Mapping Glaciers in the SWAN in the Context of Changing Climate

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Photo by Alaska Trekker, 10 June 2004 Harding Icefield
http://en.wikipedia.org/wiki/File:HardingIcefield2.jpg

Objective

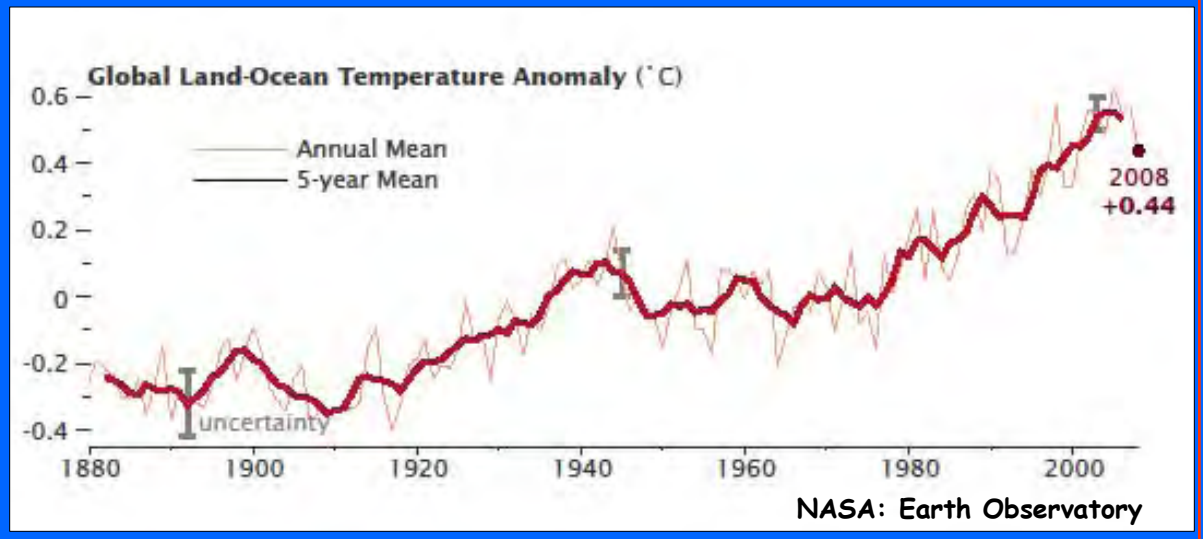
- Measure glacier-area changes in Kenai Fjords N.P., Katmai N.P.P., and Lake Clark N.P.P.
  - Measure changes approximately every 10 years
  - Use Landsat (1972 – present), and ancillary data when available

Why?

- To map land-cover change in the parks
- To enable volume of ice loss to be calculated, in conjunction with other data
- To address the contribution of SWAN glaciers to sea-level rise

In the Northern Hemisphere:

- Permafrost is warming and thawing in some areas including in Alaska
- There is evidence of a longer growing season in the Northern Hemisphere (Myneni et al., 1999)
- Sea ice extent has been decreasing* (but increasing** in the Southern Ocean)
- Duration of snow cover and lake ice has been decreasing
- Small glaciers have been shrinking
- The Greenland Ice Sheet has been losing mass
- West Antarctic Ice Sheet has been getting warmer (Steig et al., 2009)



*-3.7% / decade / ** 1% / decade

TODAY, GLACIERS COVER 10.8% OF THE EARTH'S LAND AREA

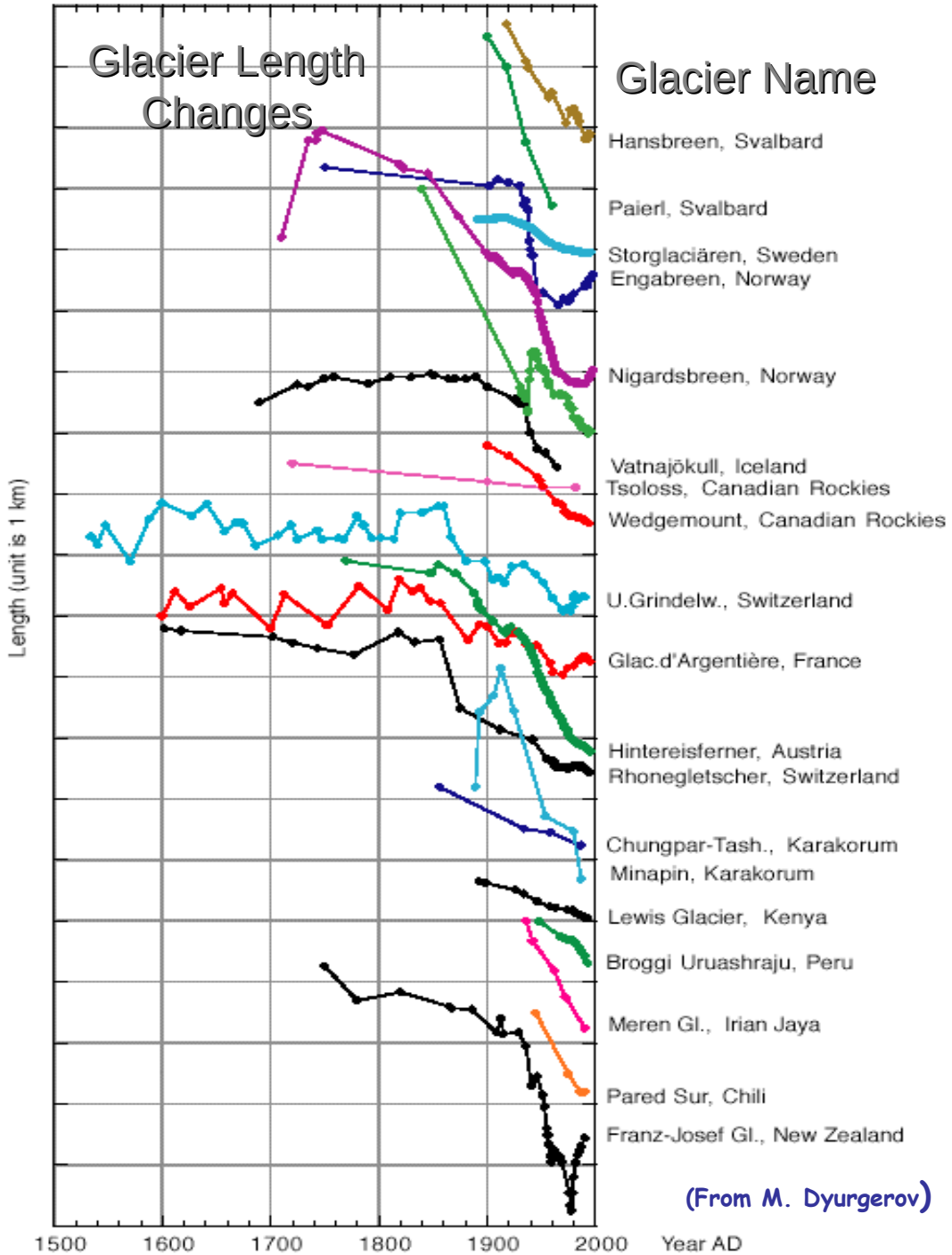
C511.001

Global Glacier Changes Summary*

- **North America** - dramatic recession in Alaska, Canada and the continental United States
- **South America** - dramatic recession in Patagonian Ice Fields
- **Tropical areas** - dramatic recession, e.g., Mt. Kenya & Mt. Kilimanjaro
- **Iceland** - shrinkage since ~1890, with some advances, but recent accelerated shrinking since ~1990 due to warm summers
- **Scandinavia** - glaciers advanced until ~2000, and are now generally receding
- **European Alps** - dramatic recession, and 50% loss of glacier volume since ~1850
- **Asia** – shrinkage in China and the Himalayas; 7% annual decrease in extent of glaciers on the Tibet Plateau
- The **West Antarctic Ice Sheet** has been warming for at least 50 yrs.
- The **Greenland Ice Sheet** is losing mass, mainly from the lower elevations

*Though most glaciers are shrinking globally, there are many glaciers that have not changed appreciably in the last few decades, and some glaciers that are expanding.

Globally, glaciers have been receding since ~1850; recession has accelerated in the last quarter century



(From M. Dyurgerov)

Dyurgerov & Meier (2004) estimate global average glacier surface lowering (mid 1960s to mid 1990s) = -0.13 m/yr

Glaciers are Found in 10 States

- Alaska
- California
- Colorado
- Idaho
- Montana (glacier changes in GNP have been well-documented)
- Nevada
- Oregon
- Utah (only 1 glacier is in Utah, in the Wasatch Range)
- Washington (75% of glaciers in the conterminous U.S. are in the State of Washington; Emmons Glacier on Mt. Rainier is the largest)
- Wyoming

Glacier National Park, Montana

- Some sources say that the glaciers in GNP formed during the LIA
- Only 25 (>0.1 km^2) glaciers remain of the ~150 estimated around the year 1900, or 16% by area remain
- Total area of glaciers in GNP = 36 km^2; most are cirque glaciers
- Accelerated shrinkage has been documented (Fagre et al., 2009)

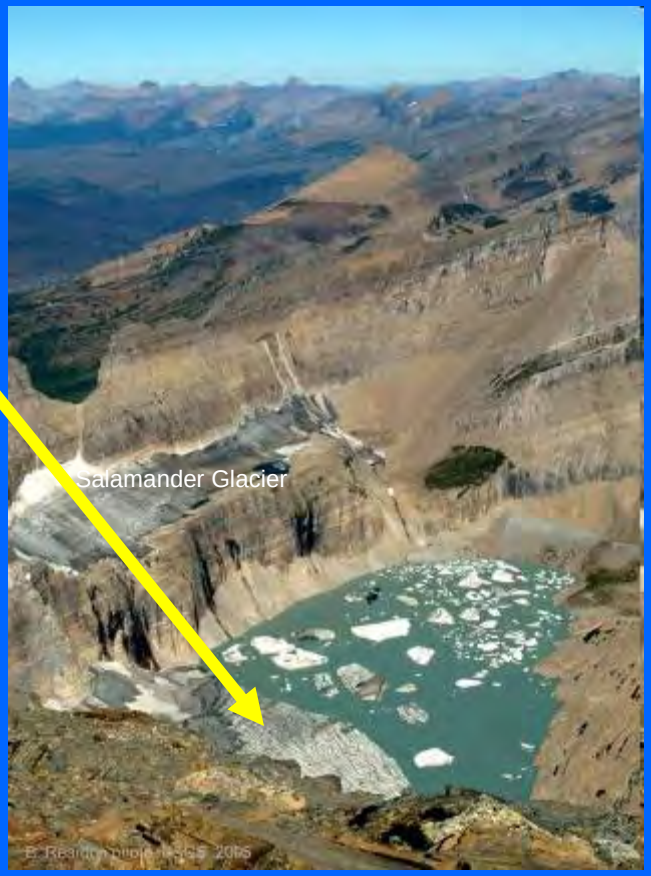
From Key et al., 2002

From Key et al., 2002

Grinnell Glacier Recession*

1938 *T.J. Hileman*

1981 *Carl Key (USGS)*



2005 *Blase Reardon (USGS)*

***Not all of the glaciers in GNP are retreating at this high rate.**

Alaska Glaciers

- Glaciers have generally been shrinking, some dramatically
- From the mid-1990s to 2001, Alaska glaciers have shown accelerated thinning, -1.8 m/yr., or 0.27 ±10 mm/yr SLR equivalent (Arendt et al., 2002) compared to the period from 1950-1990; in addition, *most** glaciers in Alaska show accelerated mass-balance loss since ~1950
- Recent work (Larsen et al., 2007) shows greater mass loss of glacier ice at the lower elevations in southeast Alaska and northwest British Columbia than reported earlier

*Glaciers in the St. Elias Mts. do not appear to be losing mass at an accelerating rate over the last few decades (Arendt et al., 2008)

Mapping Glaciers in the Southwest Alaska Network: KEFJ, KATM & LACL*

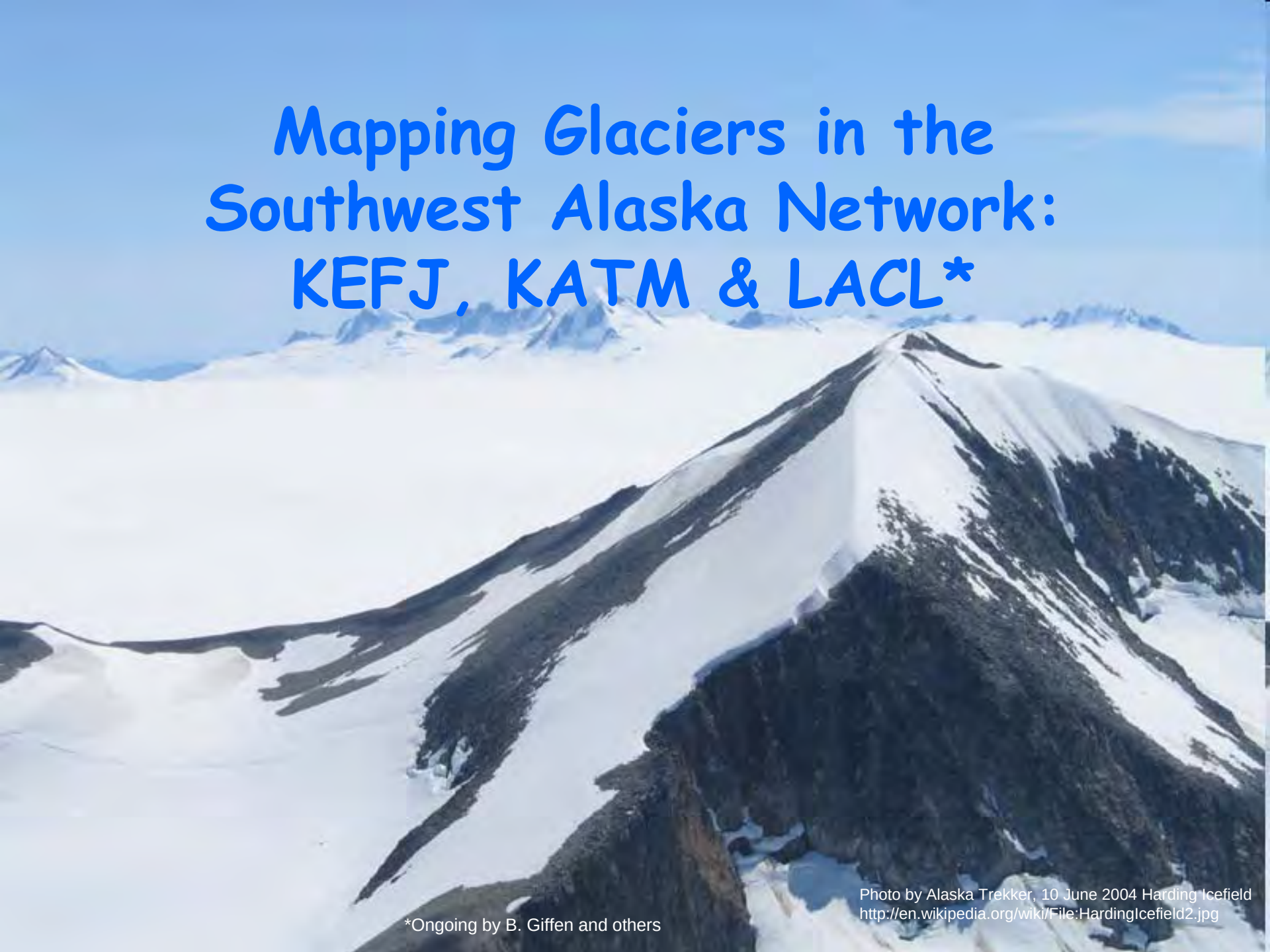


Photo by Alaska Trekker, 10 June 2004 Harding Icefield
http://en.wikipedia.org/wiki/File:HardingIcefield2.jpg

*Ongoing by B. Giffen and others

KEFJ & KATM

Two primary ice masses in KEFJ

- Harding Icefield
- Grewingk-Yalik Glacier Complex

Three primary ice masses in KATM focused on

- Mt. Douglas
- Kukak Volcano to Mt. Katmai
- Mt. Martin

Substantial recession in both KEFJ and KATM has been quantified (see Hall et al., 2005; Giffen et al., in press; and Bruce Giffen's poster for details)

Summary of Glacier Area Measurements in KEFJ & KATM

- KEFJ
  - 22 sq km of ice extent lost (-1.6%) from 1986-2000 in KEFJ; total ice loss from ice masses including parts outside of park boundaries - approx. 53 sq km (-2.2%), from 1986-2000 (Giffen et al., in press)
  - In KEFJ, some of the large losses are due to rapid recession of tidewater glaciers (e.g. Bear Glacier) or glaciers terminating in lakes (e.g., Skilak Glacier)
- KATM*
  - 76 sq km of ice extent lost (-7.7%) from 1986/87-2000 (Giffen et al., in press)

*Very little has been published on glaciers in KATM (see Field, 1975; Motyka, 1977); results of the present work (see Giffen et al., in press) represents a huge leap in knowledge about these little-studied glaciers.

Harding Ice Field

>38 glaciers flow from the Harding Ice Field

- Volume loss in Harding Ice Field documented (early 1950s-1990s) for 13 glaciers =~34 km^3 and many glaciers <1000 m in elevation disappeared (Aðalgeirsdóttir et al., 1998; Echelmeyer et al., 1996)
- Nearly all 13 have undergone accelerated surface-elevation lowering in recent years (Arendt et al., 2002)

Photo by Erin McKittrick
Harding Icefield icebergs
http://en.wikipedia.org/wiki/File:HardingIcefield2.jpg

Skilak Glacier

Summary of change in areal extent from 1986 to 2000, as measured from Landsat images

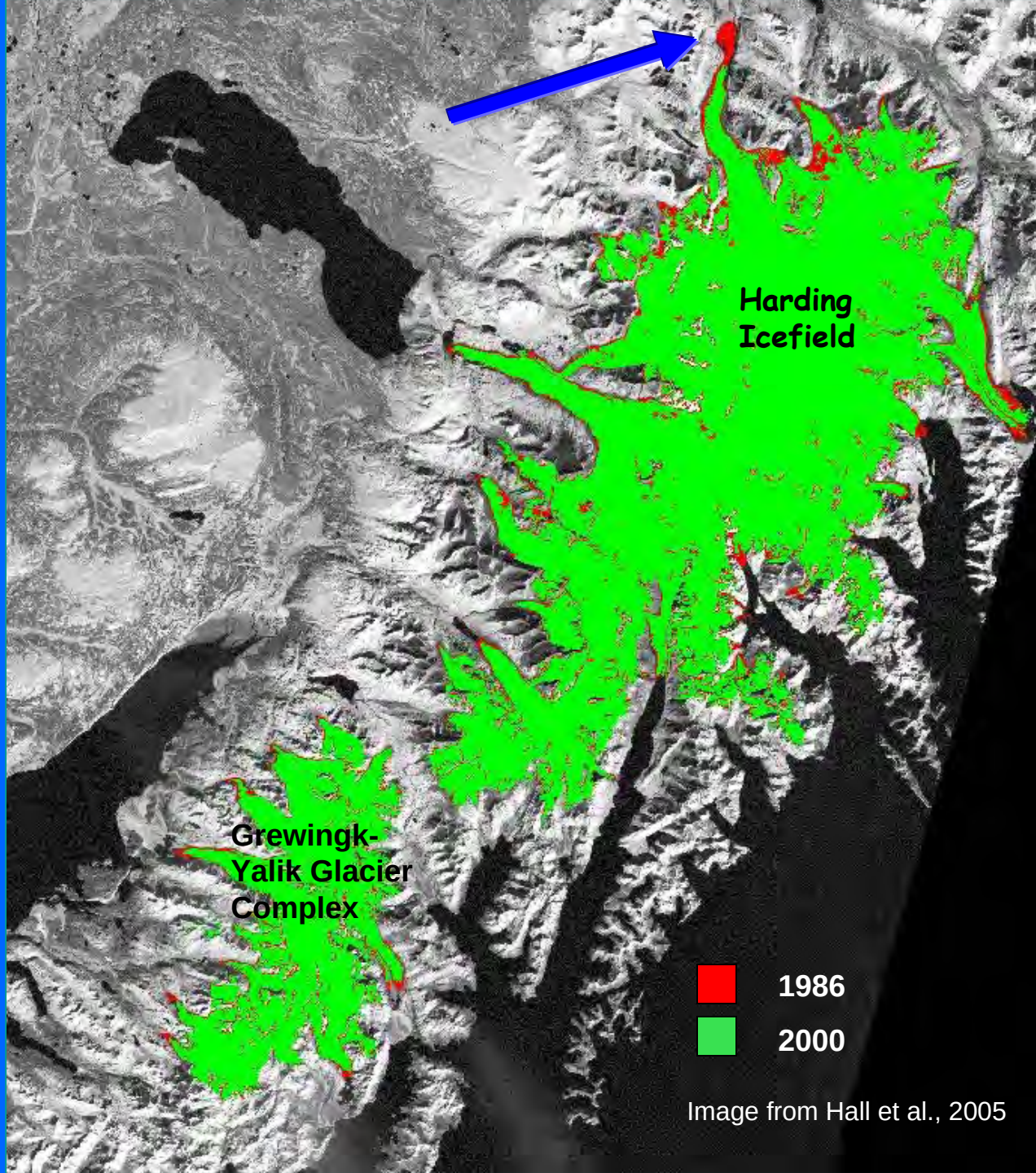
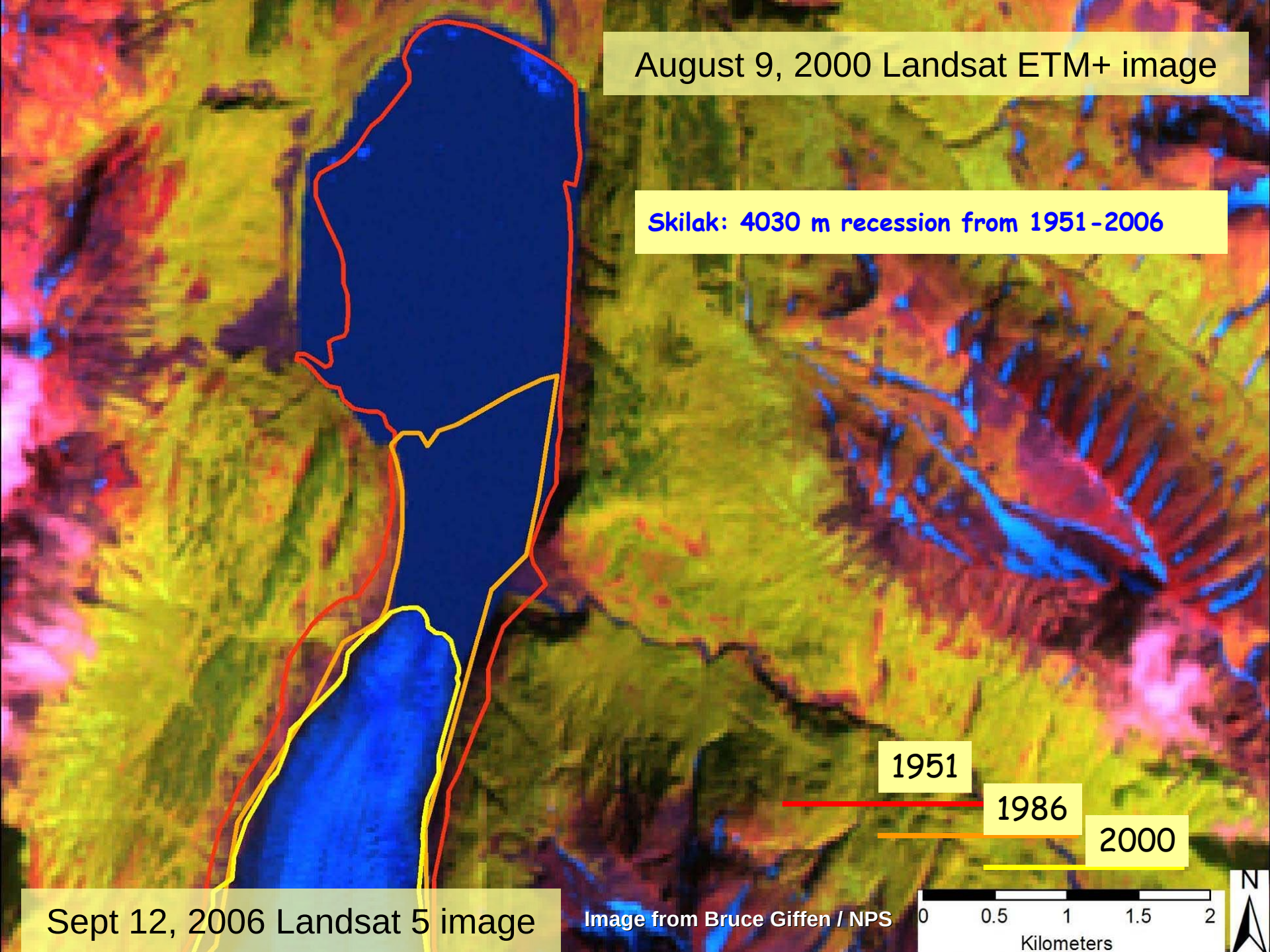
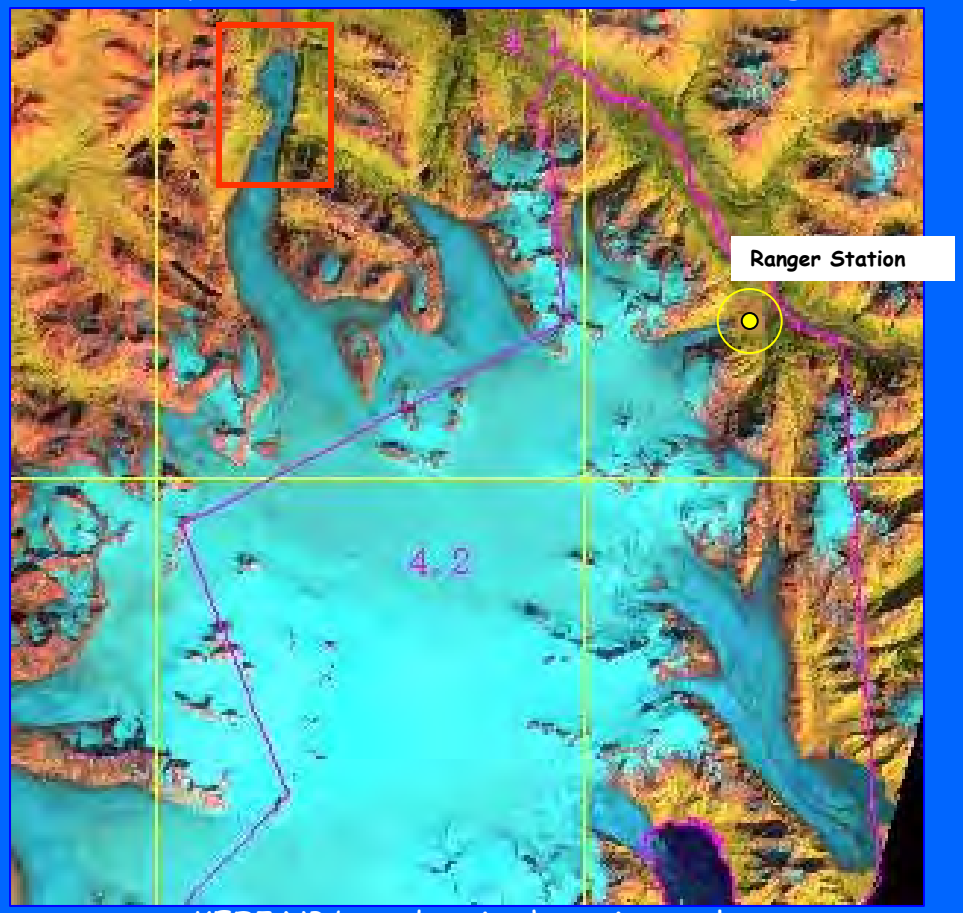


Image from Hall et al., 2005


August 9, 2000 Landsat ETM+ image
Skilak: 4030 m recession from 1951-2006
1951
1986
2000
Sept 12, 2006 Landsat 5 image
Image from Bruce Giffen / NPS
0
0.5
1
1.5
2
Kilometers
N

Skilak Glacier

September 12, 1986, Landsat TM image



KEFJ NP boundary is shown in purple

1973

1986

2000

~3811±136 m recession from 1973-2000

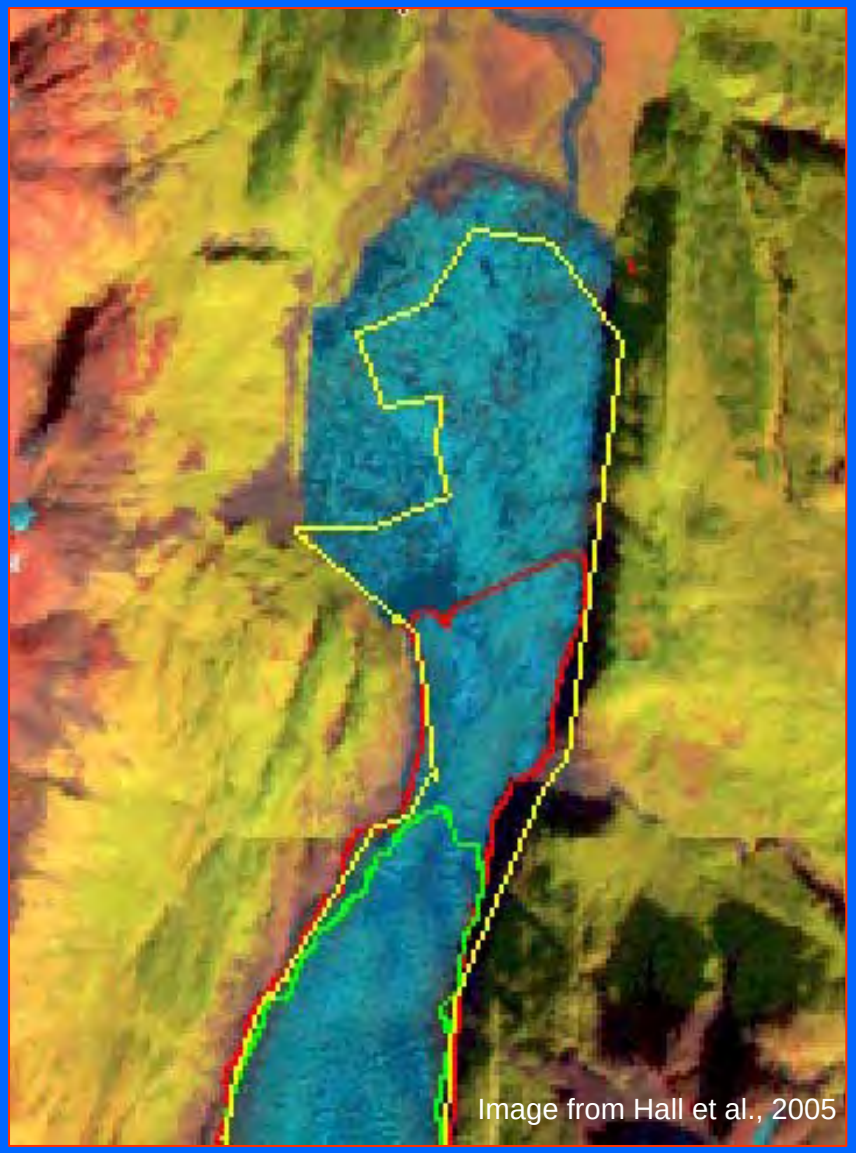


Image from Hall et al., 2005

Bear Glacier

KEFJ Bear Glacier Aerial Reconnaissance
N 59.923597° W 149.507935° NAD 83

Photo by: Chuck Lindsay, National Park Service, Southwest Alaska Network

2008/08/19 14:44:51

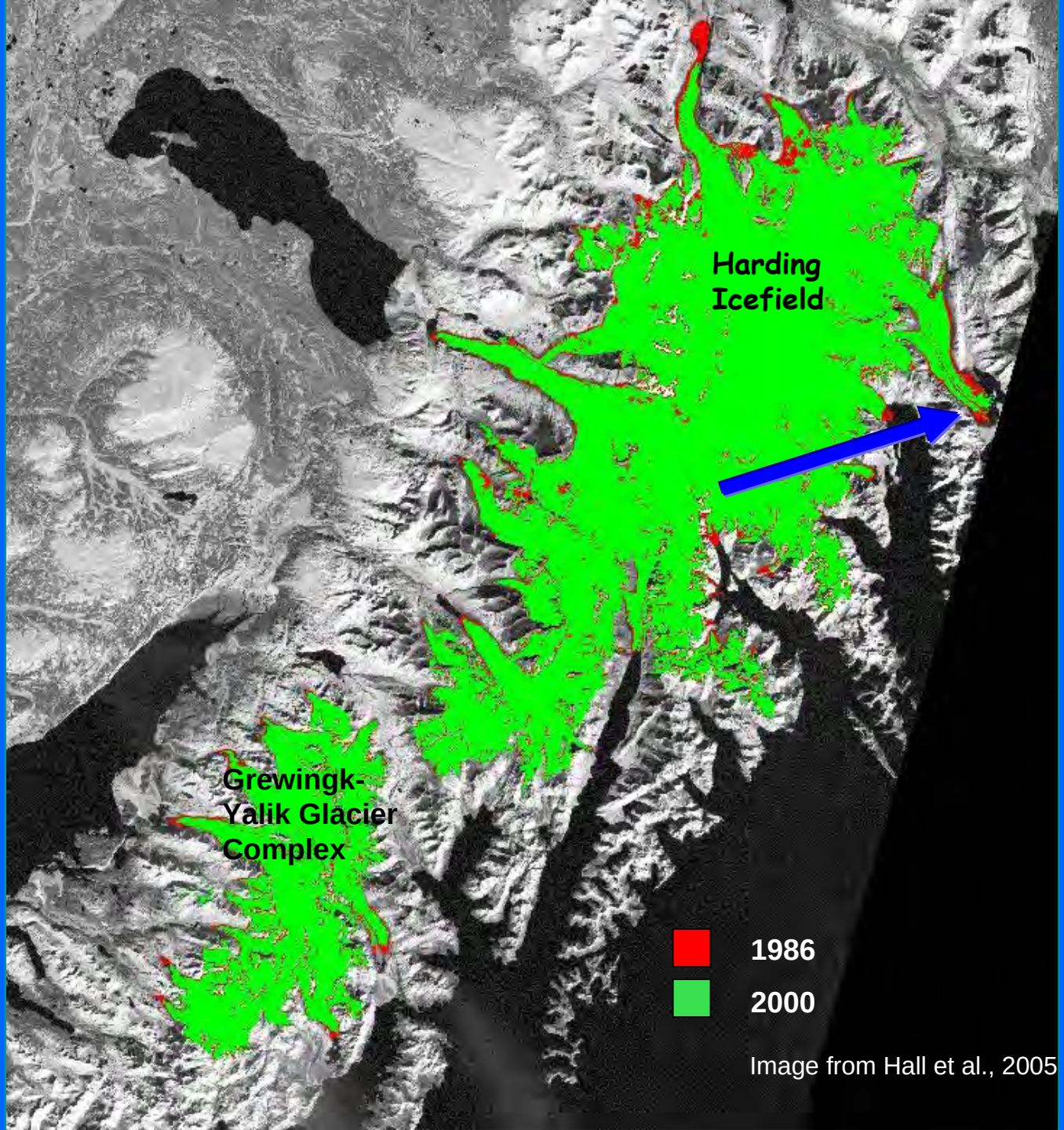
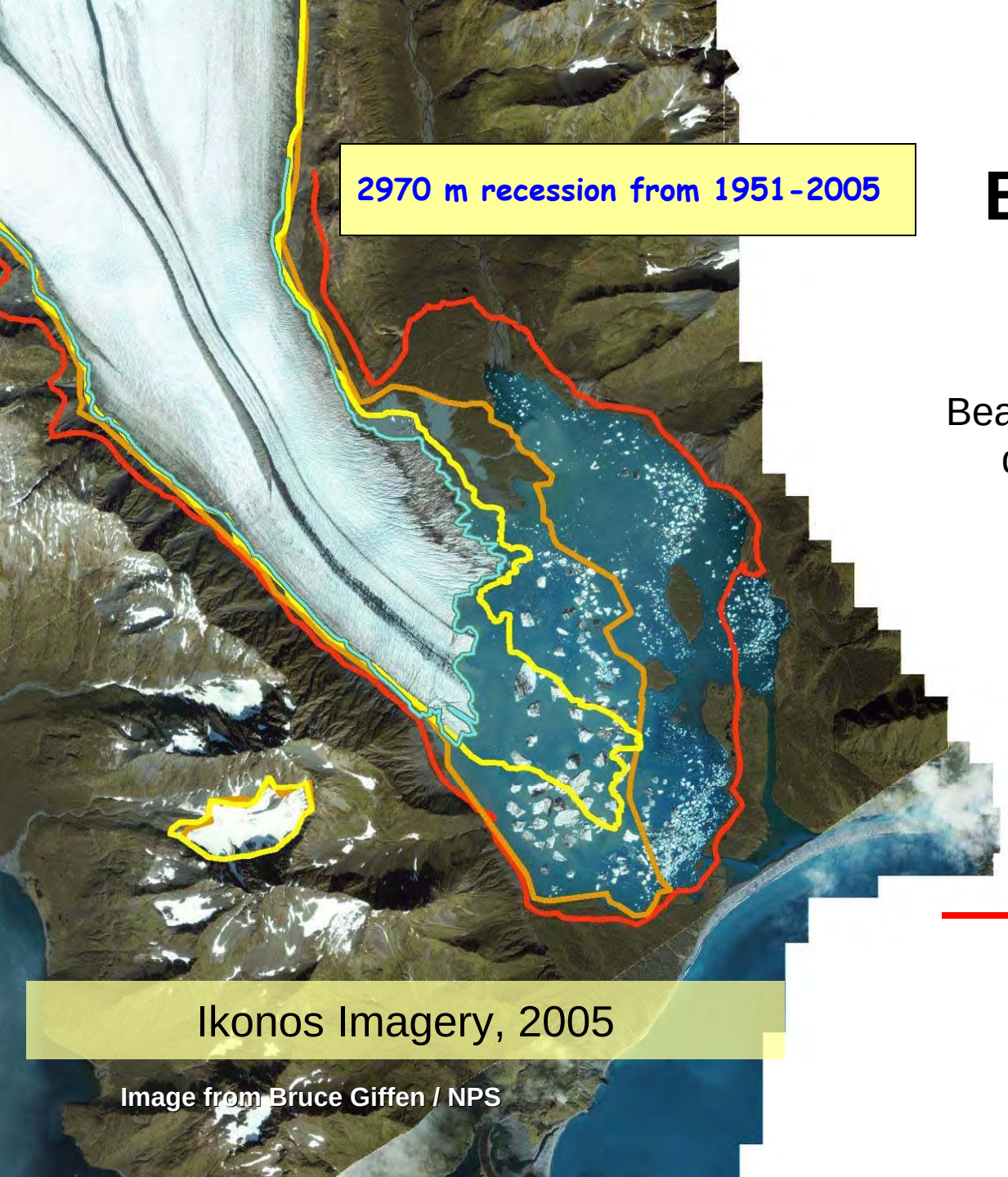


Image from Hall et al., 2005

Bear Glacier



Bear Glacier experienced a dramatic retreat from 2000 - 2005

1951

1986

2000

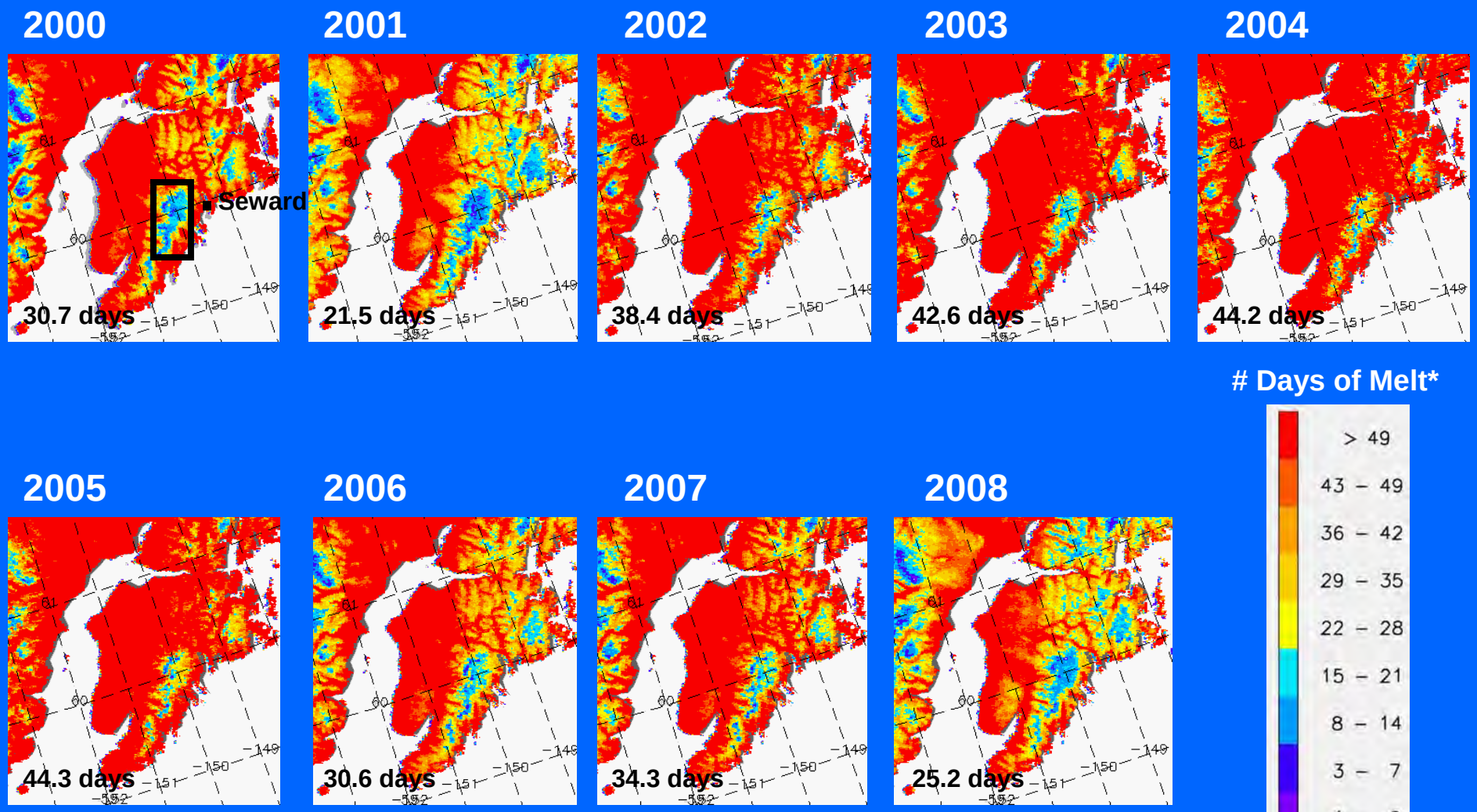
2005

0 1,000 2,000 3,000 4,000

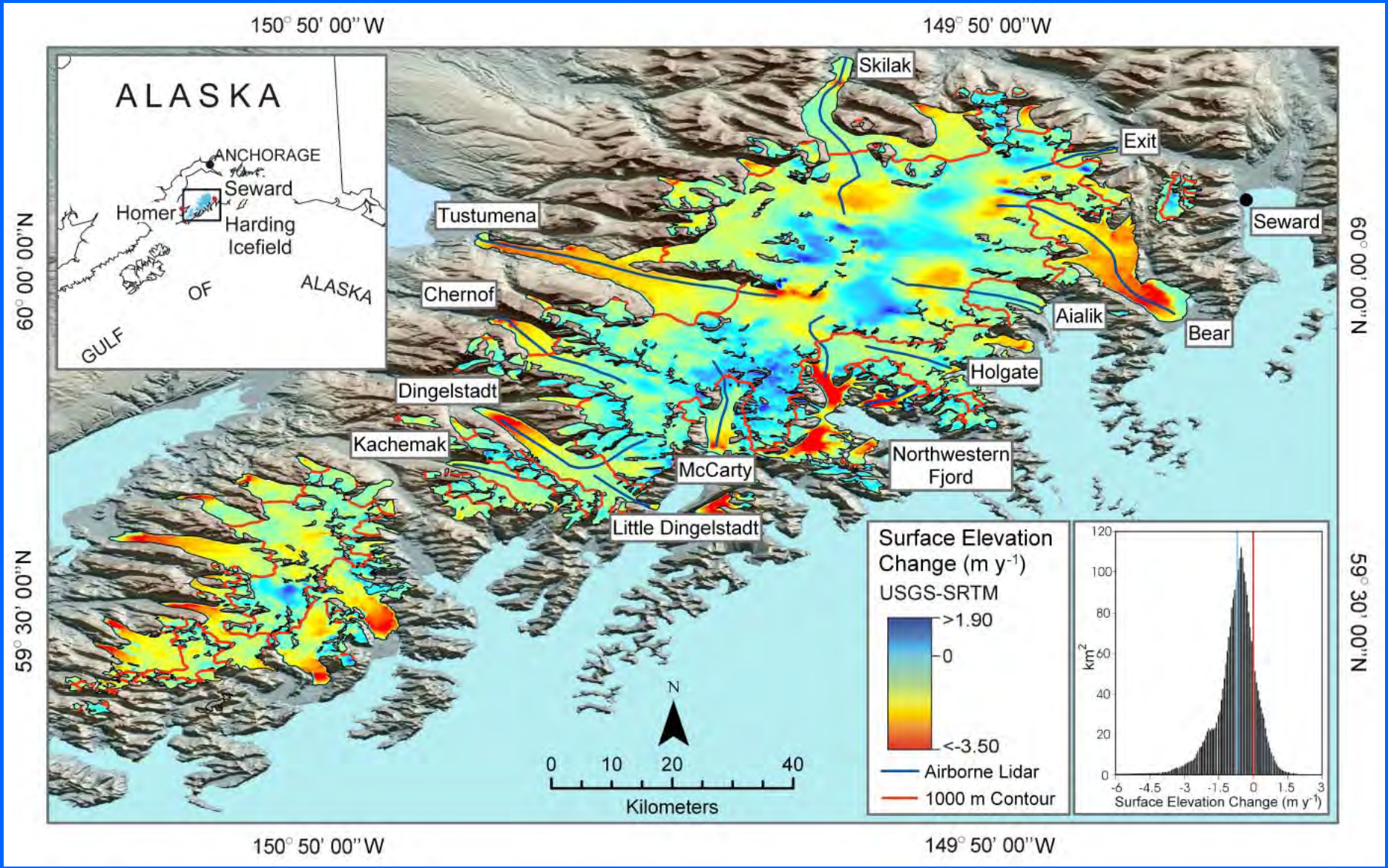
Meters

N

Mean Number of Days of Melt (per pixel) – Harding Icefield – from MODIS land-surface temperature (LST) product



*LST =>273 K



Surface elevation change rates for the Harding Icefield between 1950 and 1999. The histogram shows the distribution of surface elevation changes. Blue line of the histogram is mean surface elevation change (−0.61 m/y); red line separates thickening (+) and thinning (−) rates (from VanLooy et al., 2006, *GRL*).

Area averaged glacier surface elevation change rates below 1000 m, and glacier areas (from VanLooy et al., 2006)

Glacier	ΔZ, m y^{-1}		A, km^2	
	1950–1994/96	1994/96–1999	1950s	Mid-1990s
Exit	−0.10 ± 0.01	−0.25 ± 0.12	40.5	39.5
Bear	−0.80 ± 0.01	−1.01 ± 0.10	227.4	217.9
Aialik	+0.002 ± 0.01	−0.51 ± 0.10	87.1	87.0
Holgate	−0.23 ± 0.01	−1.37 ± 0.12	67.4	67.3
Northeastern*	−2.33 ± 0.01	−2.26 ± 0.20	14.2	11.5
Northwestern[b]	−0.94 ± 0.01	−1.03 ± 0.21	113.2	100.4
McCarty	−0.15 ± 0.01	−0.35 ± 0.15	124.6	119.4
Little Dingelstadt	−0.20 ± 0.02	−0.27 ± 0.09	34.8	34.5
Skilak	−0.13 ± 0.01	−0.16 ± 0.12	202.3	196.1
Tustumena	−0.43 ± 0.01	−0.52 ± 0.09	300.5	298.9
Chernof[b]	−0.67 ± 0.02	−1.11 ± 0.19	63.5	56.5
Dingelstadt[b]	−0.89 ± 0.01	−1.89 ± 0.18	72.7	67.2
Kachemak	−0.39 ± 0.01	−0.84 ± 0.13	23.8	22.8
Total Average	−0.47 ± 0.01	−0.72 ± 0.13		

[a]Error was calculated using the method from section 2.3. The ±1 σ of the offsets were 3.6 m for 1950–1994/96, and 3.3 m for 1994/96–1999. ΔZ is change in surface elevation in m y^{-1}; A is glacier area in km^2; (+) indicates thickening, (−) indicates thinning.
[b]Calculation determined for area below 1200 m.

Area-averaged glacier surface elevation change rates below 1000 m, (from VanLooy et al., 2006)

Glacier	ΔZ, m y^{-1}	
	1950–1994/96	1994/96–1999
Exit	−0.10 ± 0.01	−0.25 ± 0.12
Bear	−0.80 ± 0.01	−1.01 ± 0.10
Aialik	+0.002 ± 0.01	−0.51 ± 0.10
Holgate	−0.23 ± 0.01	−1.37 ± 0.12
Northeastern*	−2.33 ± 0.01	−2.26 ± 0.20
Northwestern[b]	−0.94 ± 0.01	−1.03 ± 0.21
McCarty	−0.15 ± 0.01	−0.35 ± 0.15
Little Dingelstadt	−0.20 ± 0.02	−0.27 ± 0.09
Skilak	−0.13 ± 0.01	−0.16 ± 0.12
Tustumena	−0.43 ± 0.01	−0.52 ± 0.09
Chernof[b]	−0.67 ± 0.02	−1.11 ± 0.19
Dingelstadt[b]*	−0.89 ± 0.01	−1.89 ± 0.18
Kachemak	−0.39 ± 0.01	−0.84 ± 0.13
Total Average	−0.47 ± 0.01	−0.72 ± 0.13

Compare to Dyurgerov & Meier (2004) estimate (from mid-1960s to mid-1990s) of global average thinning rate = -0.13 m/yr

[a]Error was calculated using the method from section 2.3. The ±1 σ of the offsets were 3.6 m for 1950–1994/96, and 3.3 m for 1994/96–1999. ΔZ is change in surface elevation in m y^{-1}; A is glacier area in km^2; (+) indicates thickening, (−) indicates thinning.
[b]Calculation determined for area below 1200 m.

Katmai NPP

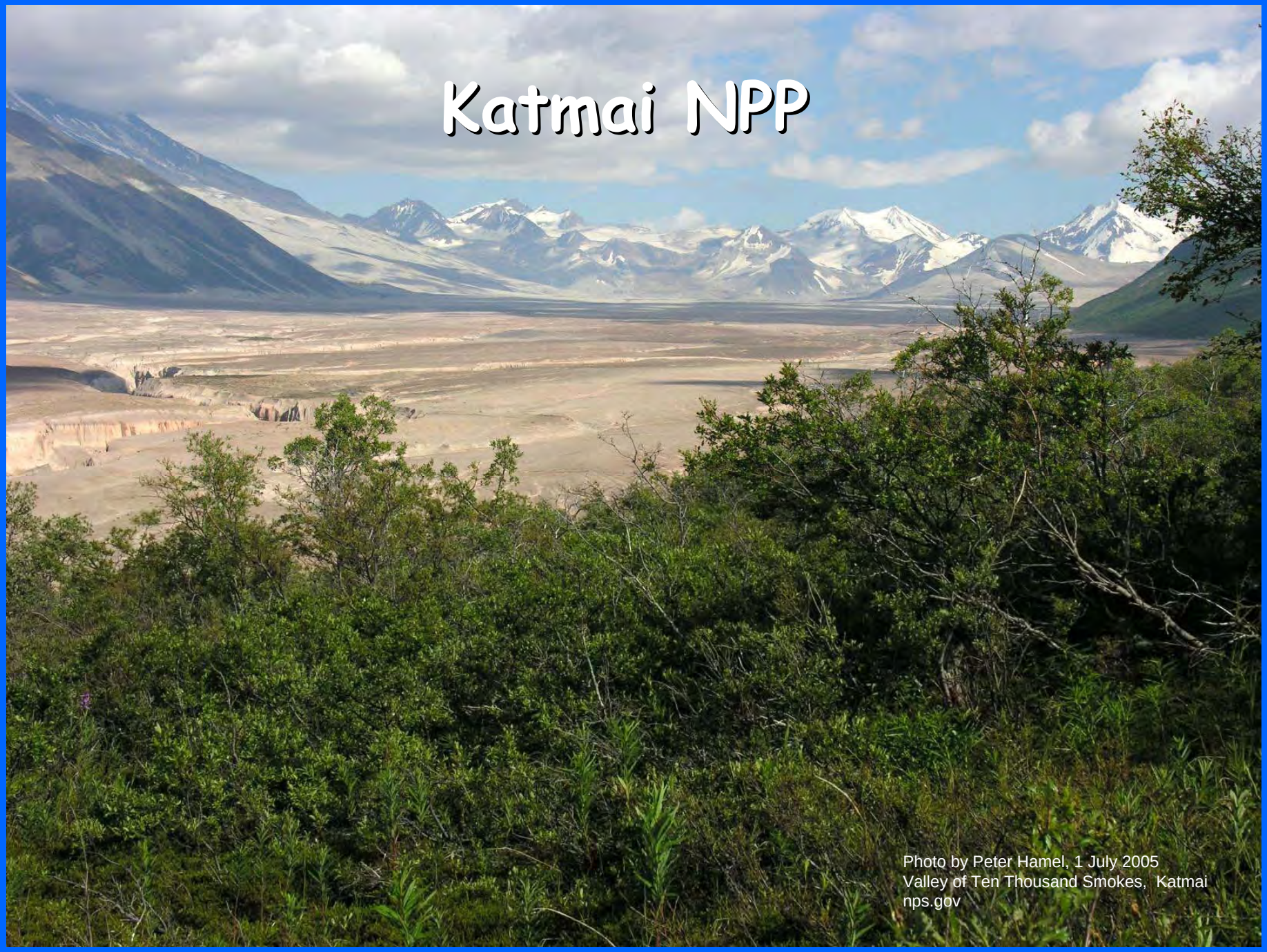
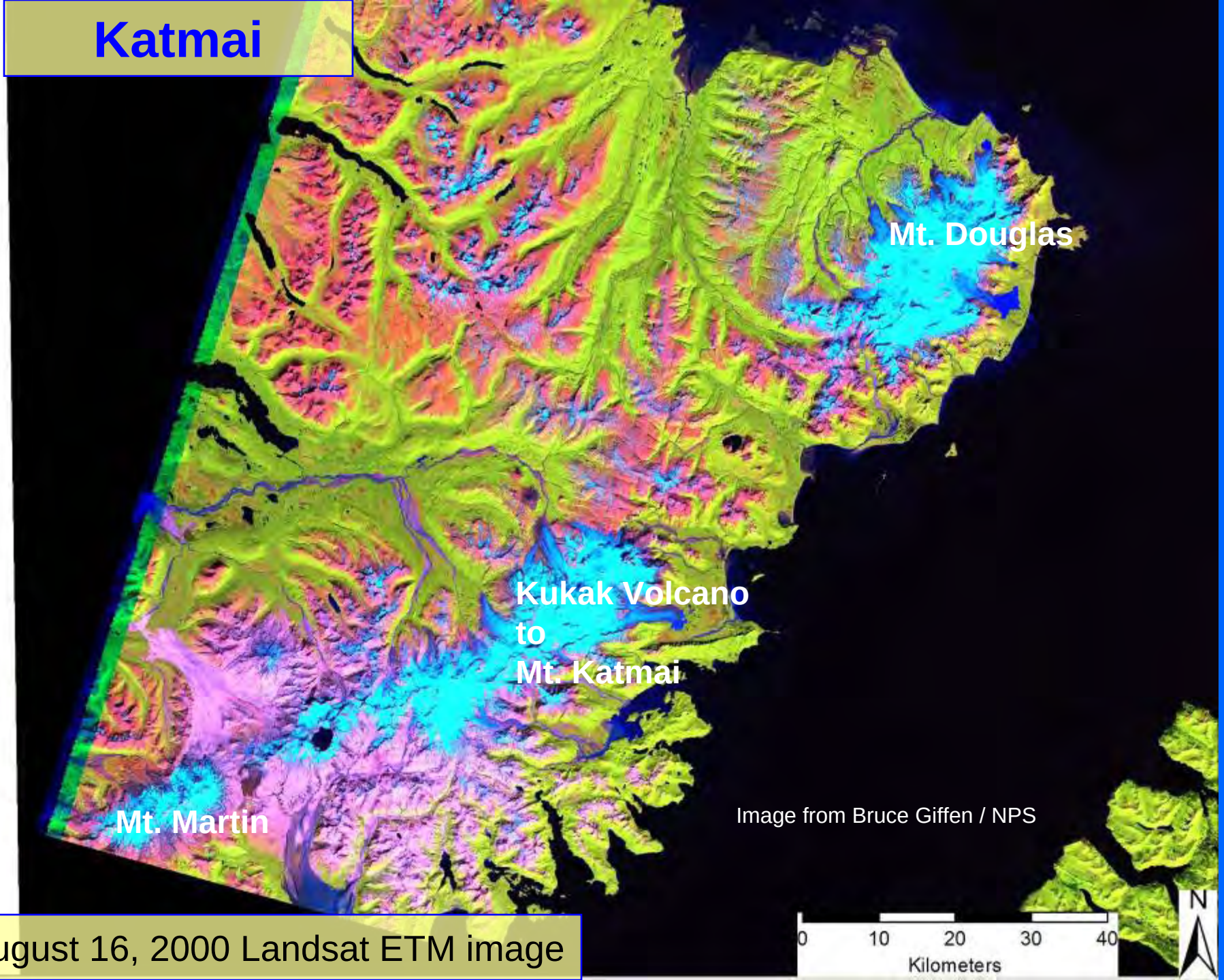


Photo by Peter Hamel, 1 July 2005
Valley of Ten Thousand Smokes, Katmai
nps.gov

Many of the glaciers in Katmai NPP are covered with thick layers of ash from volcanic eruptions, and morainal debris from stagnation & recession

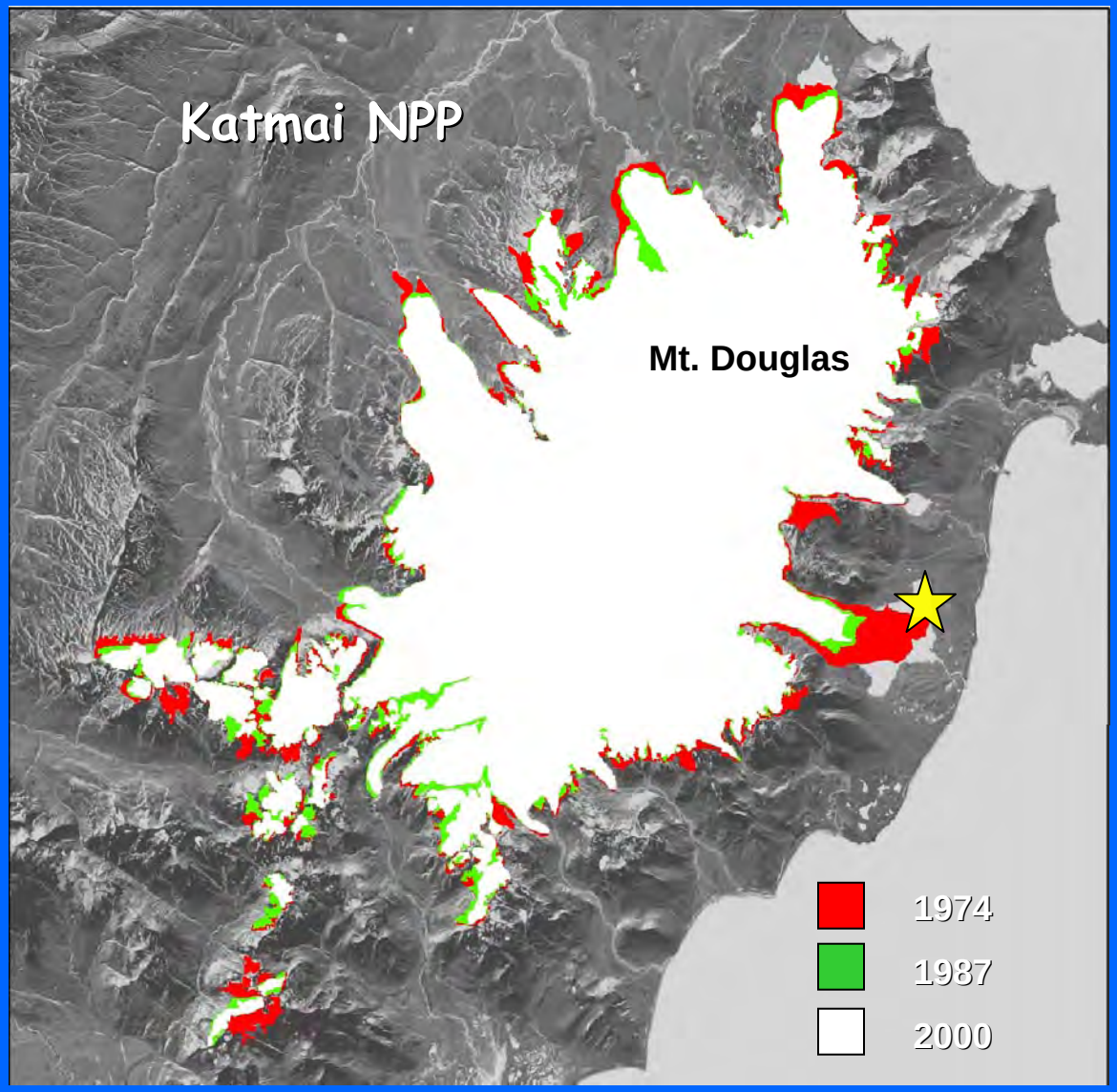
Photo by Roy Wood, 6 Aug. 2004 Ash-covered glacier on slopes of Mt. Katmai
nps.gov

Katmai



August 16, 2000 Landsat ETM image

Change in areal extent measured from Landsat images



Difference = -42.86±0.0023 km^2

10.8% decrease, 1974 – 2000

From Giffen et al., in press

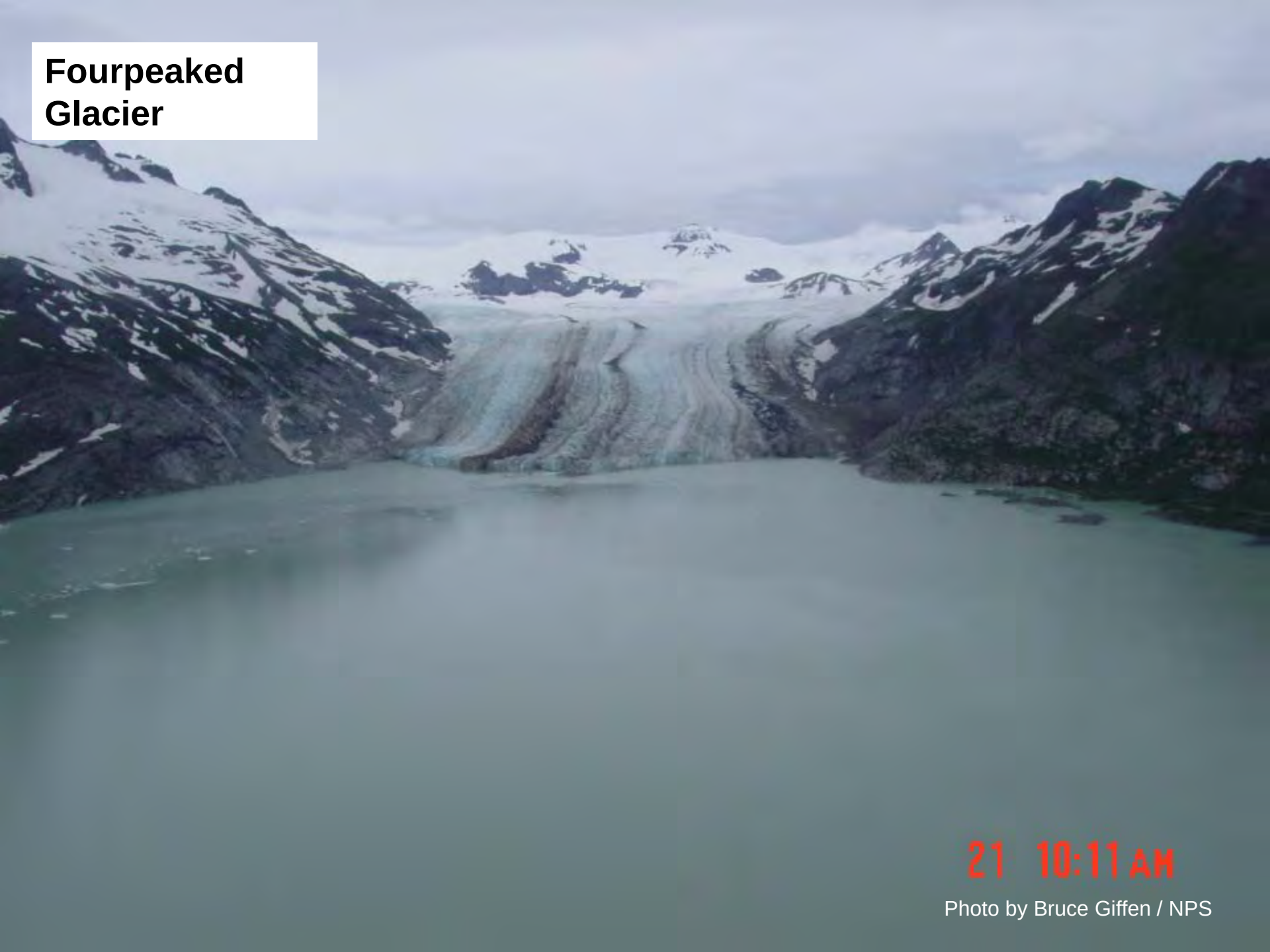
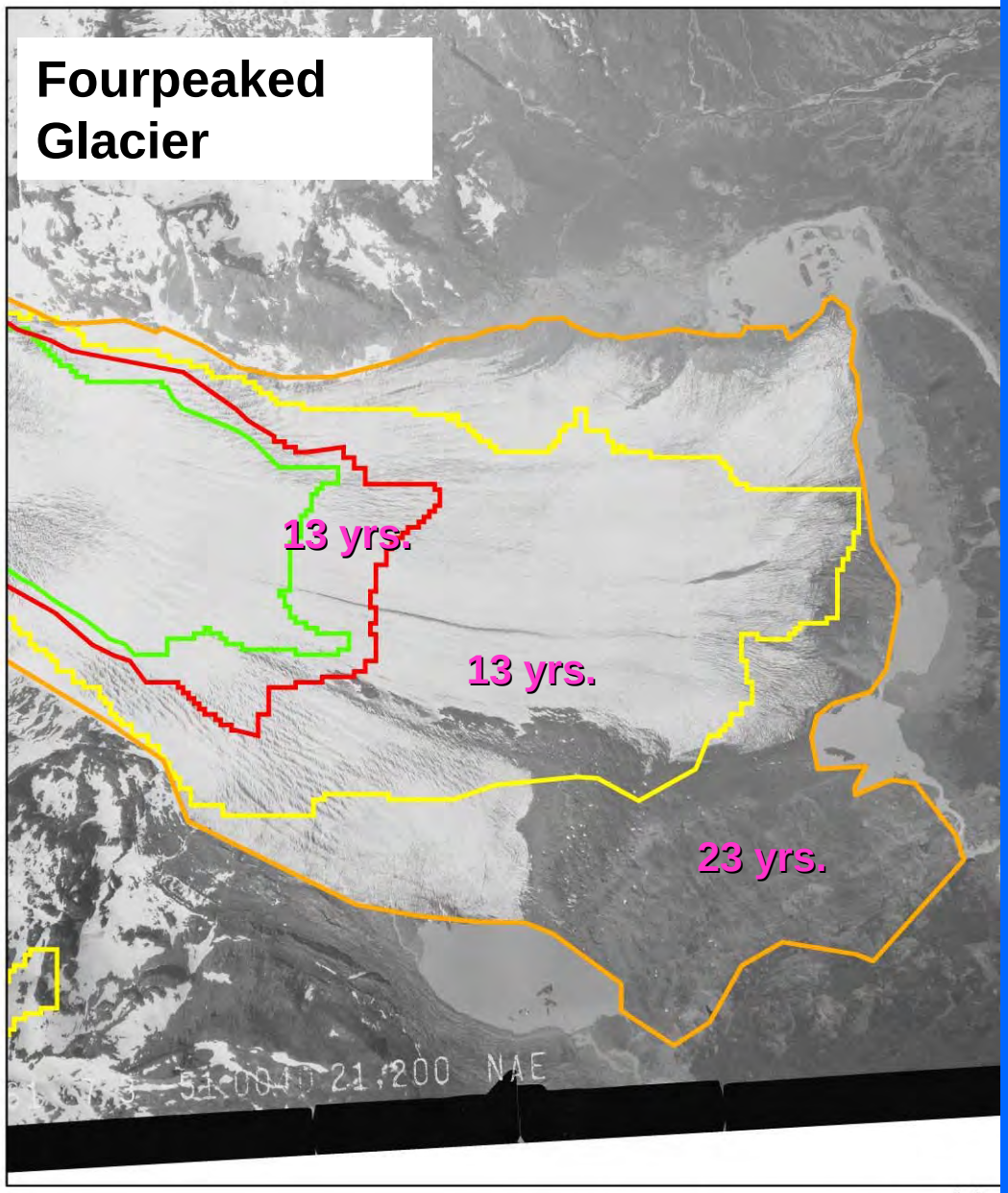


Photo by Bruce Giffen / NPS

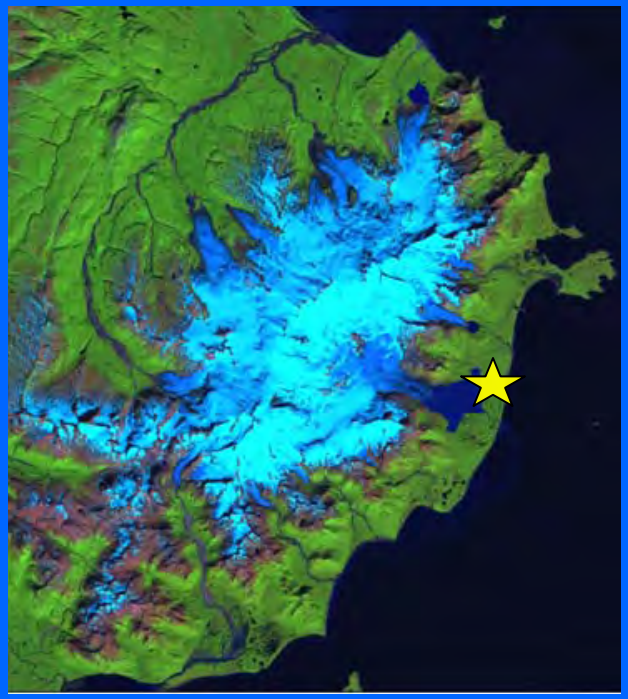


0 0.5 1 2
Kilometers

N

USGS Aerial Photo July, 1951

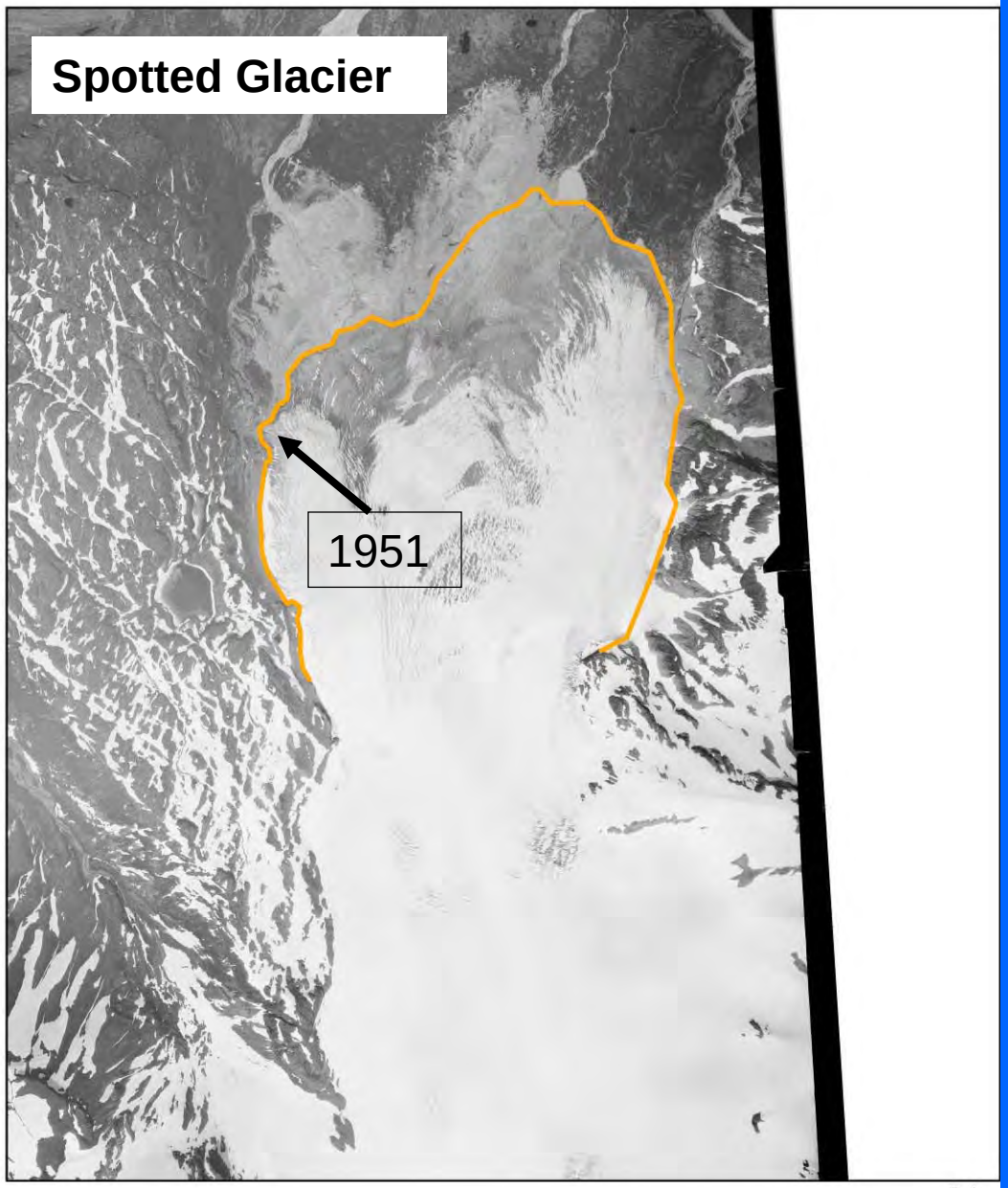
Cape Douglas Area



~3600 m recession from 1951-2000

1951
1974
1987
2000

Images from Bruce Giffen / NPS

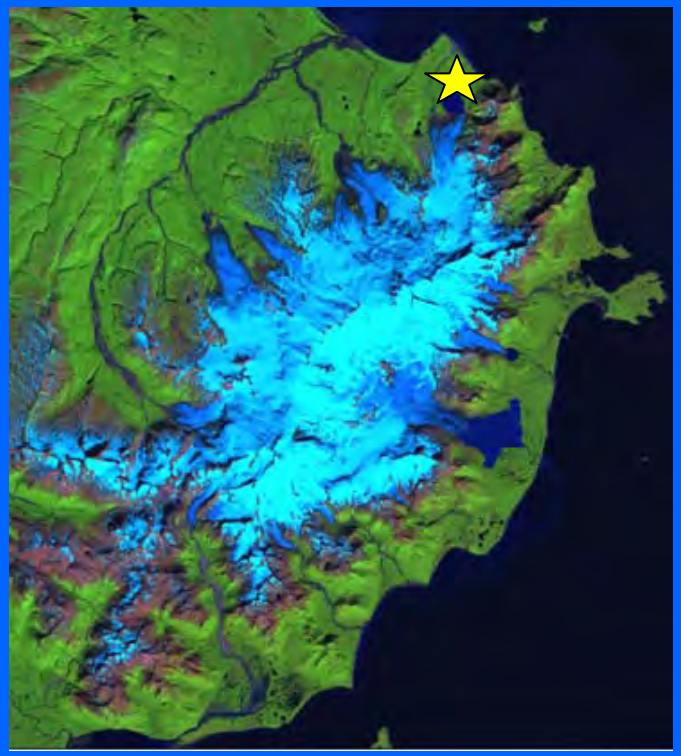


0 0.5 1 1.5 2
Kilometers

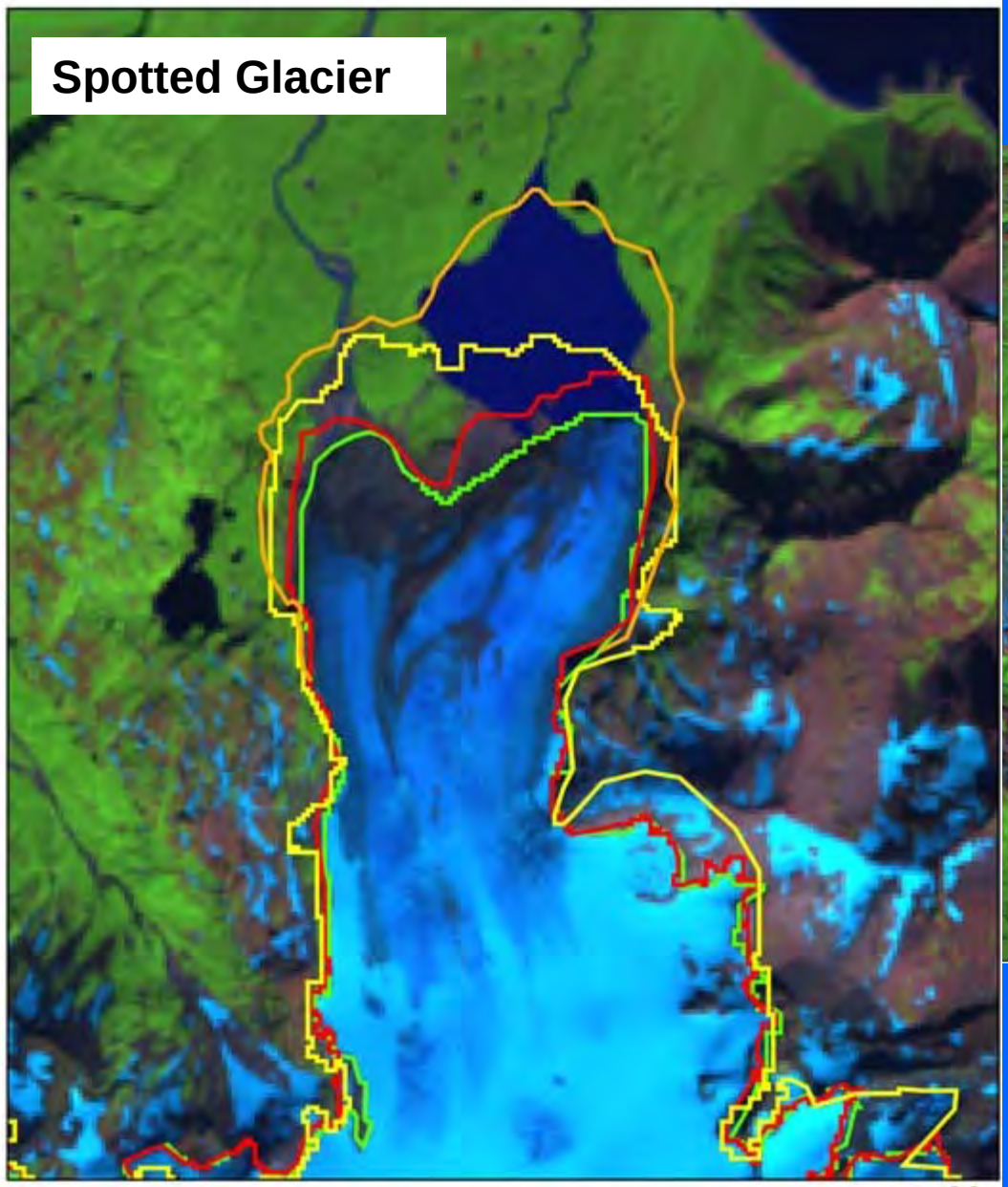
N

USGS Aerial Photo July, 1951

Cape Douglas Area

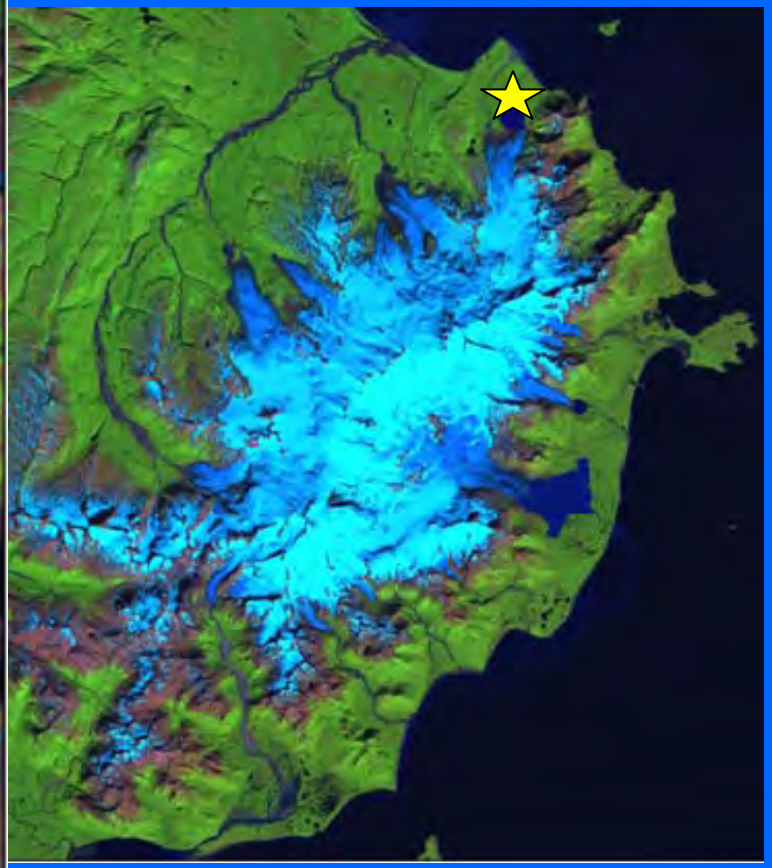


Images from Bruce Giffen / NPS



Landsat August 16, 2000

Cape Douglas Area



~1450 m recession from 1951-2000

1951

1974

1987

2000

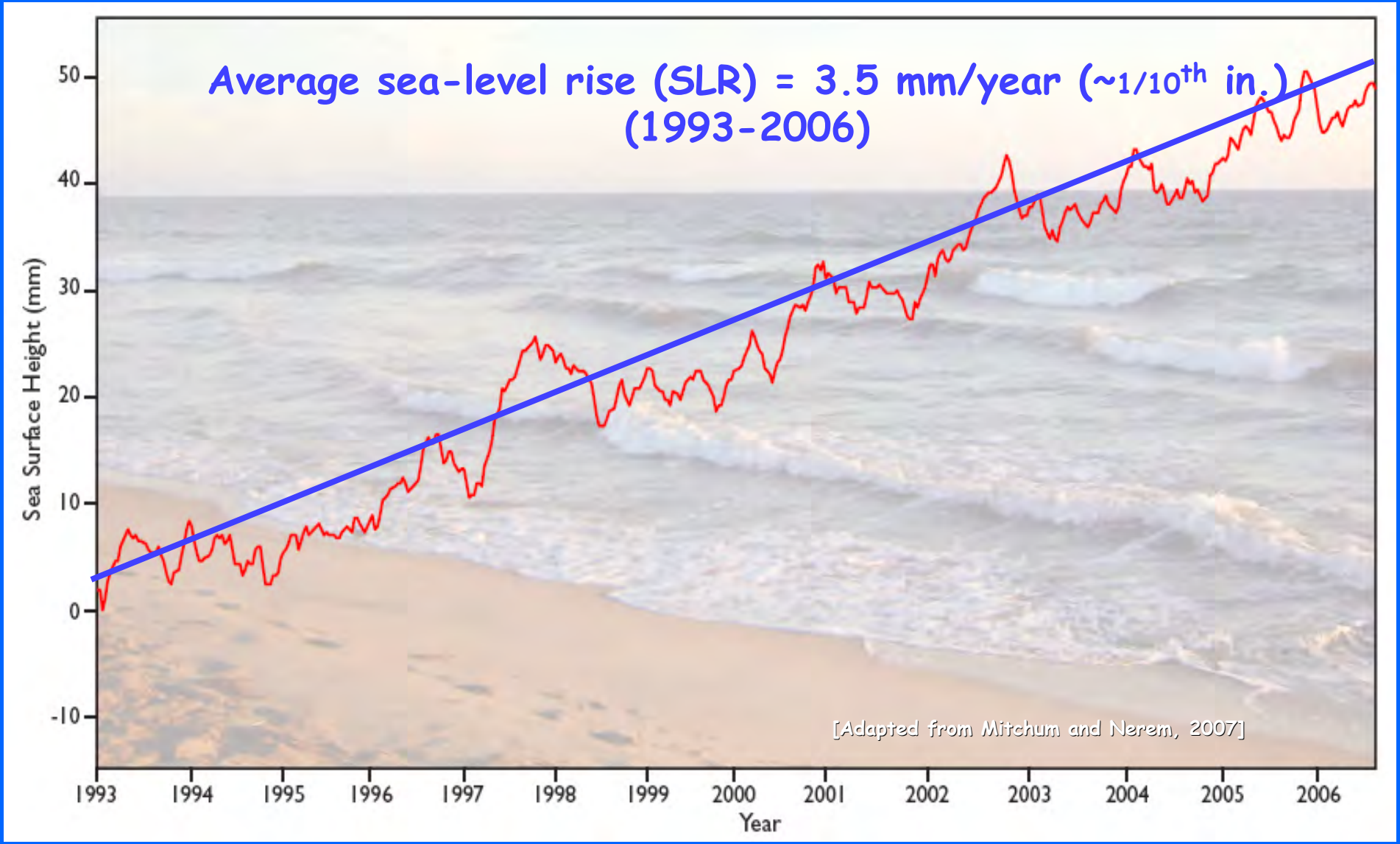
Images from Bruce Giffen / NPS

Estimated potential maximum sea level rise from the total melting of present-day glaciers

Location	Volume (km^3)	Potential sea-level rise (m)
East Antarctic ice sheet	26,039,200	64.80
West Antarctic ice sheet	3,262,000	8.06
Antarctic Peninsula	227,100	.46
Greenland	2,620,000	6.55
All other ice caps, ice fields, and valley glaciers	180,000	.45
Total	32,328,300	80.32

Mountain glaciers contribute more to sea-level rise than ice sheets, with the greatest contribution by mountain glaciers in maritime and coastal environments (Arendt et al., 2002; Dyurgerov & McCabe, 2006; Luthcke et al., 2008)

Global Mean Sea Level



From satellite altimetry

Sea Level Rise

- Sea level has risen 1-3 mm / yr. over the last century to total 30-40 cm
- The likely largest source of continued sea-level rise (SLR) are the Earth's small glaciers and ice caps (Meier et al., 2007) – about 60%
- Alaska glaciers contributed ~9% to observed SLR over the last half century (Arendt et al., 2002)

Conclusions

- The Earth's small glaciers have been receding worldwide, beginning ~1850; acceleration of melt has occurred during the past 25 years
- Dramatic recession and shrinkage has been measured in glaciers in KEFJ & KATM; recession of glaciers is more dramatic in KATM
- Very little work appears in the peer-reviewed literature about the glaciers in the three ice fields in KATM; this work (Giffen et al., in press) represents the first comprehensive study of those glaciers
- Shape files of these carefully-measured glacier areas will be provided to the Global Land Ice Measurements from Space (GLIMS) project
- Accuracy of glacier-area measurements is important for area-wide calculation of glacier-volume measurements (from aircraft and satellite Lidar)

Thank you!

Tustemena Glacier and
Arctic Lake (drained)
7/12/2004
Erin McKittrick