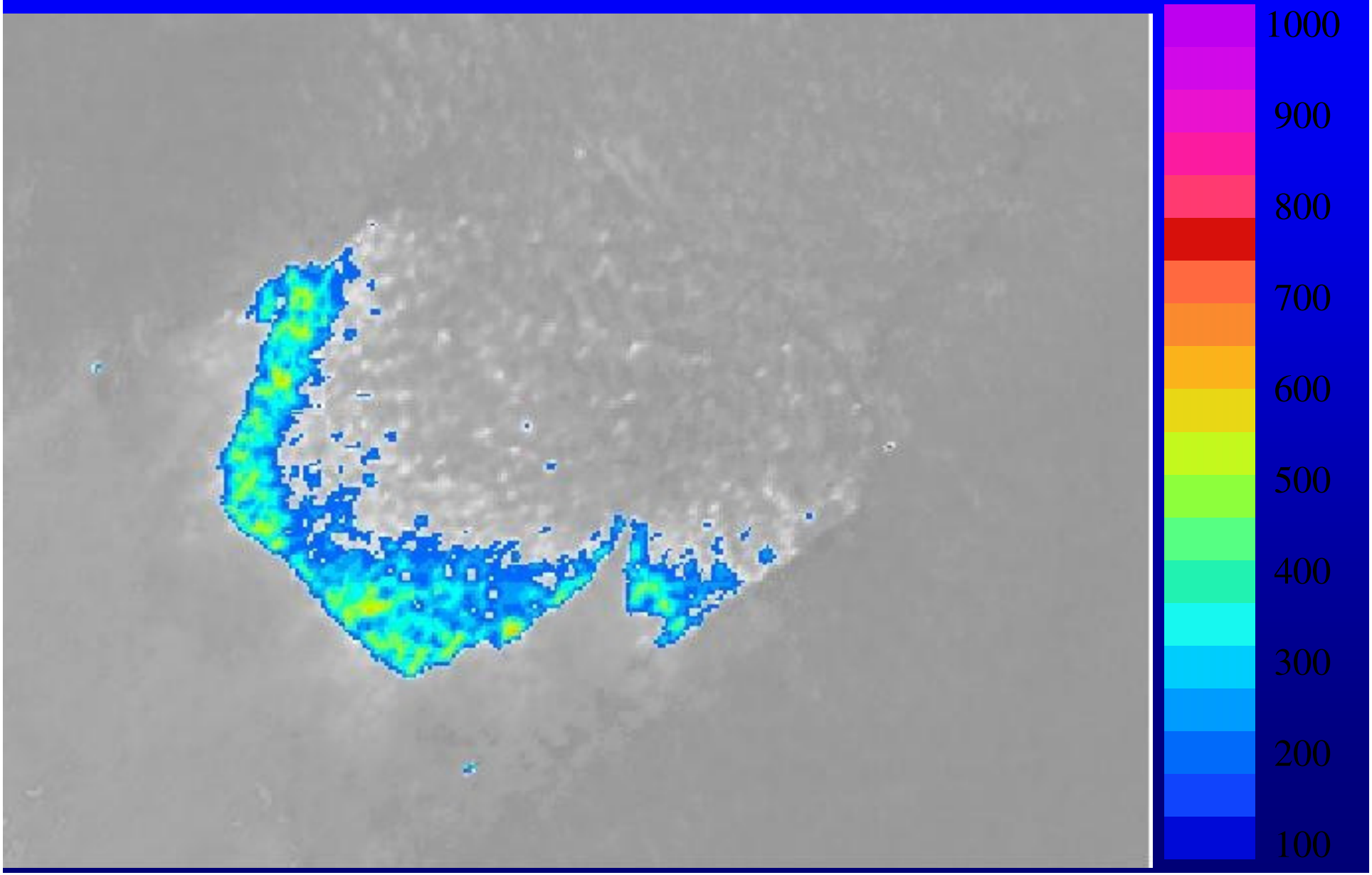
Boguchany, Russian, June 18, 2002



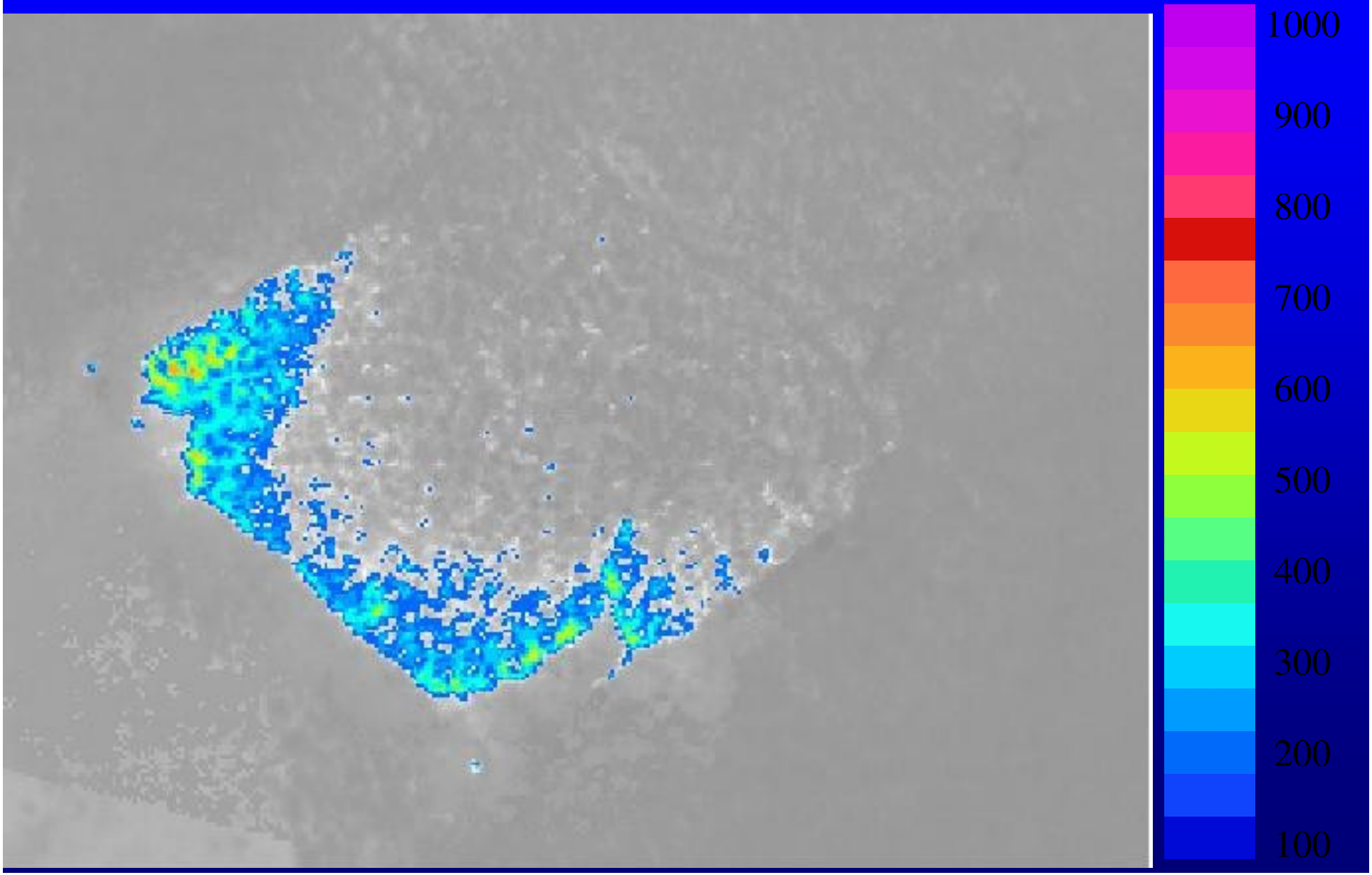
Boguchany, Russian, June 18, 2002



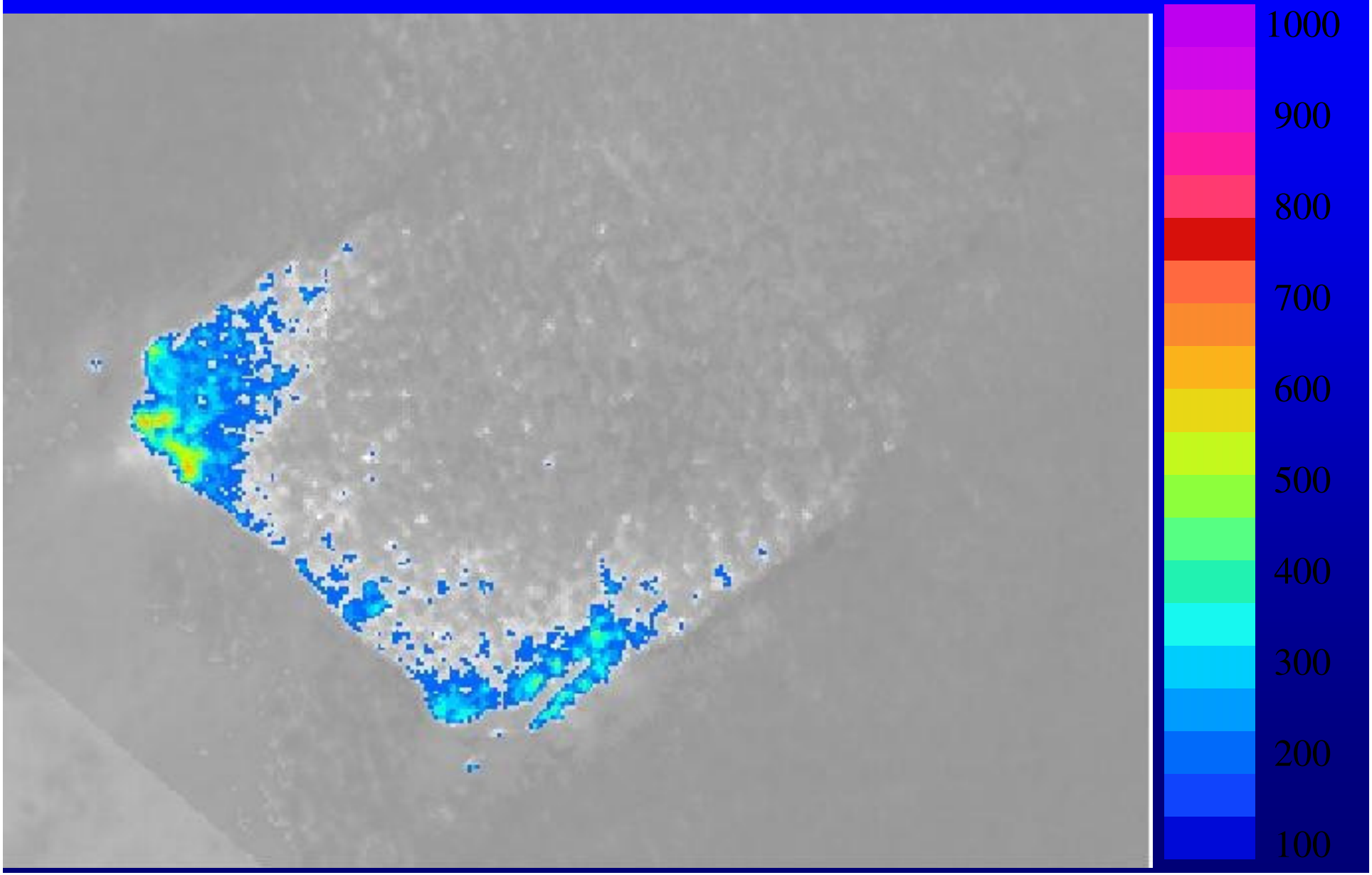
Boguchany, Russian, June 18, 2002



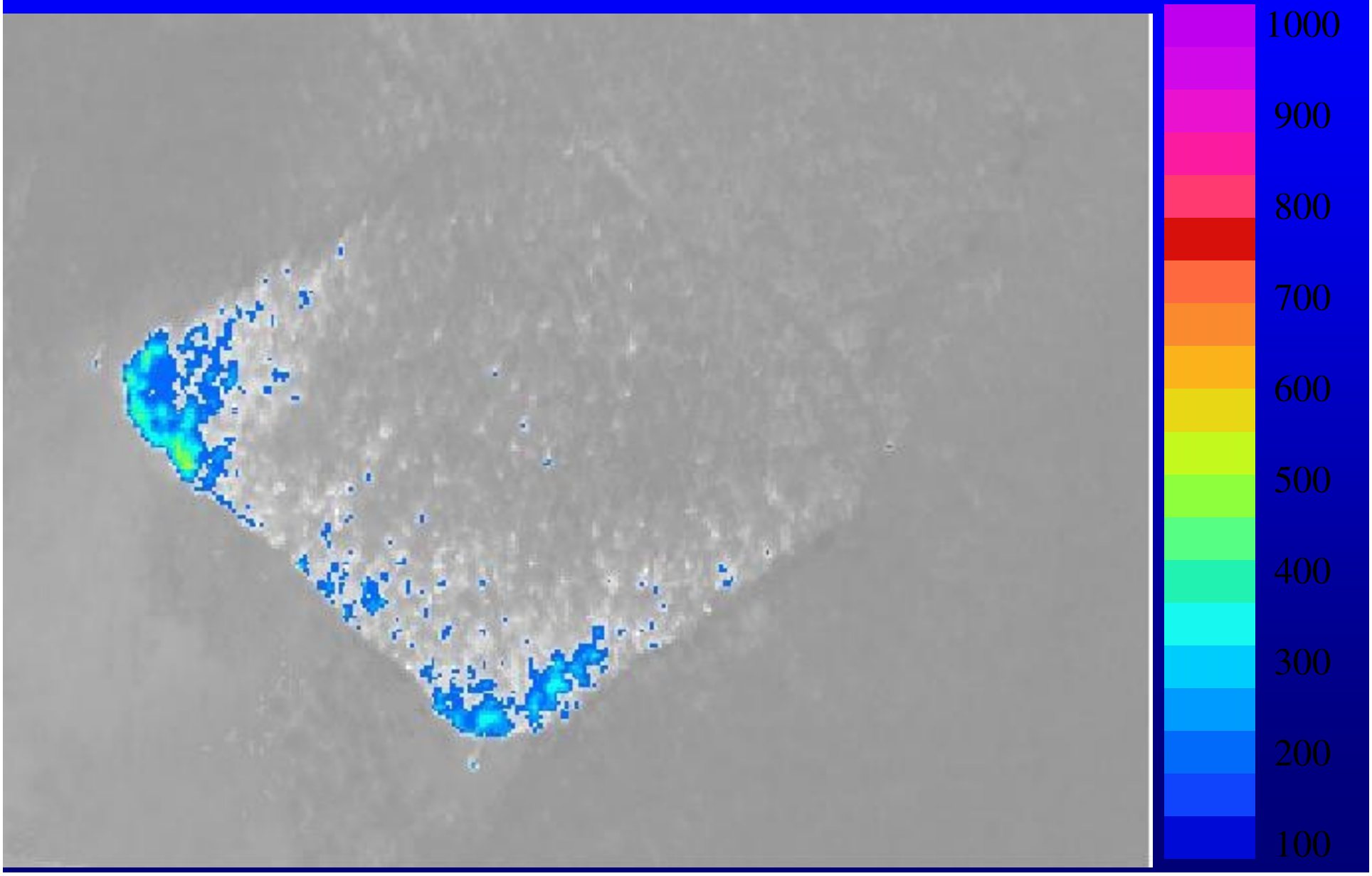
Boguchany, Russian, June 18, 2002



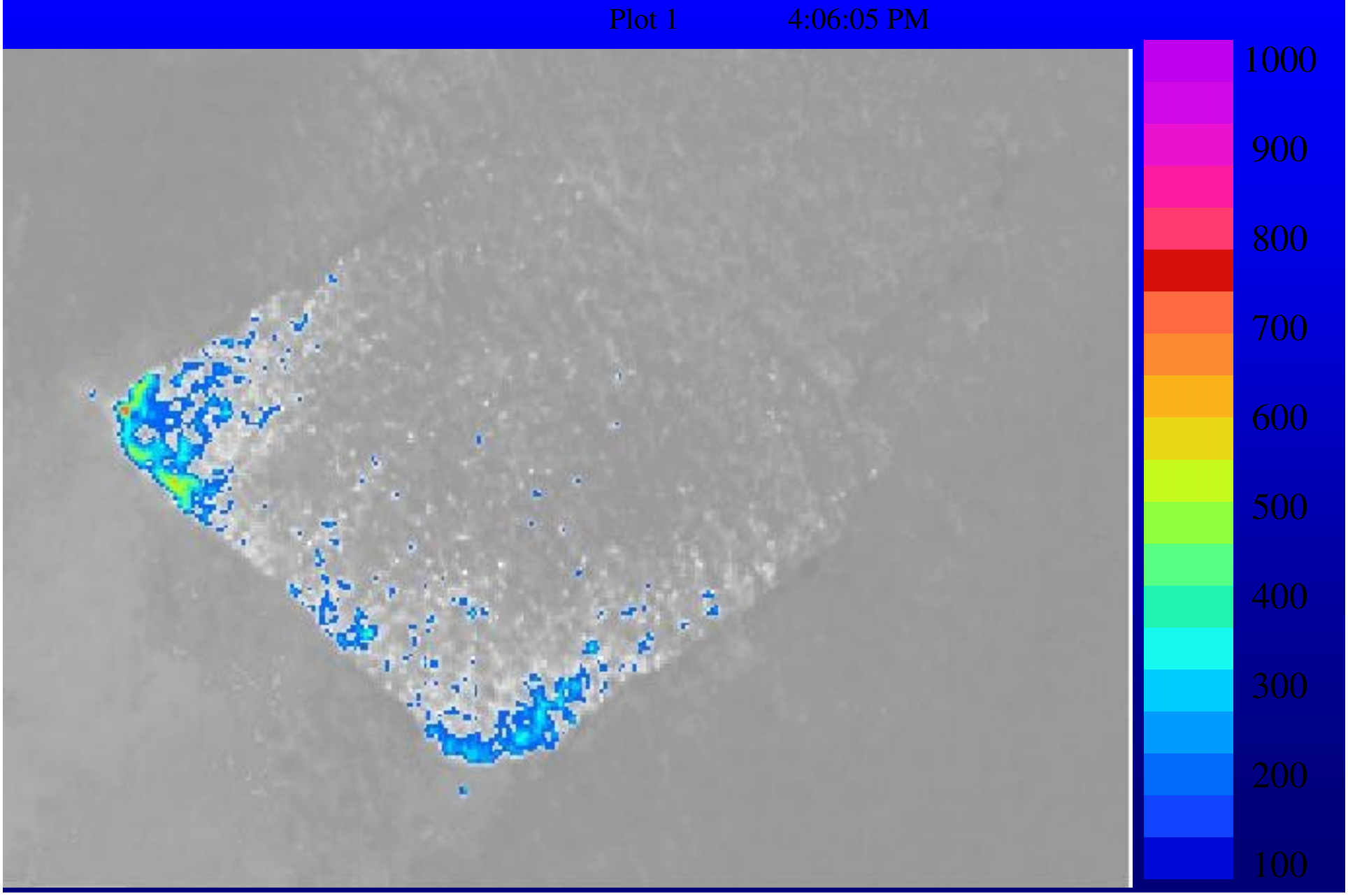
Boguchany, Russian, June 18, 2002



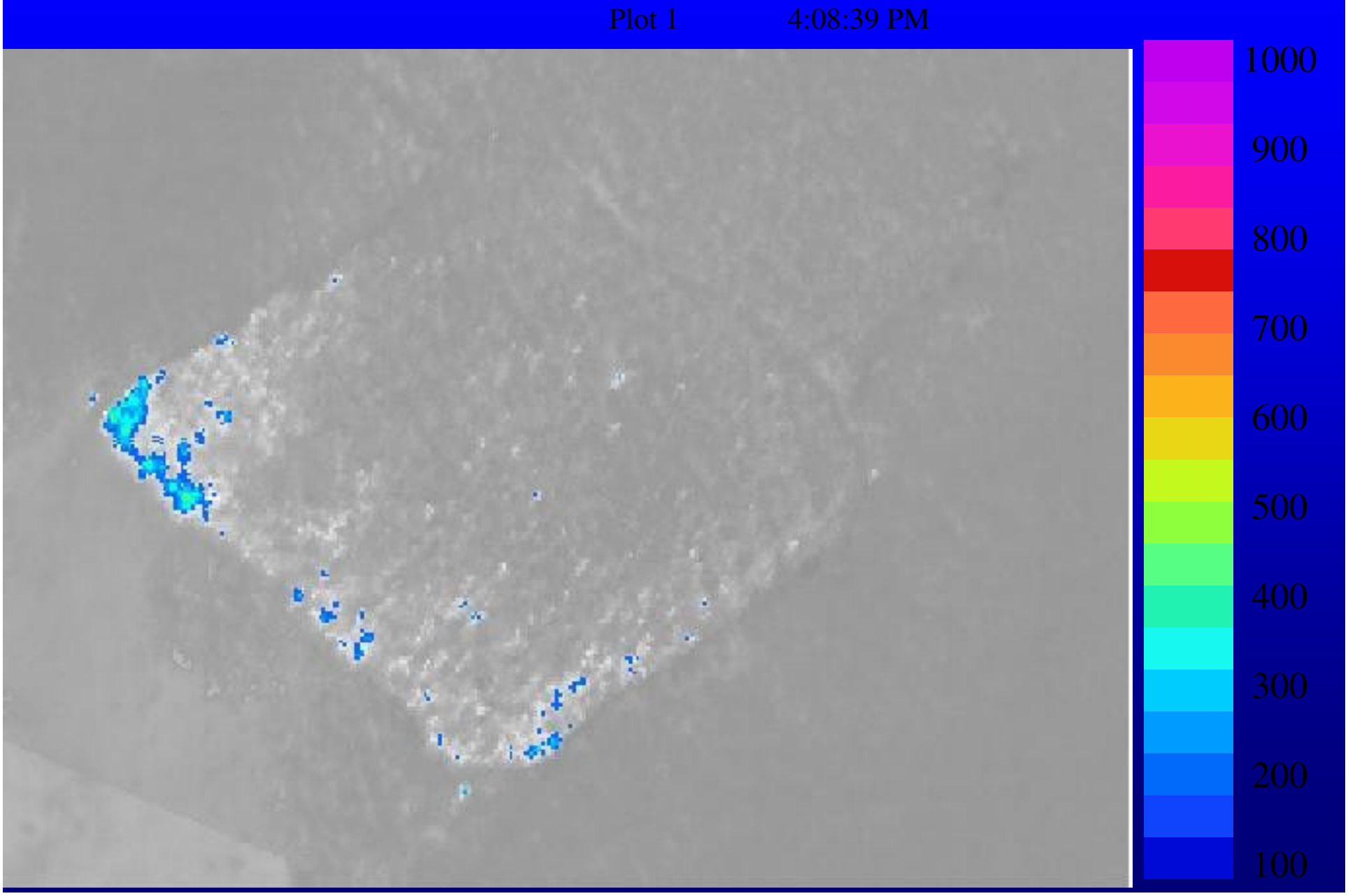
Boguchany, Russian, June 18, 2002



Boguchany, Russian, June 18, 2002

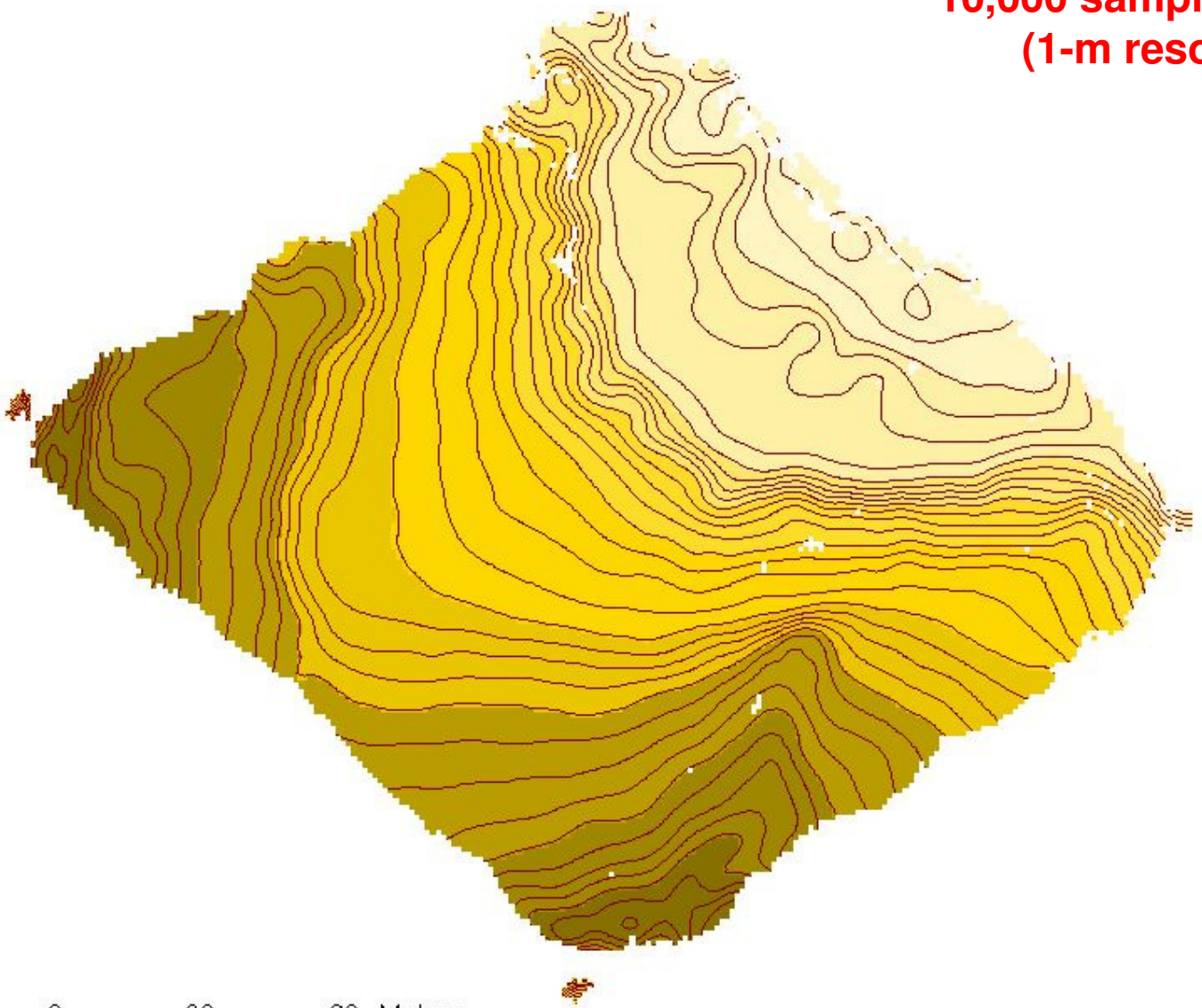


Boguchany, Russian, June 18, 2002



Infrared data analysis

10,000 sample points/ha
(1-m resolution)



Isolines showing firefront locations (seconds)

- 0 - 240
- 240 - 480
- 480 - 720
- 720 - 960
- 960 - 1200
- 1200 - 1440
- 1440 - 1680
- 1680 - 1920
- 1920 - 2160
- 2160 - 2400

0 30 60 Meters

Fire head front location
1-min interval

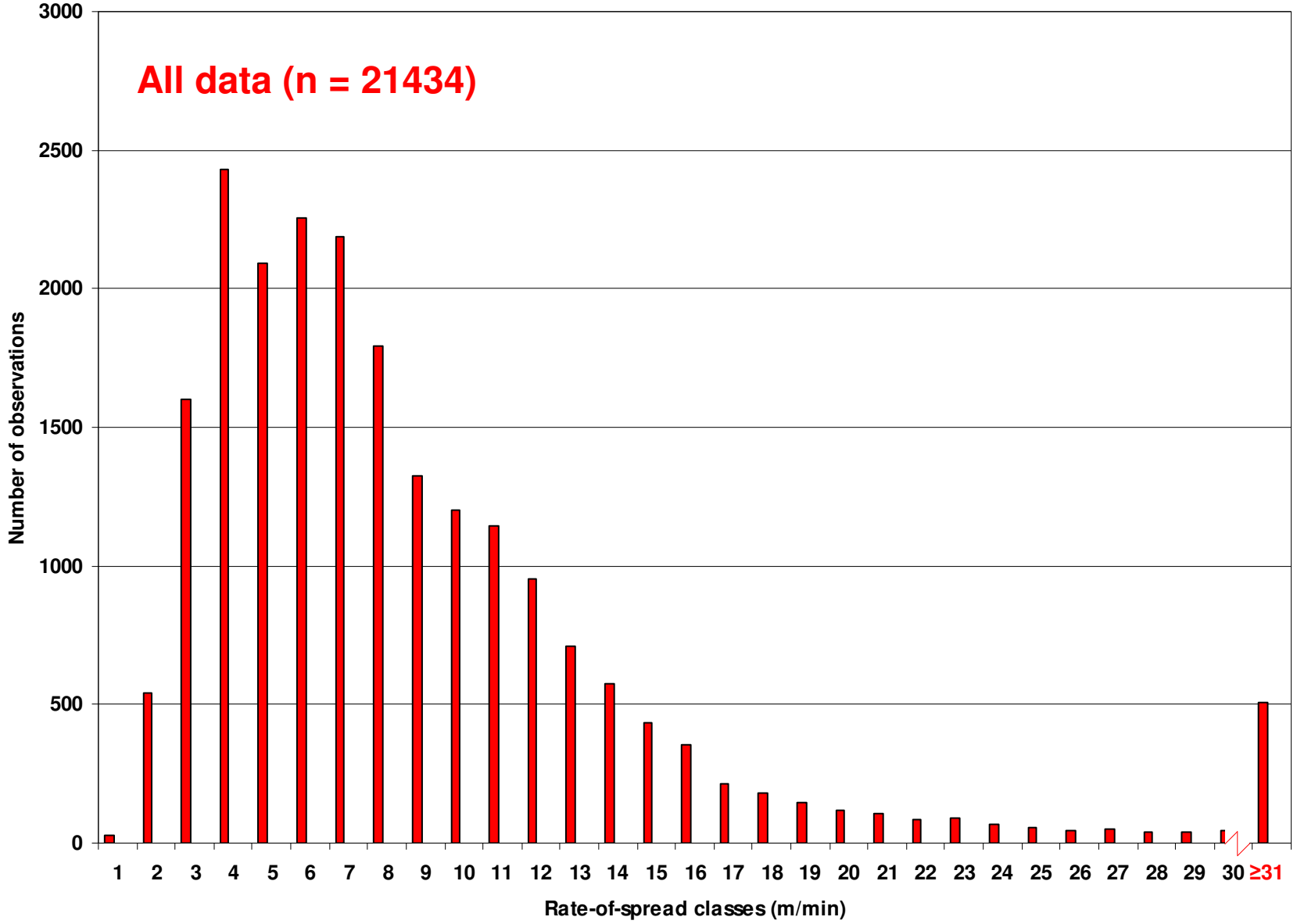
Rate of spread (m/min)

- 0 - 2
- 2 - 4
- 4 - 6
- 6 - 8
- 8 - 10
- 10 - 12
- 12 - 14
- 14 - 16
- 16 - 18
- 18 - 20
- 20 - 22
- 22 - 24
- 24 - 26
- 26 - 28
- 28 - 30
- 30 +

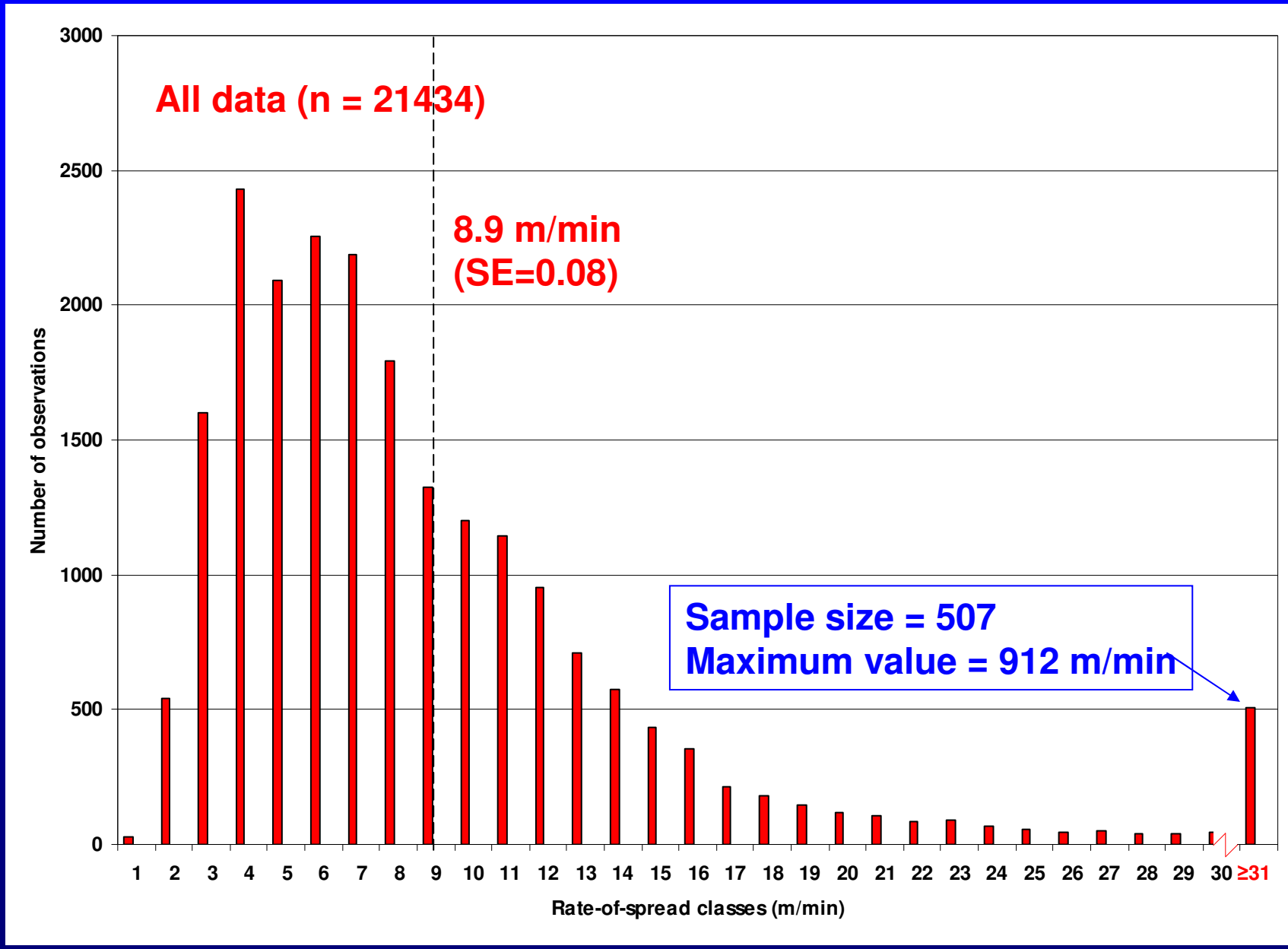
0 30 60 Meters

Fire head front location
1-min interval

Rate of spread



Rate of spread

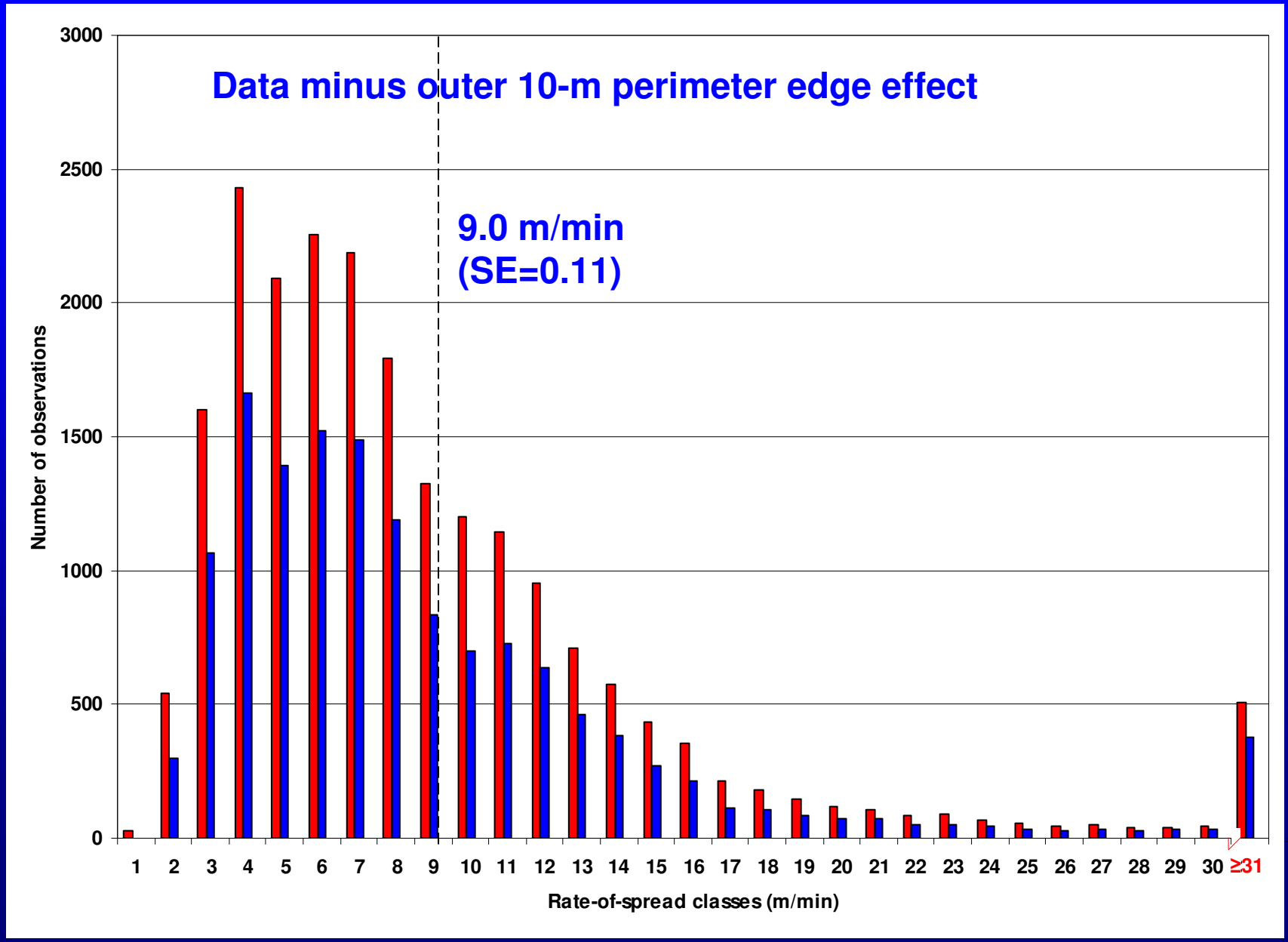


Rate of spread

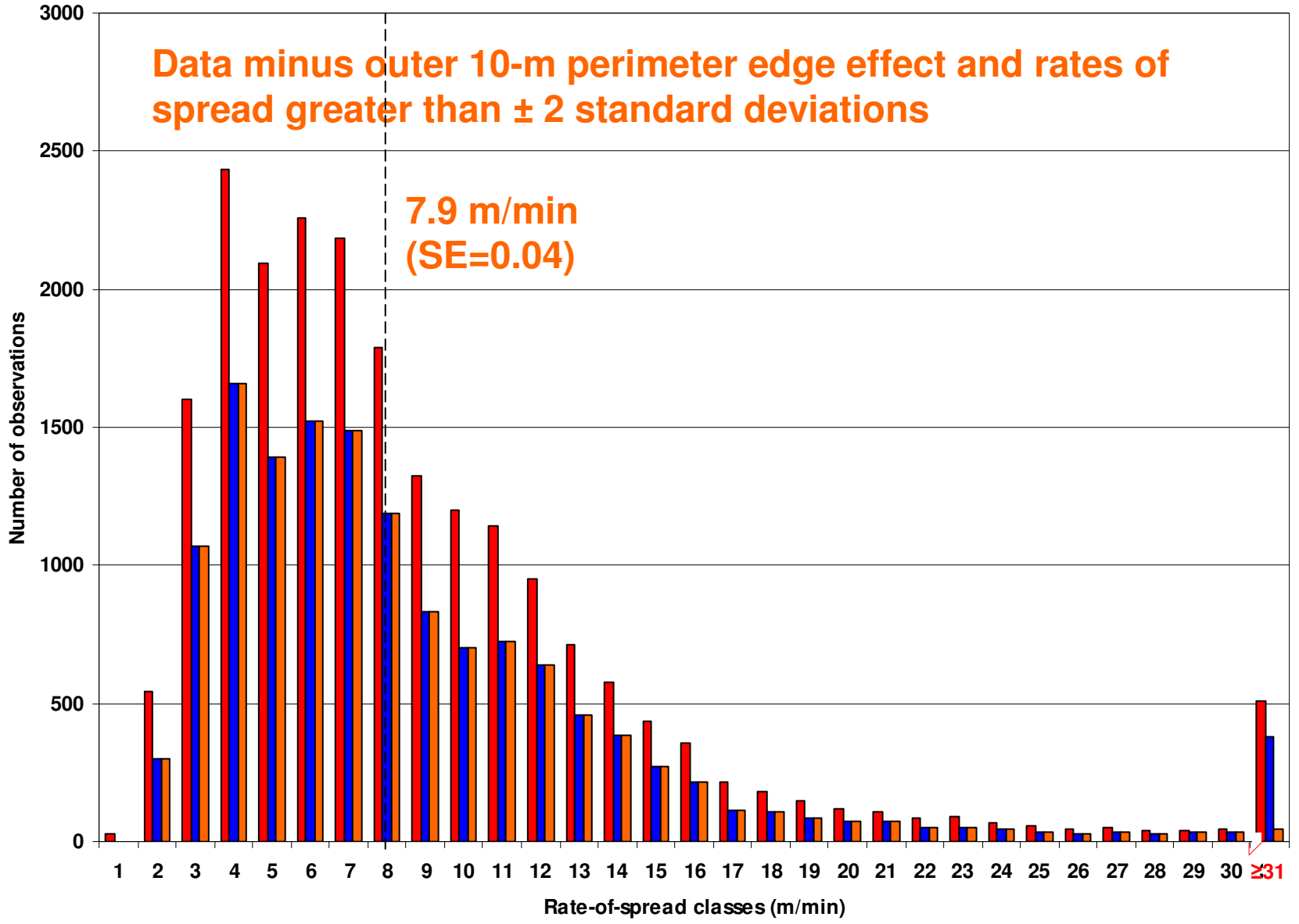
Variability in rates of spread can be caused by:

- Differences in fuel structure.
- Differences in soil (ground fuel) moisture.
- Gusts and lulls in wind speed.
- Changes in wind direction.
- Channeling and acceleration effect on wind.
- Junction zone effects.
- Edge effect of experimental plot.
- Impact of tree density on solar radiation and fuel dryness.
- Spotting.
- Analysis problems.

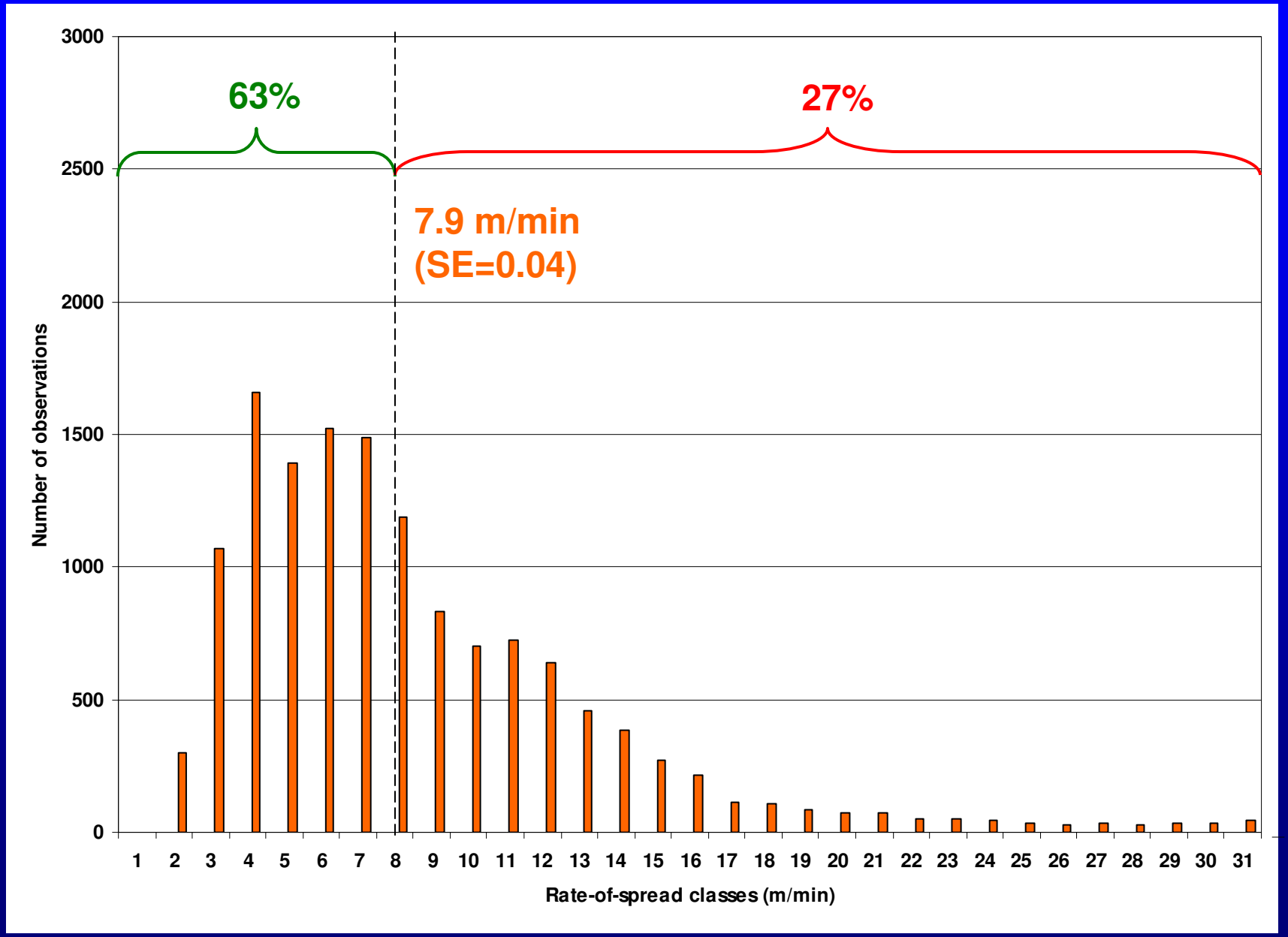
Rate of spread



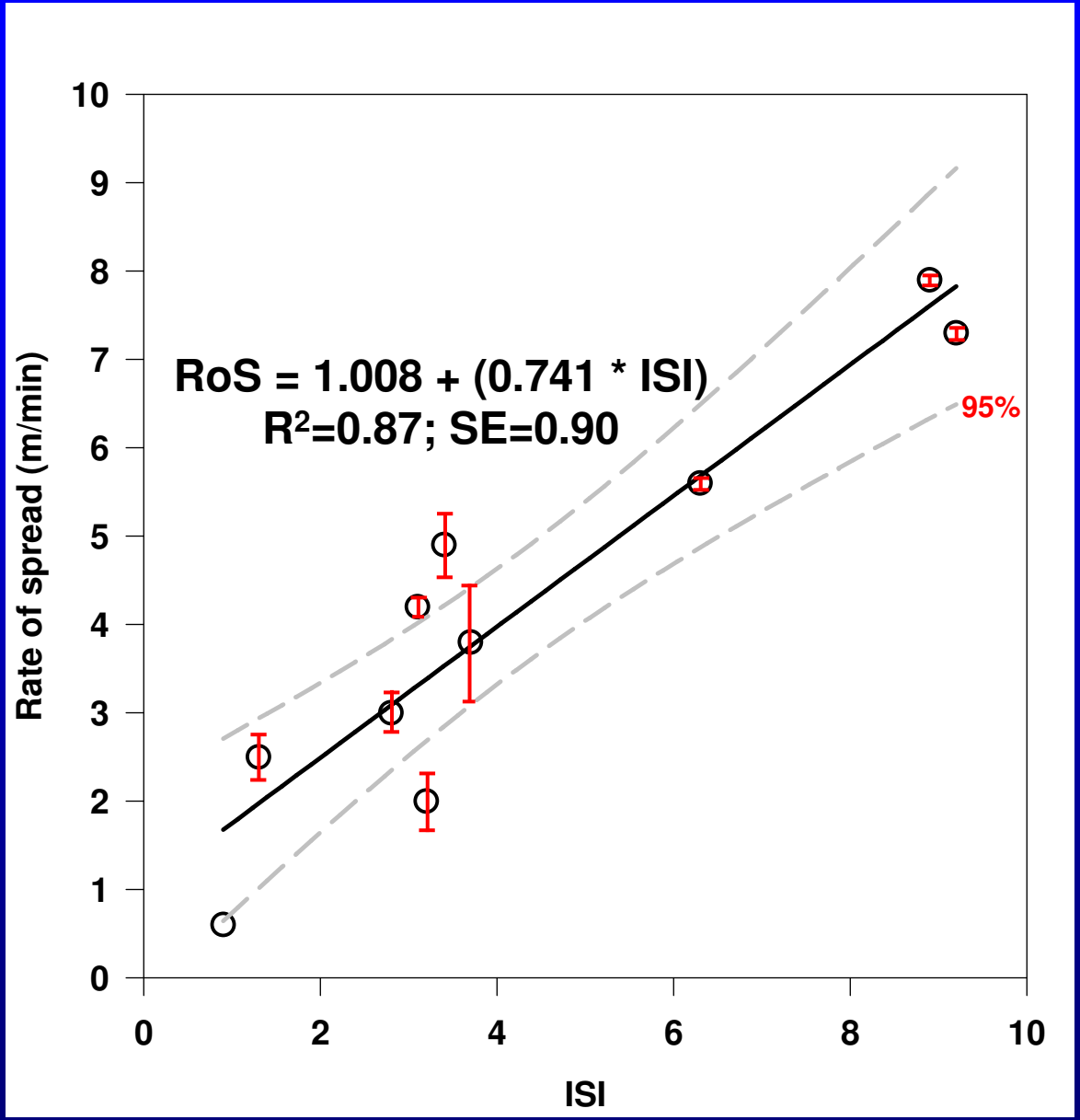
Rate of spread



Rate of spread

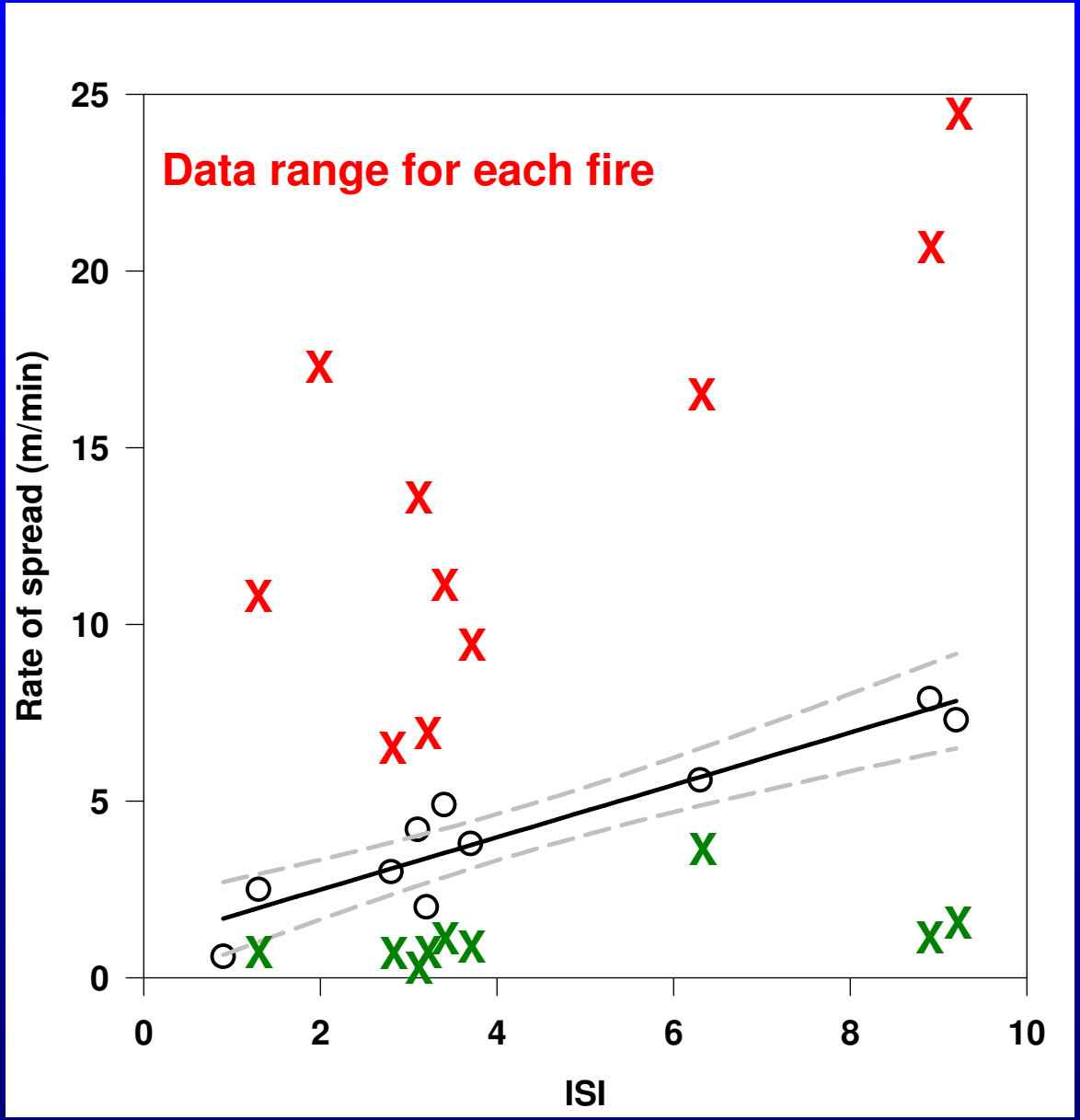


Application to Models

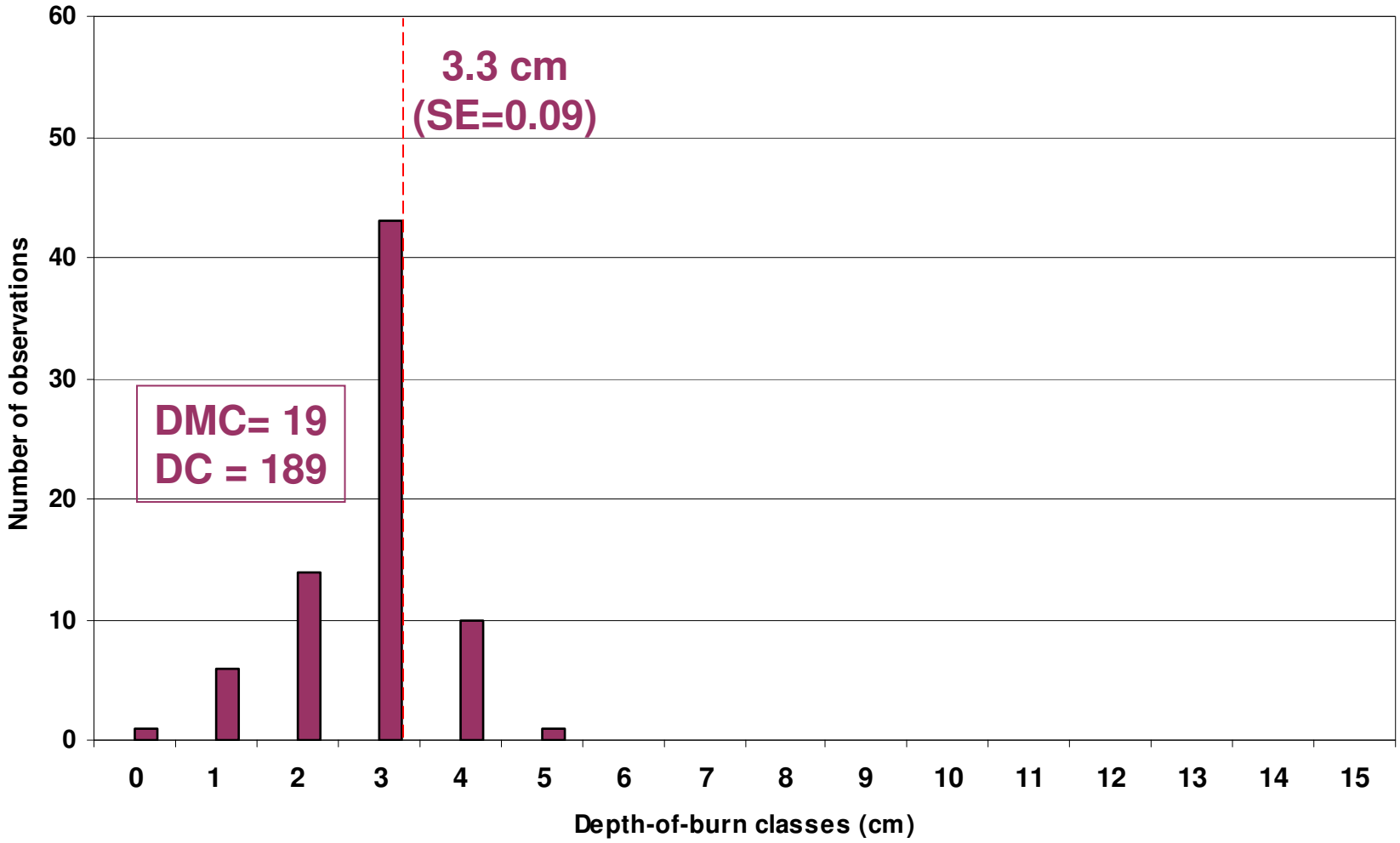


Error bars indicate one standard error from the mean

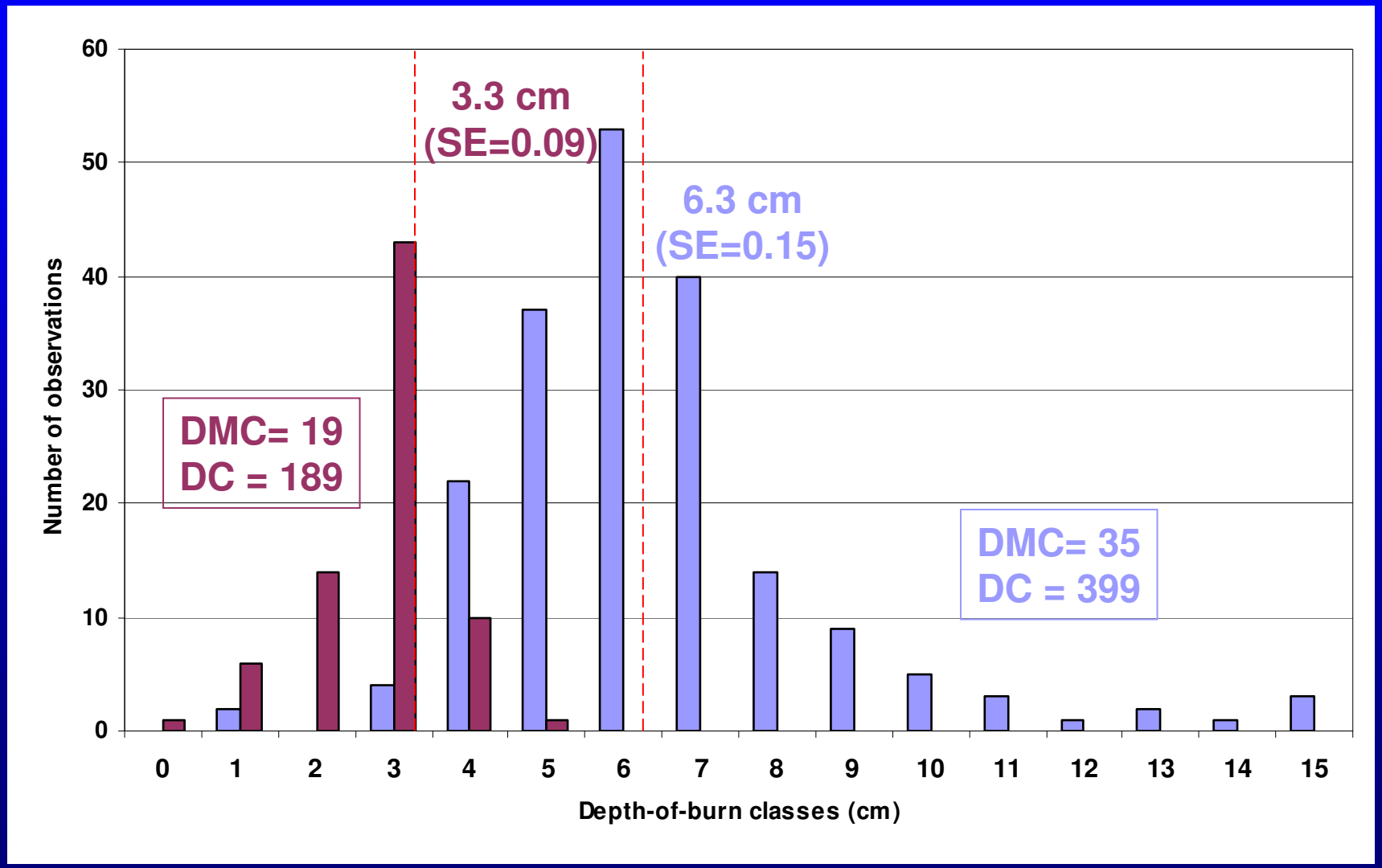
Application to Models



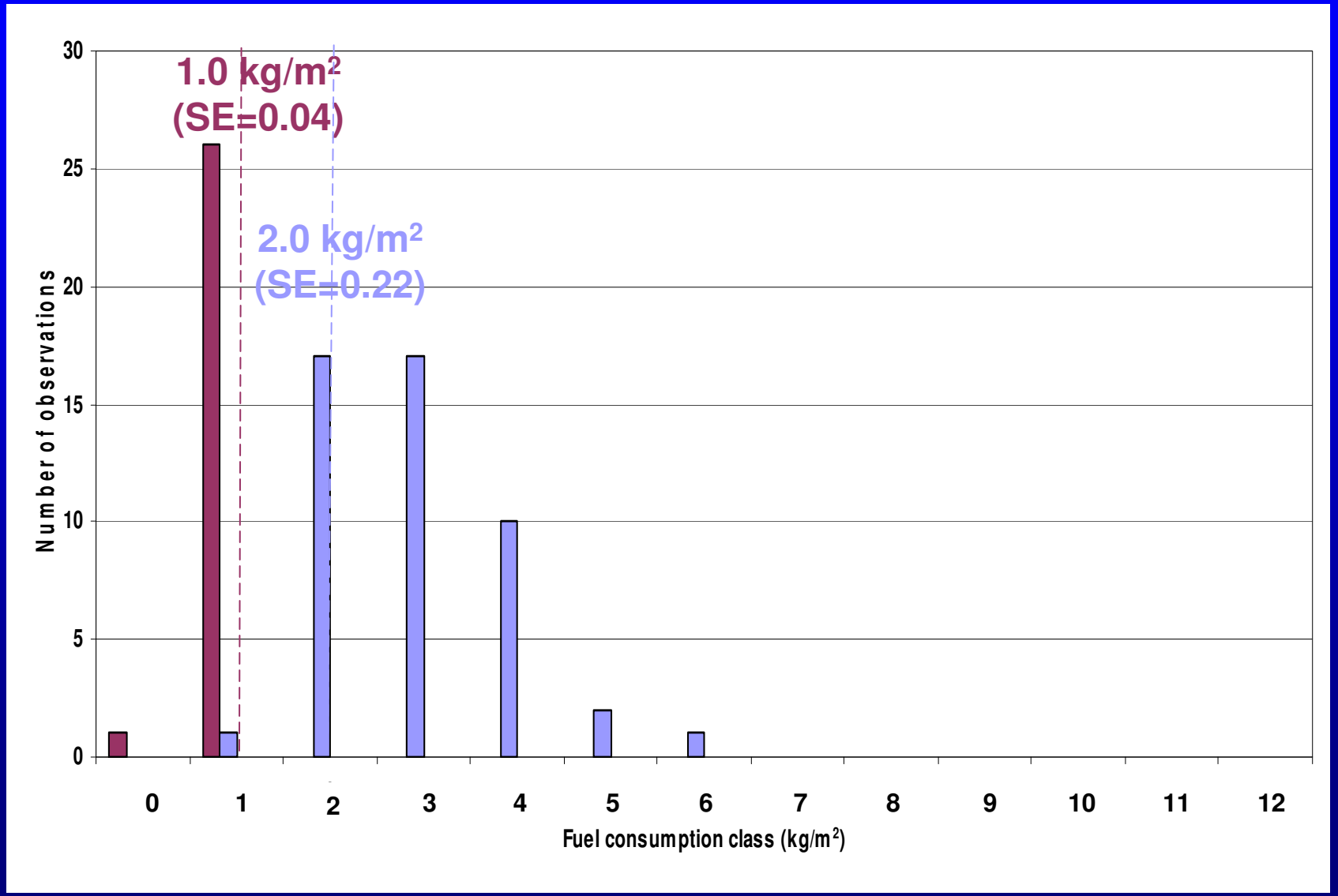
Depth of burn



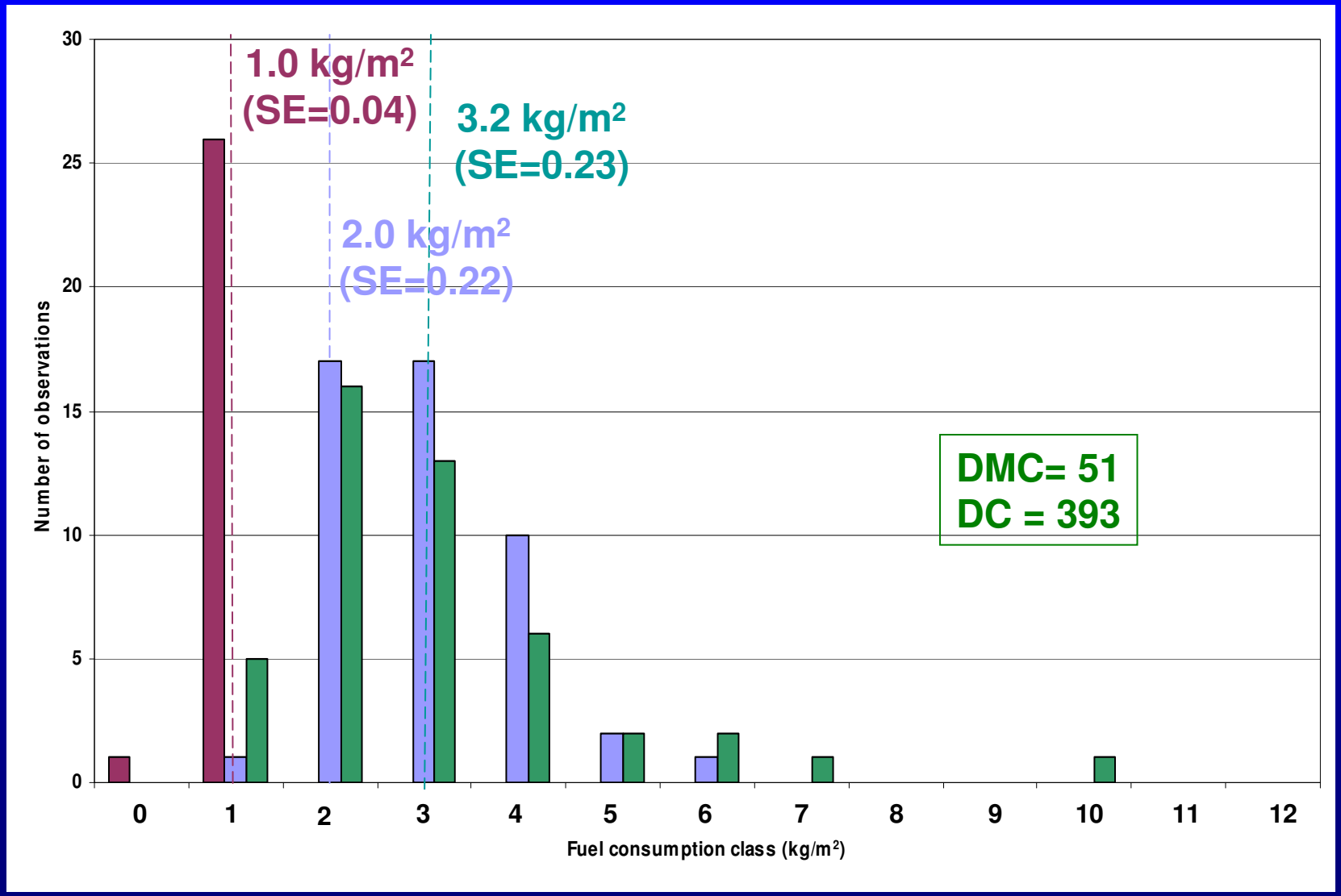
Depth of burn



Total fuel consumption



Total fuel consumption

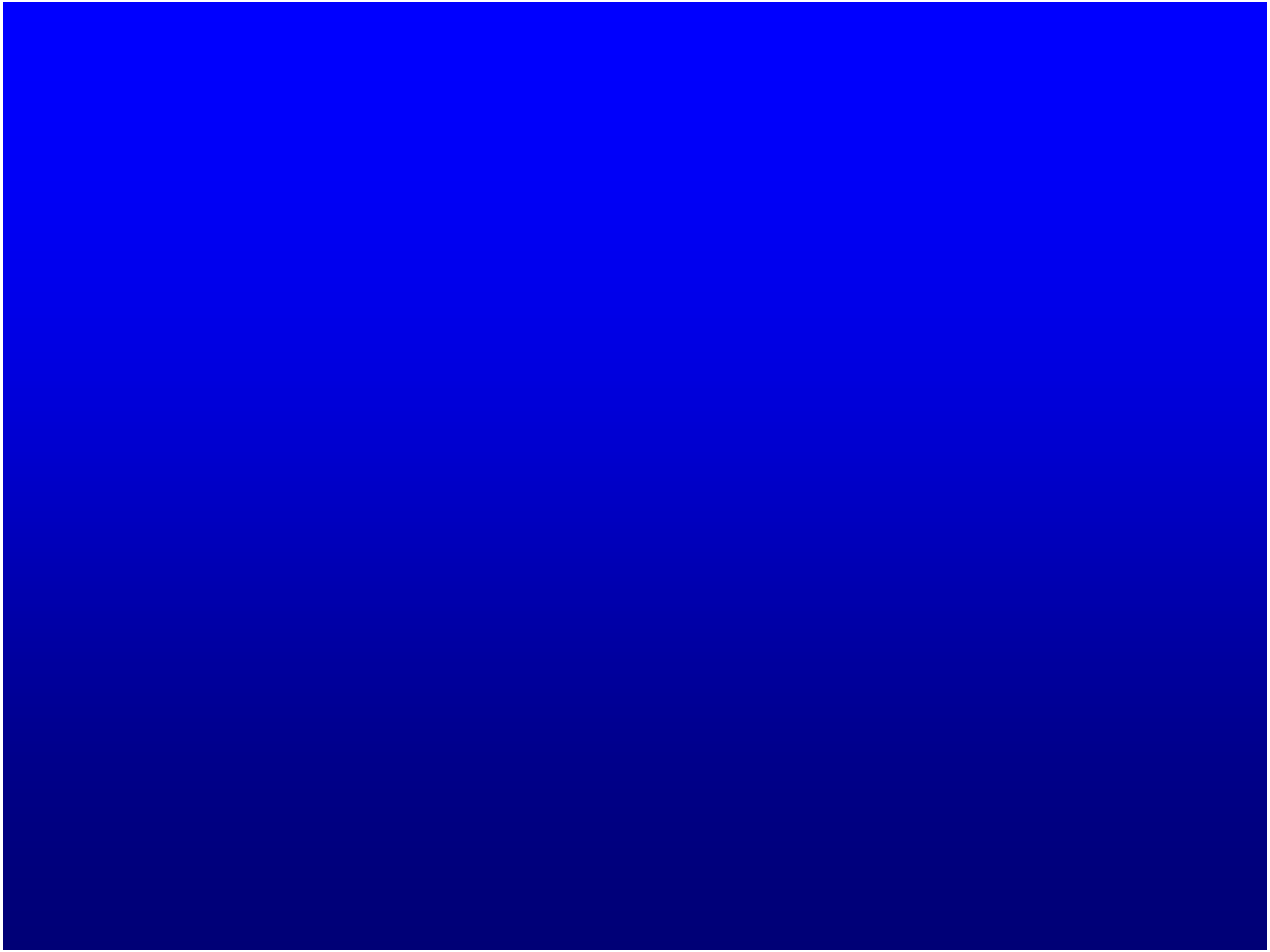


Conclusions

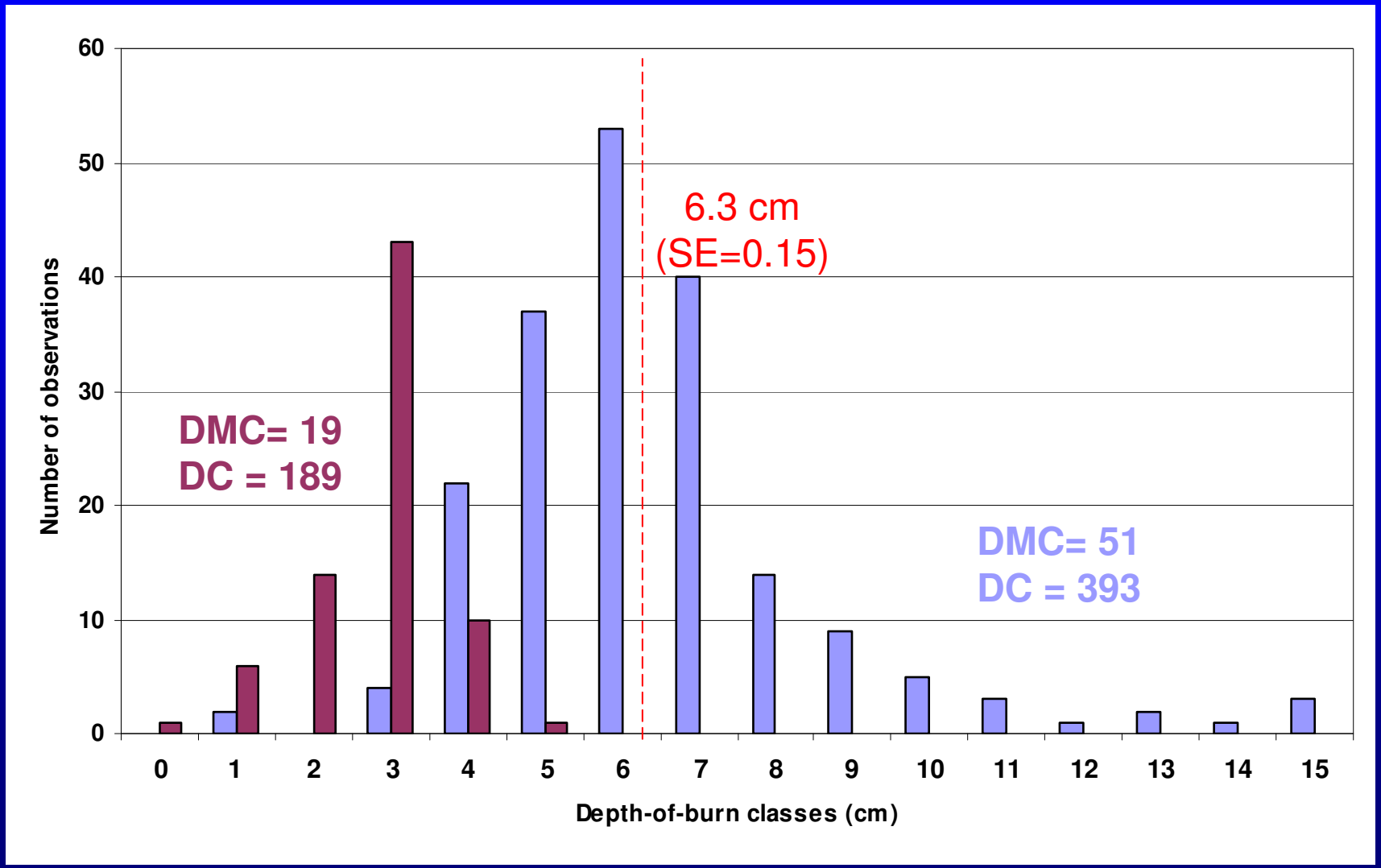
Fire behavior

- Fire behavior is a highly variable phenomena at the microsite level (e.g., 1- m pixel).
- Due to the lack of statistical data in the past, most current models do not indicate the actual ranges of fire behavior.
- Remote sensing using infrared cameras allows for multiple sampling to take place, which allows for adequate sample numbers to allow for statistical analysis.
- For fire crew safety, realize that there is a range of possible values around any average!
- Other applications for infrared monitoring (e.g., fuel consumption, carbon emission).

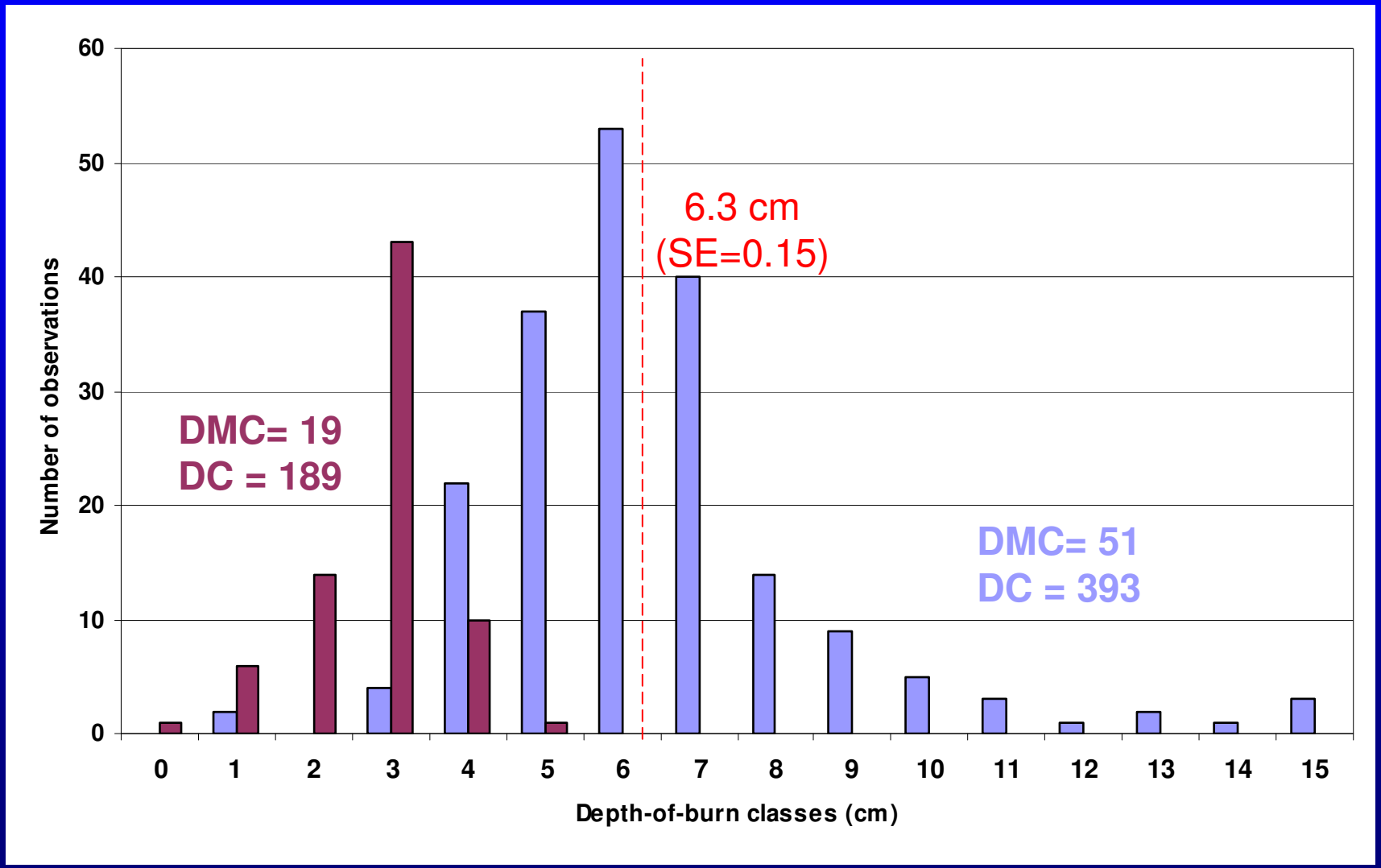

Thank you!
Wildland Fire Canada 2010, 6 October 2010, Kitchener, ON.



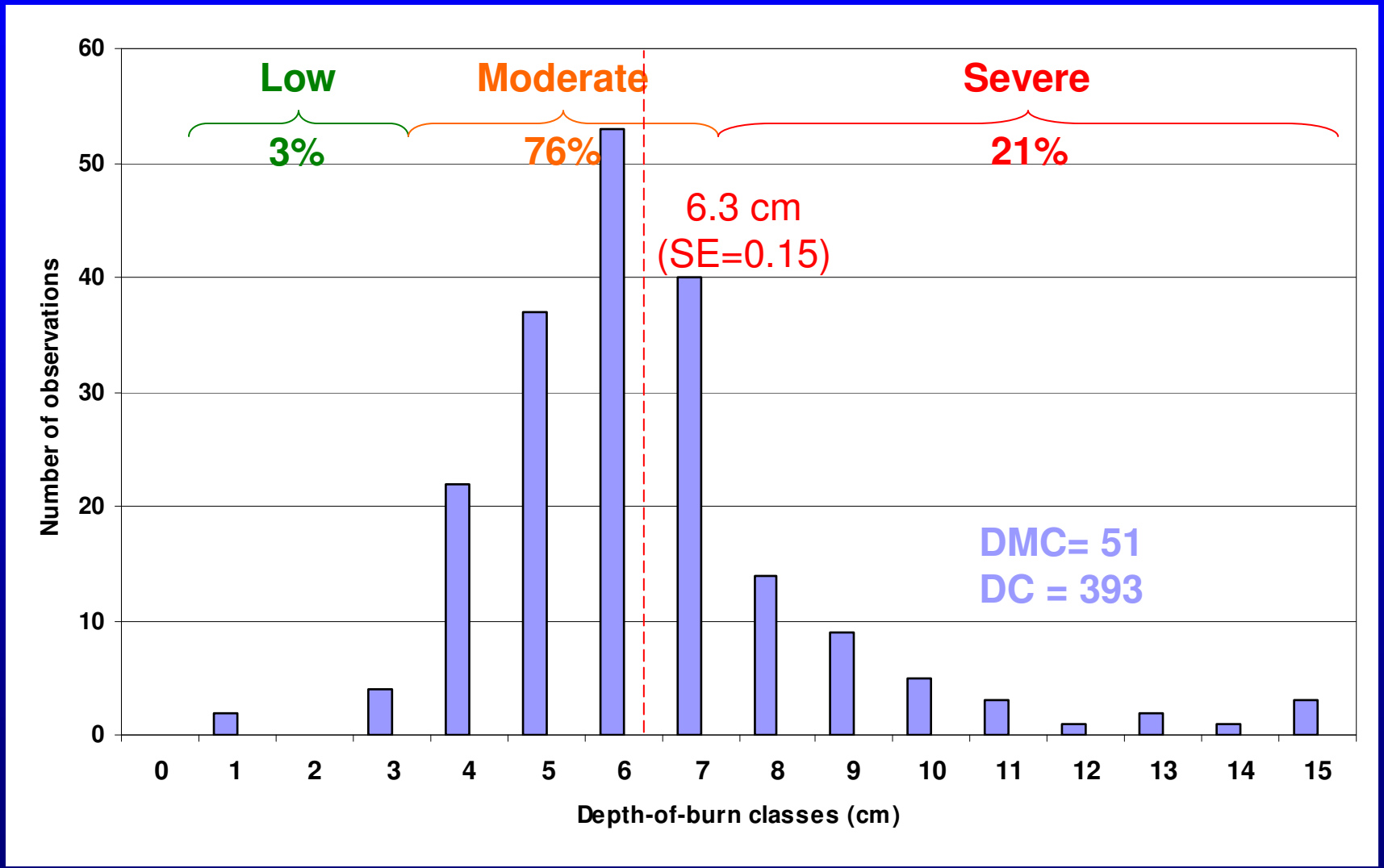
Depth of burn

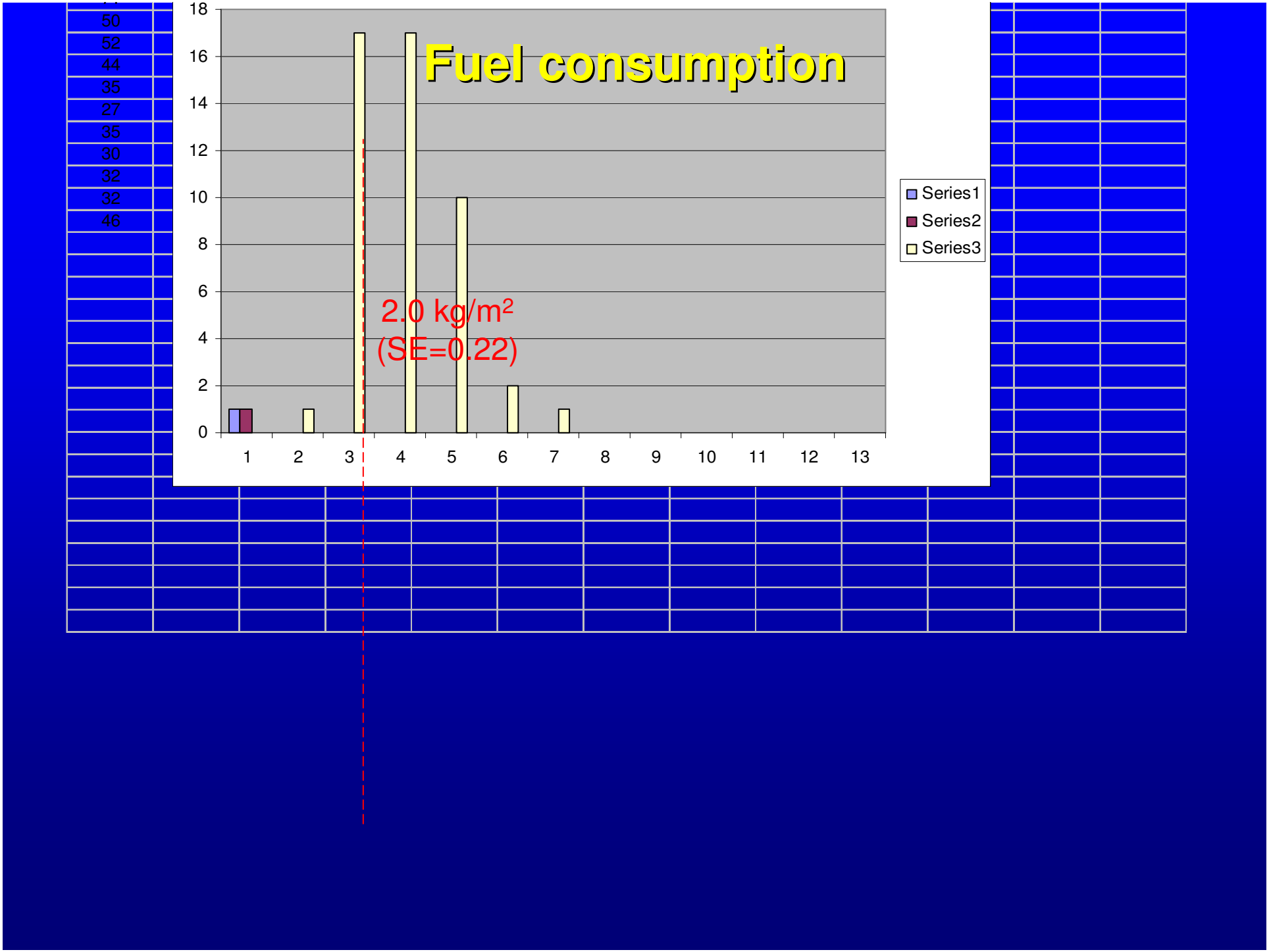


Depth of burn

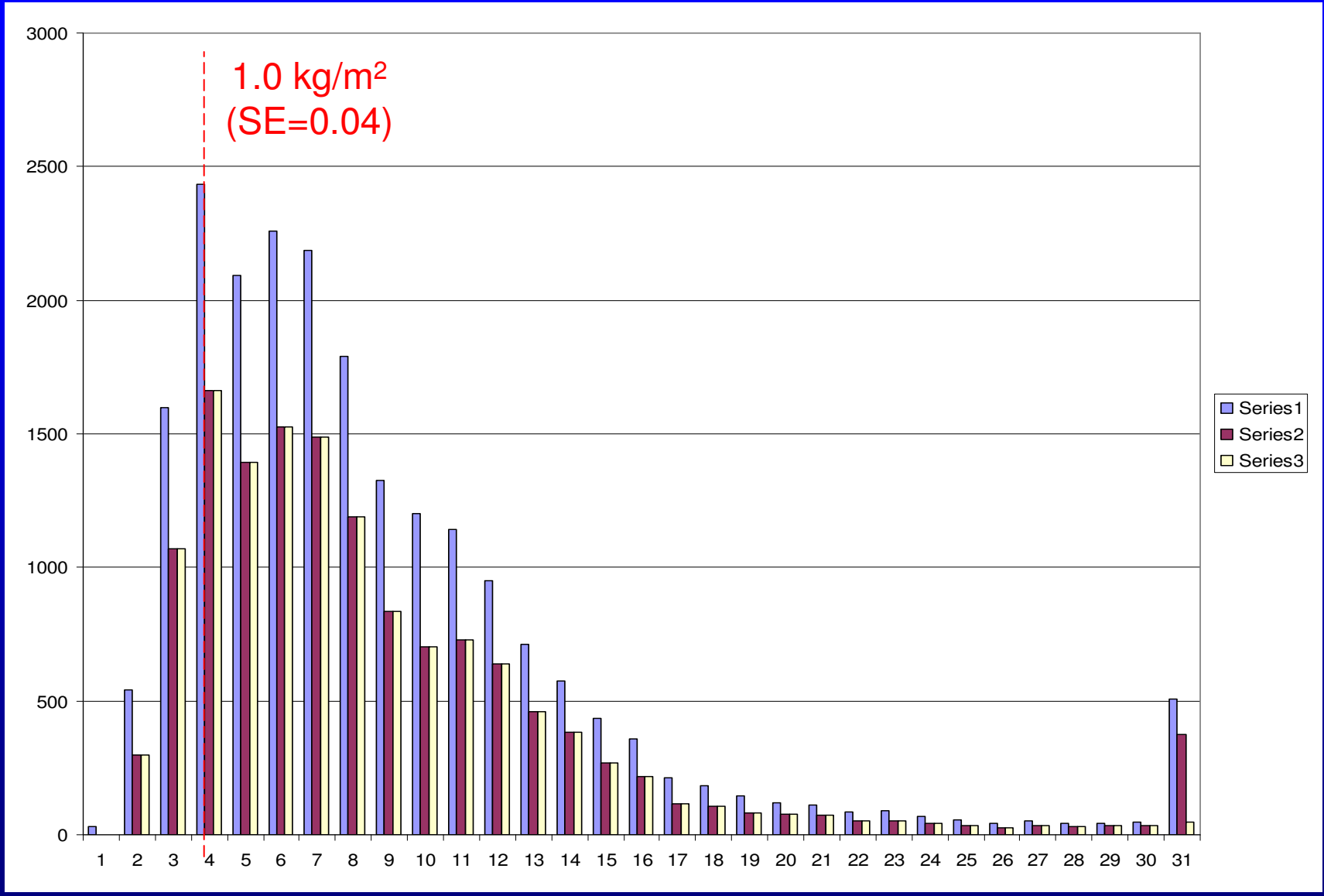


Depth of burn

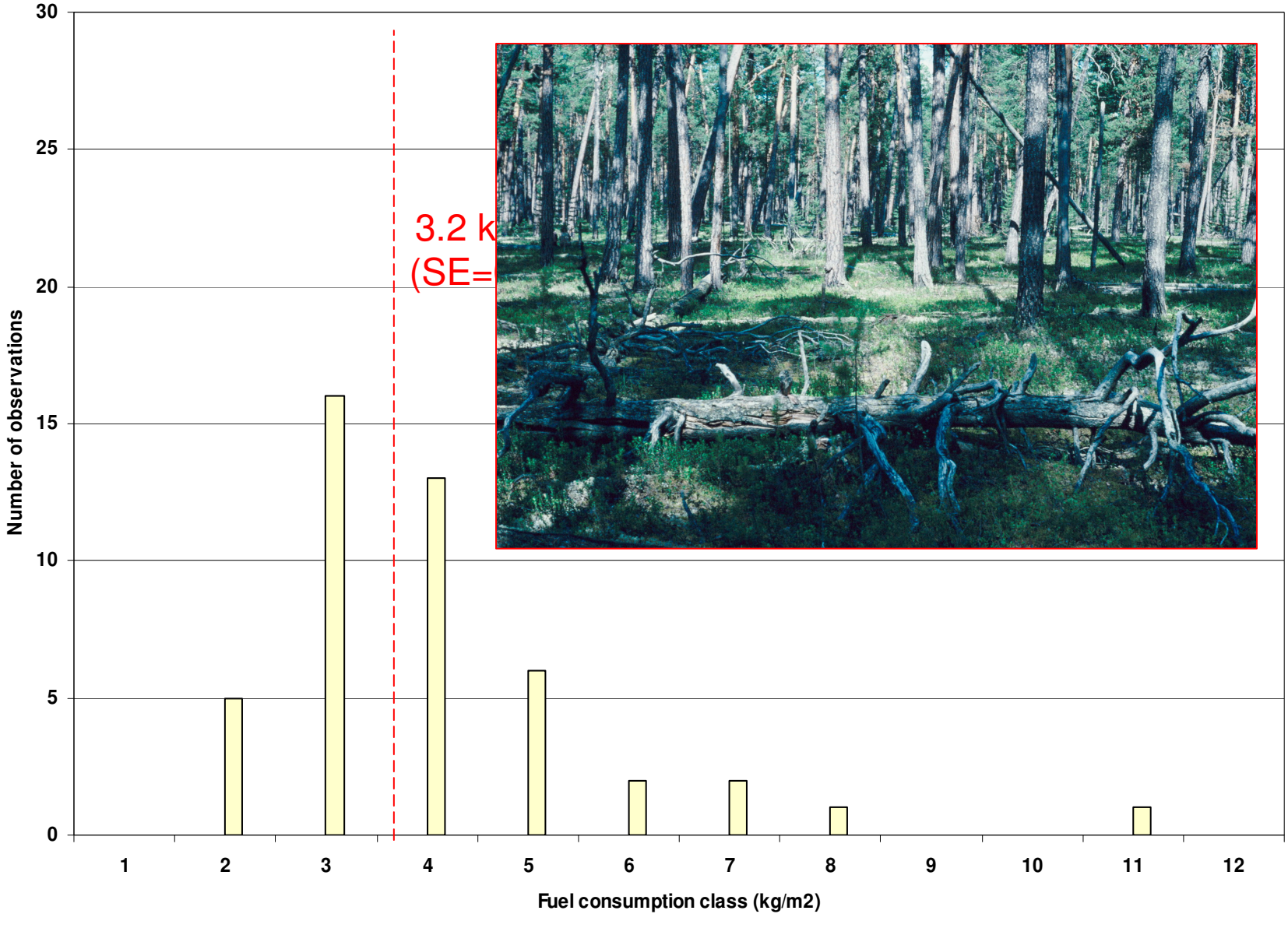



Fuel consumption
2.0 kg/m2
(SE=0.22)
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Series1
Series2
Series3
50
52
44
35
27
35
30
32
32
46

Fuel consumption



Fuel consumption



Results

Table 2. Fuel consumption values (plot averages with standard error) observed for each experimental Siberian Scots pine fire

Fire No.	Consumption (dry weight) by category (kg/m2)				
	Vegetation	Dead & Down	Litter	Forest Floor	Total
1	0.03±0.01 (0-0.09)	0.28±0.10 (0.02-3.28)	0.16±0.03 (0.03-0.55)	1.45±0.08 (0.03-4.63)	1.80±0.16 (0.34-5.23)
2	0.03±0.01 (0-0.12)	0.18±0.06 (0.00-2.28)	0.11±0.02 (0.00-0.28)	1.36±0.06 (00.0-4.90)	1.68±0.12 (0.32-4.32)
3	0.00±0.04 (0.00-0.12)	0.04±0.01 (0.00-0.30)	0.18±0.04 (0.07-0.37)	0.74±0.04 (0.00-2.00)	0.93±0.04 (0.49-12.43)
13	0.07±0.01 (0.00-0.16)	0.41±0.17 (0.00-7.43)	0.30±0.06 (0.02-1.50)	1.50±0.08 (0.02-5.53)	2.03±0.22 (0.26-10.47)
14	0.07±0.01 (0.00-0.13)	0.44±0.18 (0.00-7.55)	0.25±0.25 (0.07-0.51)	2.45±0.12 (0.09-10.36)	3.03±0.23 (1.17-9.79)
20	0.02±0.02 (0.00-0.13)	0.30±0.15 (0.01-7.33)	0.11±0.01 (0.01-0.27)	1.16±0.05 (0.12-3.65)	1.50±0.15 (0.53-7.79)

Values in parentheses show the range in consumption values

Results

Equilibrium (steady-state) fire behavior characteristics (plot averages with standard error) observed for each Siberian experimental Scots pine fire

Fire No.	Depth of burn (cm)	Rate of spread (m/min)	Fireline intensity (kW/m)	Total fire intensity (kJ/m2)
1	5.6 ± 0.20 (0.5-9.4)	7.9 ± 0.04 (1.3-17.9)	2259 ± 189 (207-6800)	27 662 ± 2316 (25235-83261)
2	4.4 ± 0.13 (1.1-9.8)	4.9 ± 0.35 (1.2-9.9)	2259 ± 189 (207-6800)	27 662 ± 2316 (25235-83261)
3	3.3 ± 0.09 (1.1-5.9)	2.5 ± 0.25 (1.1-9.4)	620 ± 34 (260-1038)	14 878 ± 828 (6230-24920)
13	4.6 ± 0.15 (0.9-10.5)	2.0 ± 0.34 (0.8-5.7)	1214 ± 149 (52-6981)	36 450 ± 4474 (1564-209443)
14	6.3 ± 0.15 (1.2-15.0)	5.6 ± 0.07 (3.6-14.8)	5220 ± 434 (805-18372)	55 938 ± 4646 (19344-196851)
20	4.2±0.10 (1.7-8.3)	6.5±0.05 (2.4-16.5)	2790 ± 341 (718-17049)	25 757 ± 3145 (6629-157376)

Values in parentheses show the range in values