Climate and Glacier Change in the Mountains of Siberia

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Where are we?

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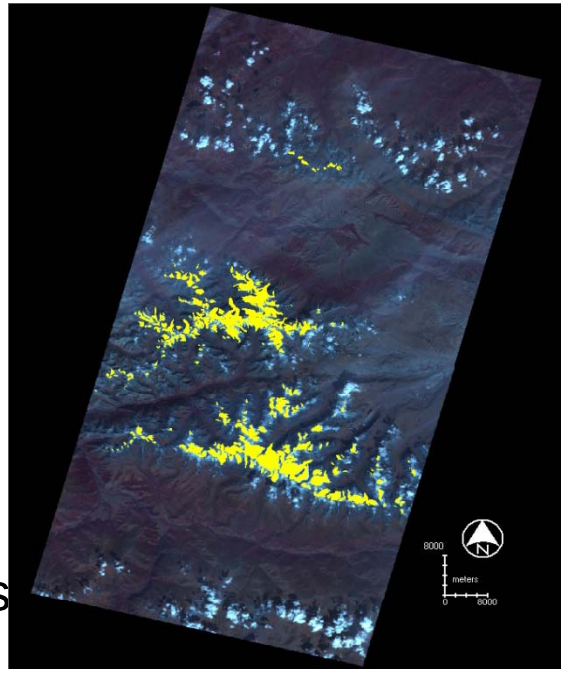
Research questions

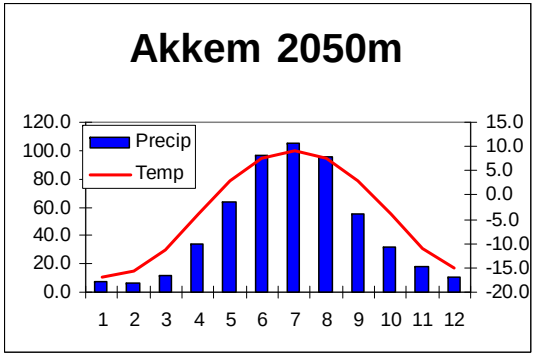
- How has climate changed during the period of instrumental records?
- How have the glaciers changed since the end of the LIA and especially since the middle of the 20th century?
- How do climatic fluctuations (local, synoptic, global) control glacier change?
- How will climate change in the future?
- How will glaciers respond to the projected climate change?

Altai: Regional characteristics and methods

- ~910 km^2 glaciated in 1950s; ~2000 glaciers (WGI)
- In the 1950s, 53% were very small glaciers with an area less than 0.5 km^2 and 4.6 % were larger than 5 km^2
- Gain mass throughout the year (mostly autumn & spring); ablation season in June-August



- ASTER 10 September 2004
- WGI data for the Altai based on aerial photographs Sep 1952 and a selection of the original photographs
- Verification of WGI data by re-mapping 21 glaciers (0.8-22 km^2) from original photographs
- 5.5% average difference in original areas resulting in 3.3% difference in 1952-2004 area change
- Absolute values of differences for individual glaciers ranged between 0% and 12%
- WGI mostly overestimated surface areas in comparison with the results of re-mapping

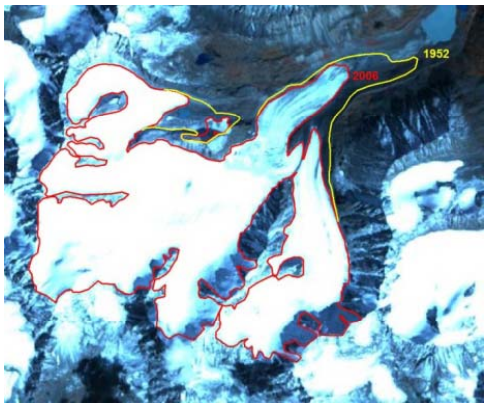


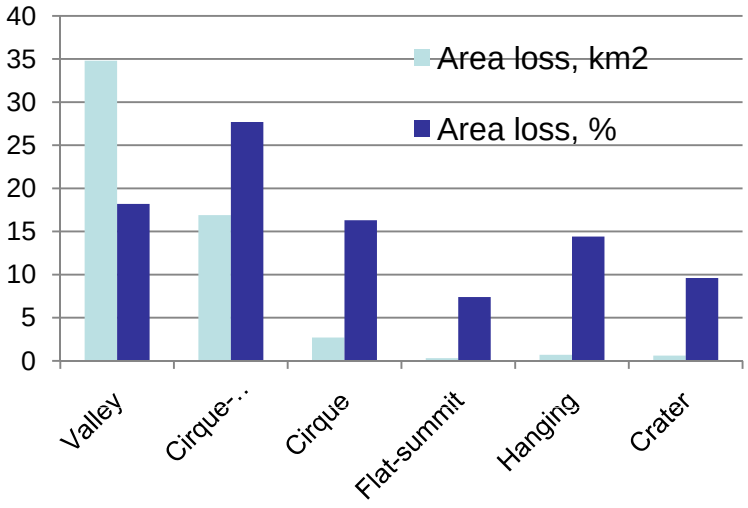
Changes in the extent of glacier surface area in the Altai since 1952

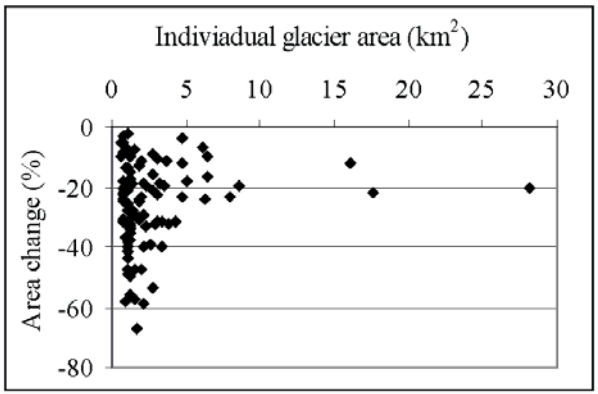
- 2004: 256 glaciers with a combined area of 253 km^2
- Area reduction of 82 km^2 from 1952
- Increase in number of glaciers from 238 to 256 due to the fragmentation of 16 glaciers

- Statistical analysis for 126 glaciers > 0.5 km^2
- Decline of glaciated area from 284 km^2 in 1952 to 228 km^2 in 2004: 19.7% reduction

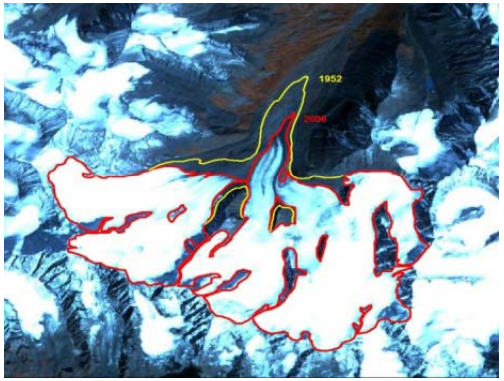
Sophyiskyi Glacier



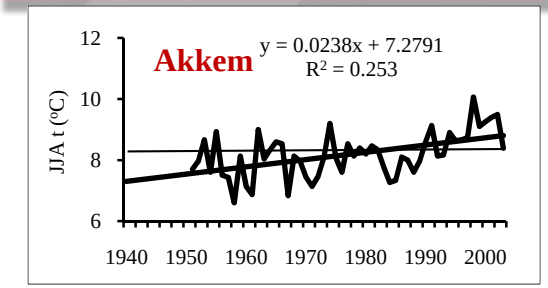


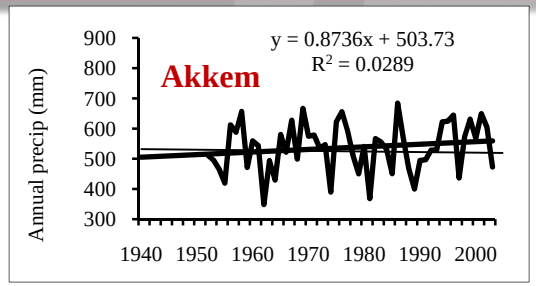


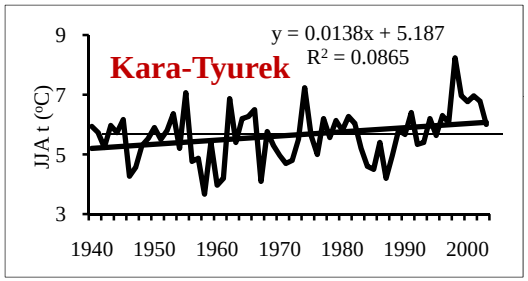
Taldurinskyi Glacier

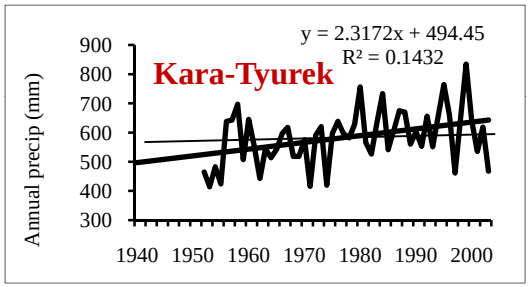


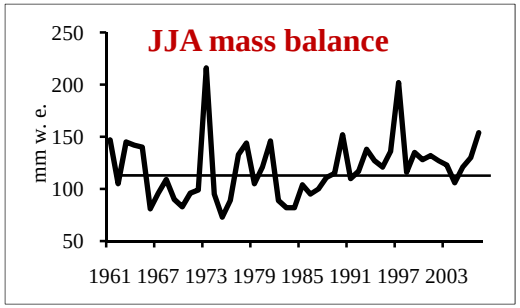
Observed changes in climate and glacier mass balance

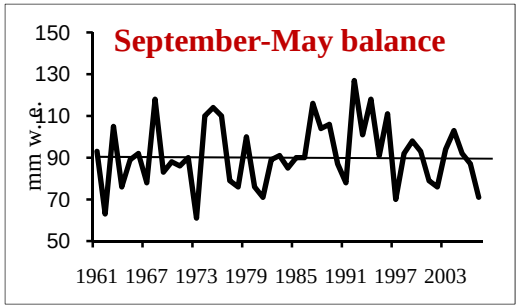


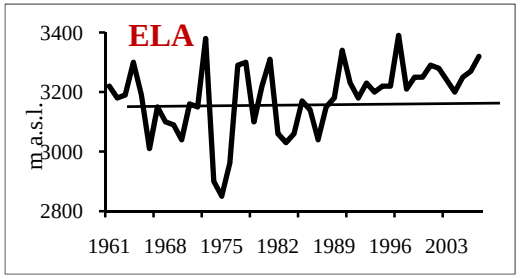


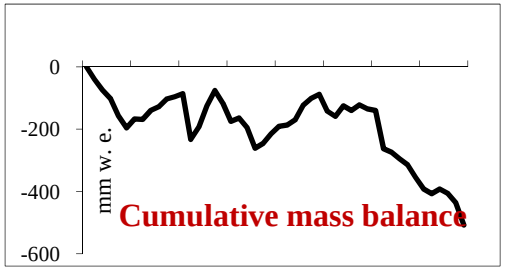








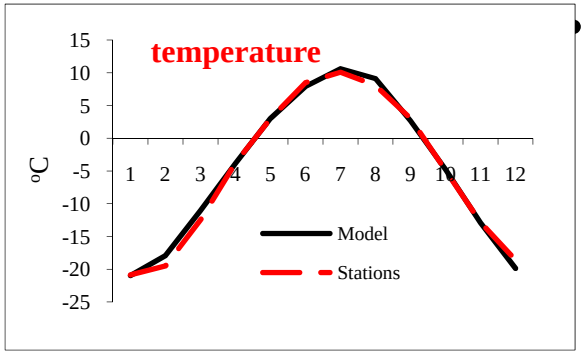


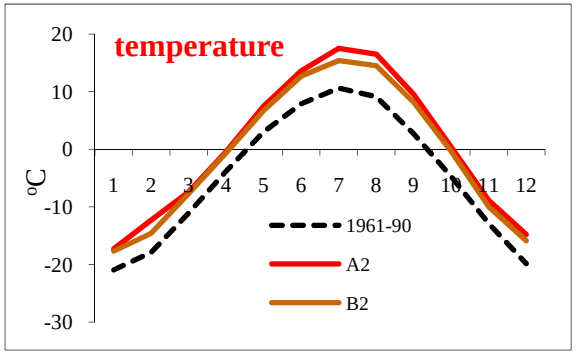


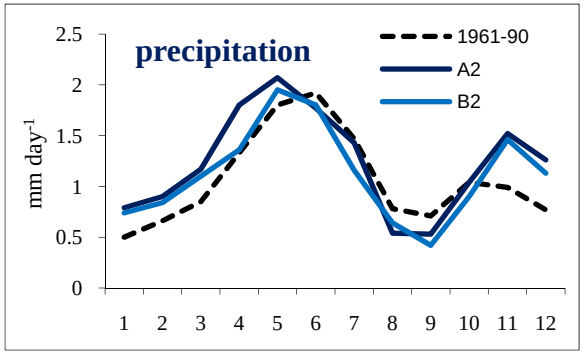
- Positive linear trend in JJA since the 1940s
- Intensification of summer warming since 1985: linear trends explain 0.58-0.61% of variance
- Since 1985, warming at a rate of 0.10-0.13ºC a^{-1}
- Weak increase in annual precipitation at higher elevations
- Increasing ELA on Malyi Aktru Glacier from 3140 m (1961-1987) to 3230 m (1988-2004): 120-140 m increase per 1º warming
- Declining cumulative mass balance
- Glacier wastage is linked to summer warming

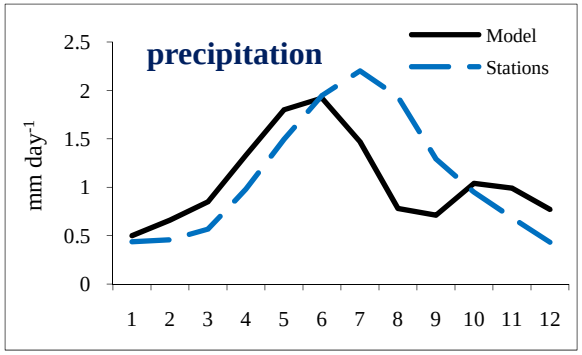
Future climate change: RRECIS (HadRM3) RCM

- Hydrostatic RCM with 25 km horizontal resolution forced by HadCM3 GCM
- Experiments: 1961-1990 GCM; 2071-2100 A2 & B2 scenarios (increase in CO2 concentrations to 830 ppm and 600 ppm)
- Altai region 48-50.5ºN; 86-89ºE
- Validation against 6 high-altitude stations





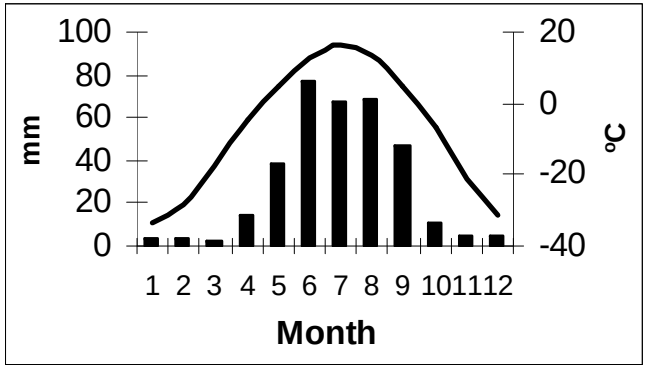




- JJA warming 6-7ºC (A2) and 3-5ºC (B2)
- Annual precipitation increase of 15% and 5%
- Further glacier retreat in the 21st century

Kodar (57 N, 117 E)

- Little published work
- Preobrazhenskiy (1960) documented 30 glaciers covering 15 km^2
- Catalogue of Glaciers (WGI) based on 1963 aerial photographs includes 30 glaciers (18.8 km^2)
- Glaciological oddity! Deep valley shading, avalanche nourishment
- Cold glaciers: grow through the formation of superimposed ice in summer
- Main control: summer t
- Precipitation: change in albedo reducing melt if solid; supply energy for melt and induce runoff if liquid



Chara (50 km from Azarova Glacier; 709 m a.s.l.)

Azarova Glacier: Assessment of glacier retreat from field-work in 2007-2008

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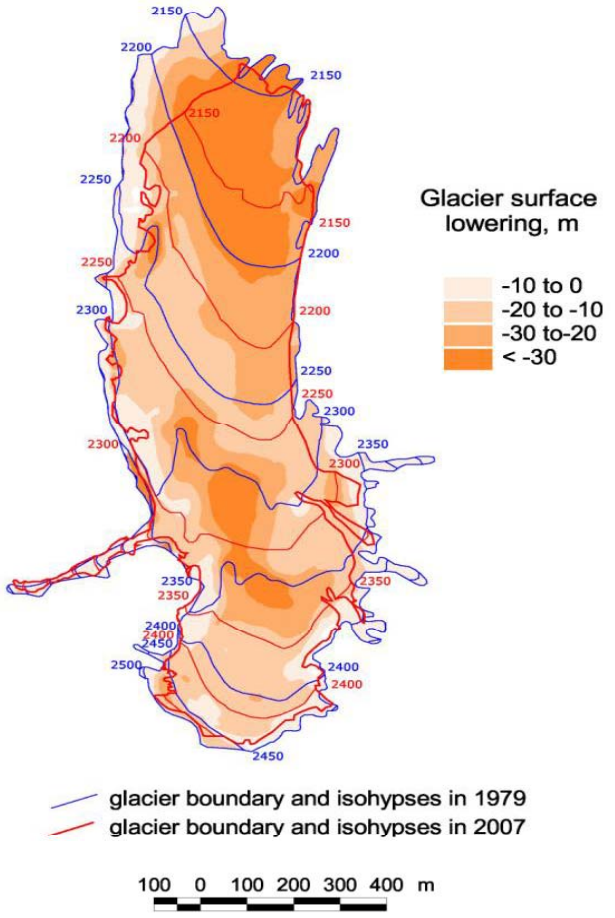
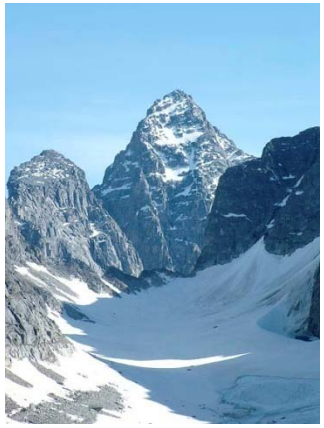
Glacier surface lowering 1979-2007





- Map of Azarova glacier 1979 (by V. Plyusnin, Institute of Geography RAS, Irkutsk)
- Photo-theodolite and GPS survey 2007
- Terminus retreat: 28 m in 28 years
- Fast thinning across the glacier: average 20 m reaching 69 m
- Strongly negative cumulative mass balance: 670 mm w.e. between 1979 and 2007

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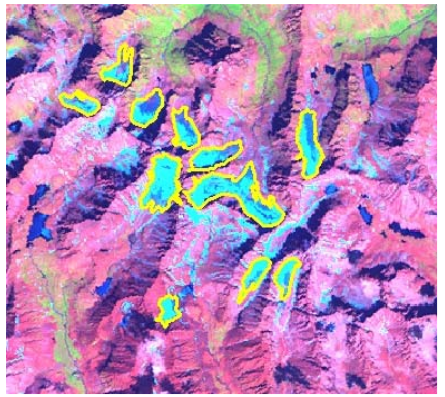
Methods: Remote sensing

- Manual mapping from satellite imagery:

Imagery	Date	Coverage of Glaciers
– EROS B image	9 Jul 2007	7 glaciers
– Landsat ETM+	11 Jul 2001	27 glaciers
– Landsat TM	17 Jul 1995	23 glaciers

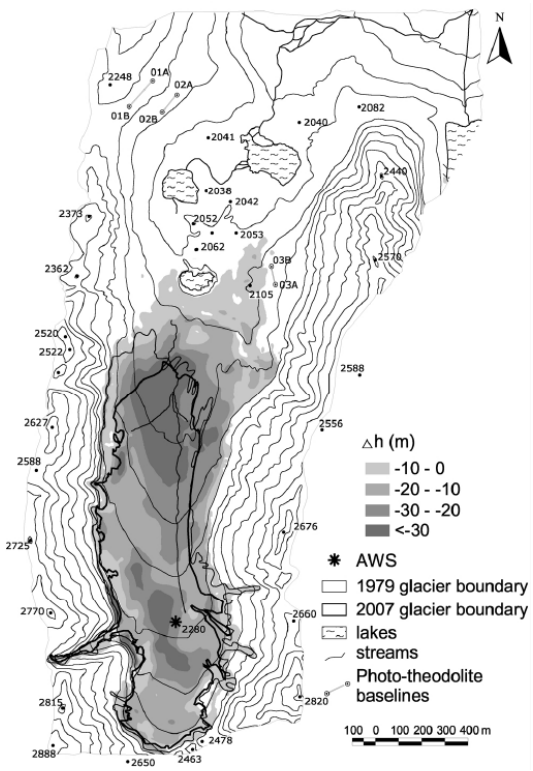


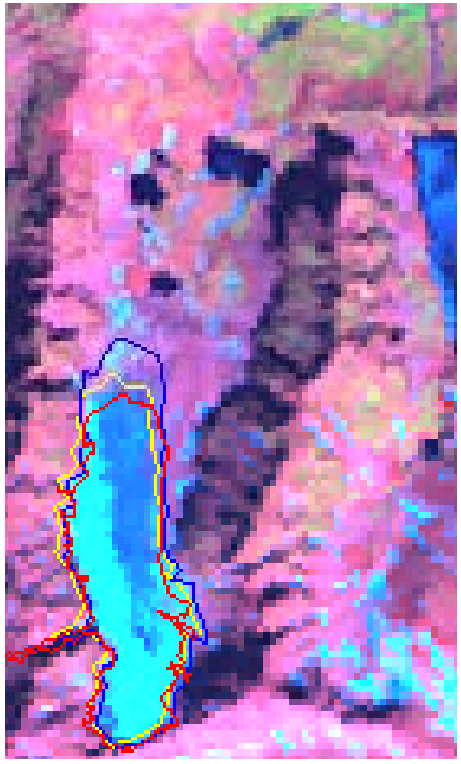
- Compare to data in WGI (1963)
- Compare to LIA limits
- Compare to field-work on Azarova Glacier

Azarova glacier on EROS B satellite image

- Small glaciers make it very difficult to map
- Debris cover is hard to map: changes in extent of clear ice
- Possible to observe general trends

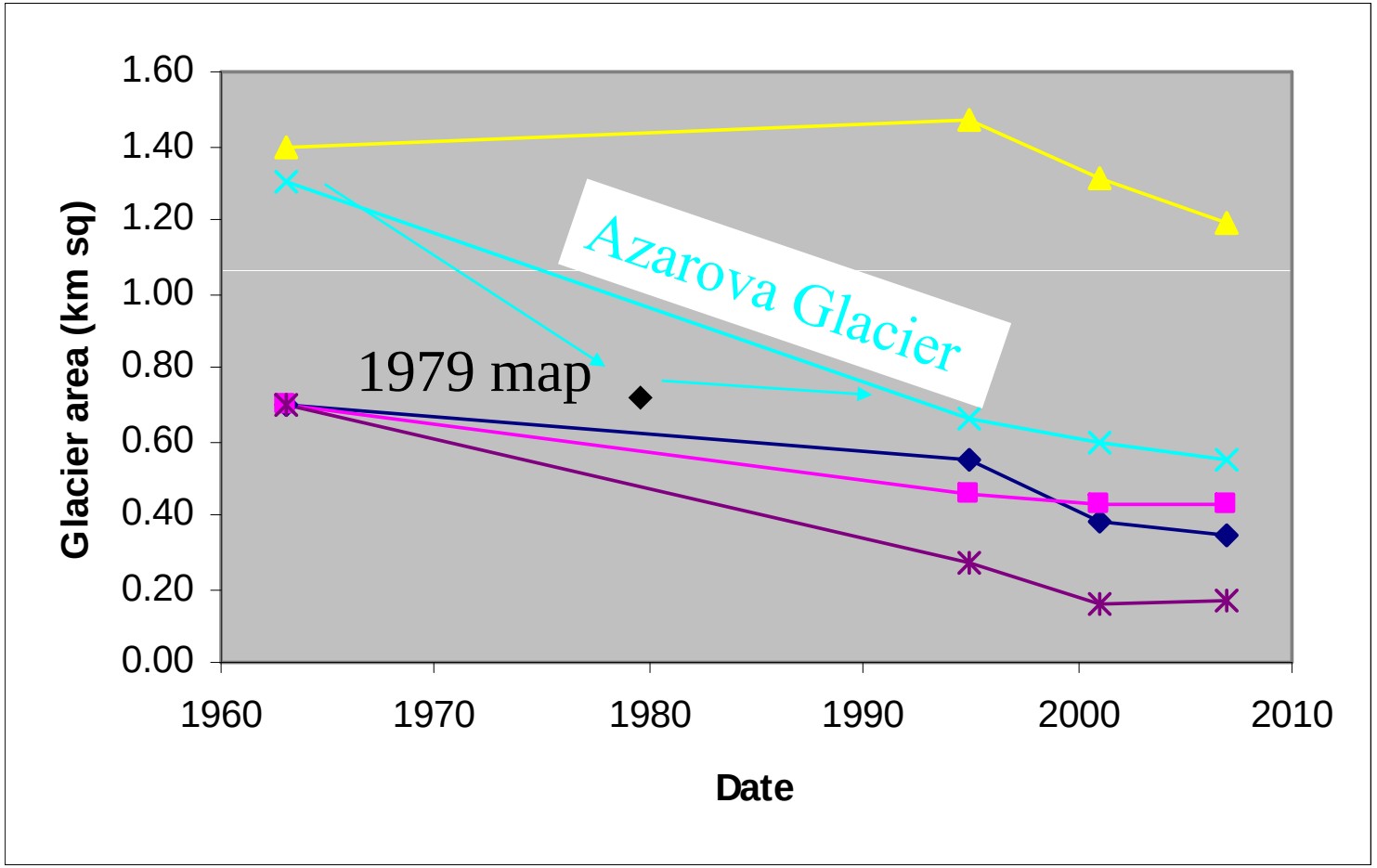
Comparison to field data on Arazova Glacier





Date	Area (km^2)
1963	1.30 (WGI)
1979	0.70 (field)
1995	0.66
2001	0.60
2007	0.55
2007	0.56 (field)

Change in area of 5 glaciers: 1963, 1995, 2001, 2007



Results

27 glaciers (2 glaciers are treated as the same and 2 outside the image)

Mean % clear ice area loss between:

1963- 1995 (n = 27) = 30.8%

1995 - 2001 (n = 27) = 18.7%

2001 - 2007 (n = 5) = 4%

Rate of loss between:

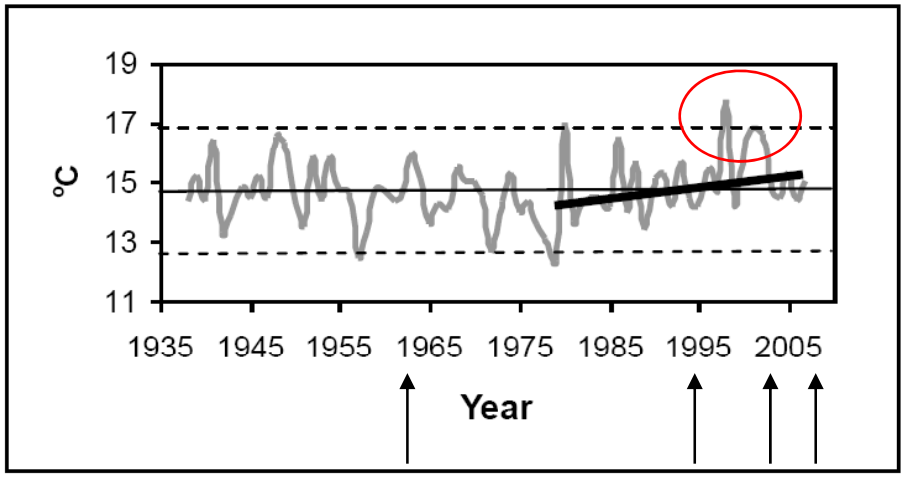
1963- 1995 (n = 27) = 1% a^{-1}

1995 - 2001 (n = 27) = 3% a^{-1}

2001 - 2007 (n = 5) = 0.7% a^{-1}

- Retreat undeniable and rather steady but high variability on individual glaciers
- Linked to recent warming (0.04 °C a^{-1} : 1979-2005)
- Small cold glaciers = sensitive and fast response to summer temperatures?

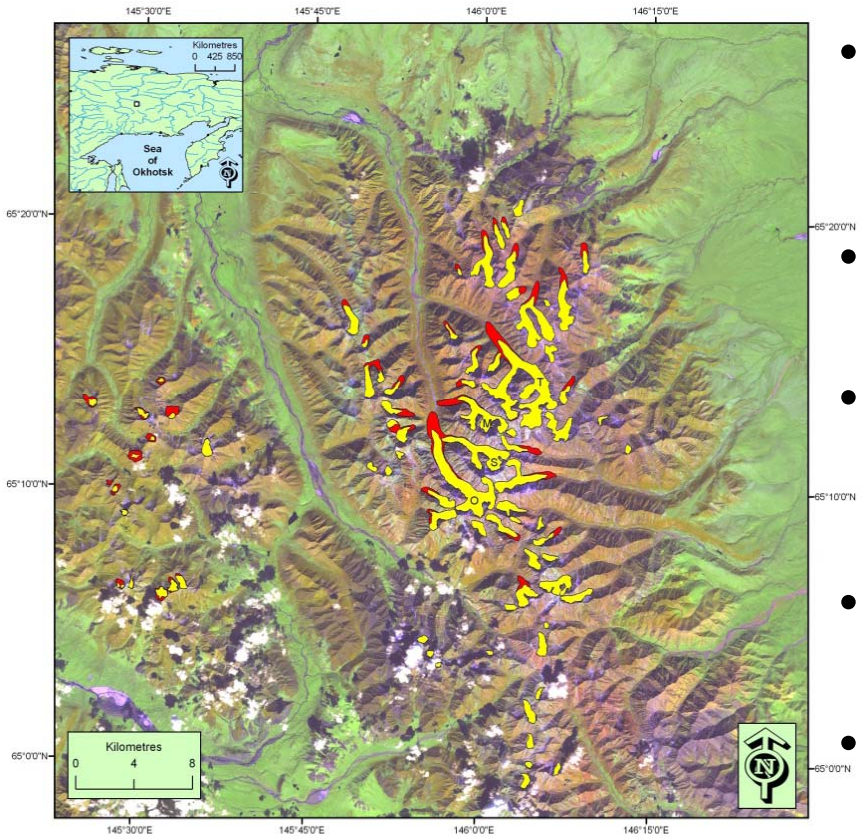
June-August temperature from Chara



- Increase in rate of retreat between 1995 and 2001 linked to warm summers

- Influence of precipitation is weaker than on temperate glaciers

Buordakh massif in Chersky Mountains (65 N, 145 E)



Slower retreat than in other regions but visible signs of downwasting

See: Gurney et al 2008 AAAR

- Glacier inventory and assessment of glacier retreat between the LIA and 2000-2001
- Landsat 7 ETM+ from August 2000 and July 2001 and GPS surveys 2004
- 80 glaciers with a combined area of about 70 km^2 (small glacierets, niche glaciers not included)
- Glacier size range between 0.1 km^2 and 10.4 km^2
- Cold glaciers growing through the formation of superimposed ice
- Glaciers lost 14.8 km^2 or 17% of their LIA area
- 62% of glaciers exhibit measurable extent and 38% were stable

Discussion and conclusions

- Glaciers of Siberia retreat in response to climatic warming
  - Altay: 19.7% 1952-2004. Possible overestimation by ~3%
  - Kodar: 53.5% 1963-2007 but for clear ice. How accurate?
  - Buordakh: 17% LIA – 2000/01
- Loss of ice through downwasting: more important than lateral retreat for cold glaciers?
- Hard to apply remote sensing in some areas due to topography and nature of glacier tongue surface
- Strong summer warming is projected which will not be compensated by increase in annual precipitation. Are cold glaciers more vulnerable than temperate glaciers?
- Climate models perform well in Siberia but hard to validate through lack of high-altitude meteorological stations
- Still less information than for most other regions!
- Do we want to know more about Siberian glaciers and how do we go about it?

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Thanks for your time!

http://www.reading.ac.uk/SHESresearch/Geography/Landscape/GlacialDynamics.htm

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