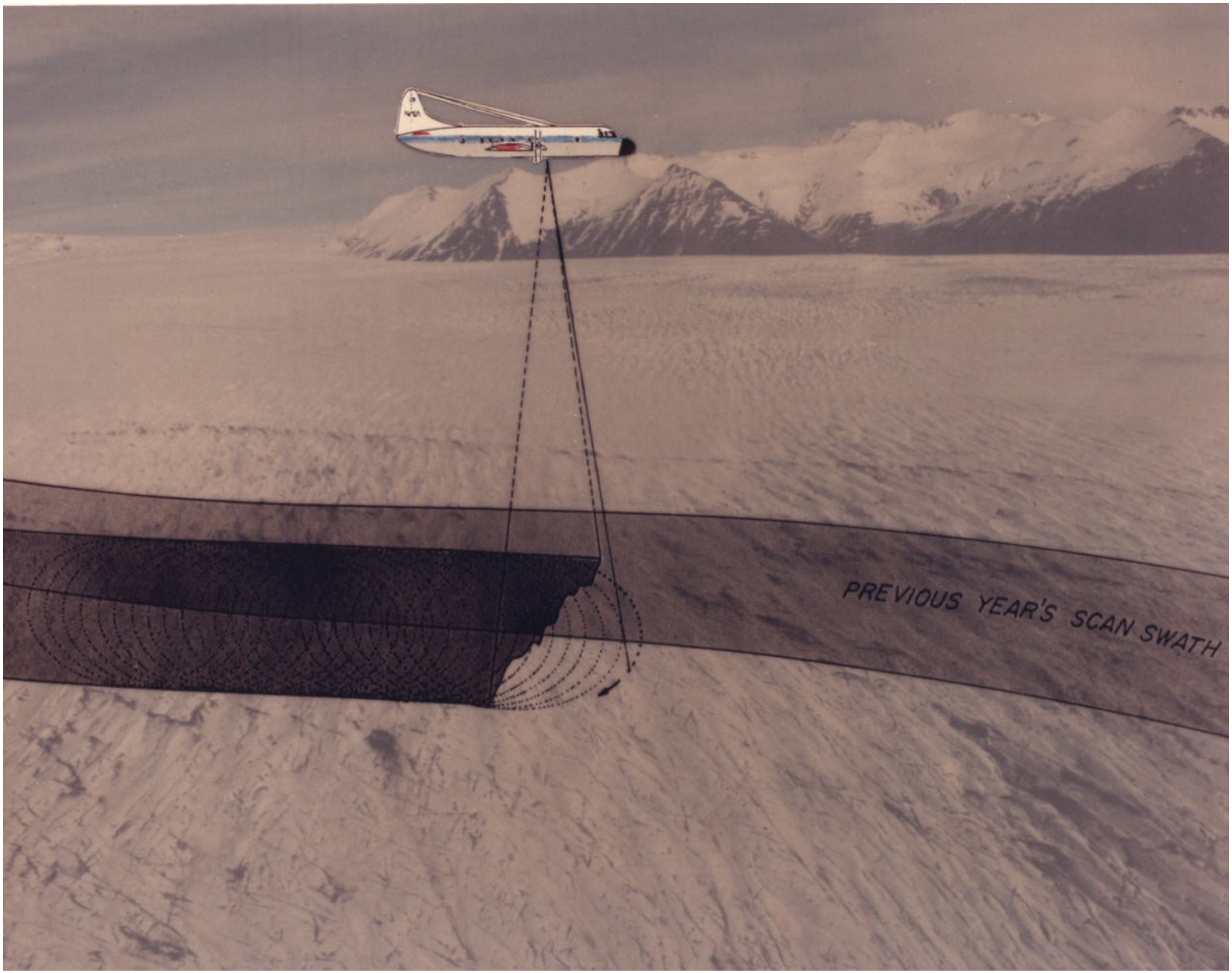
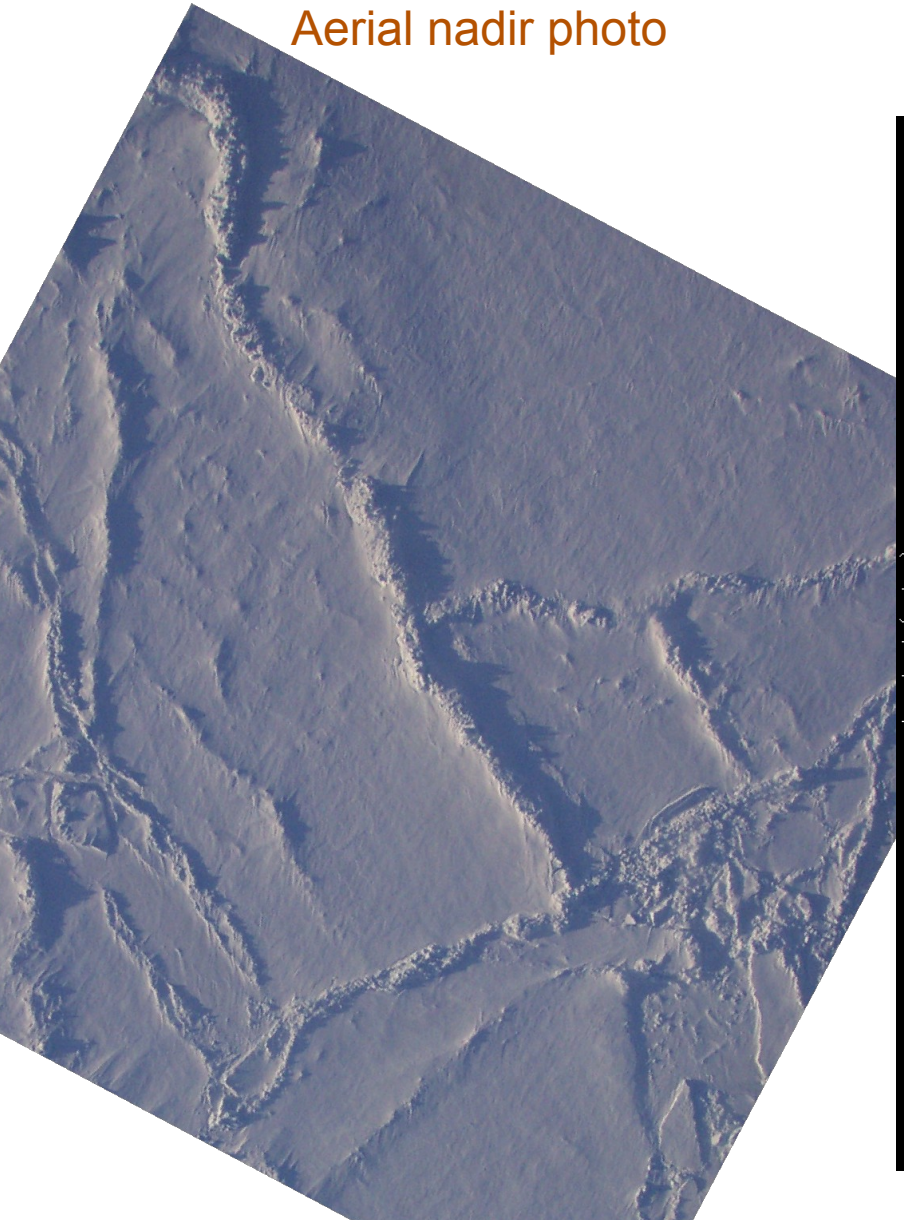
Bill Krabill
NASA/GSFC

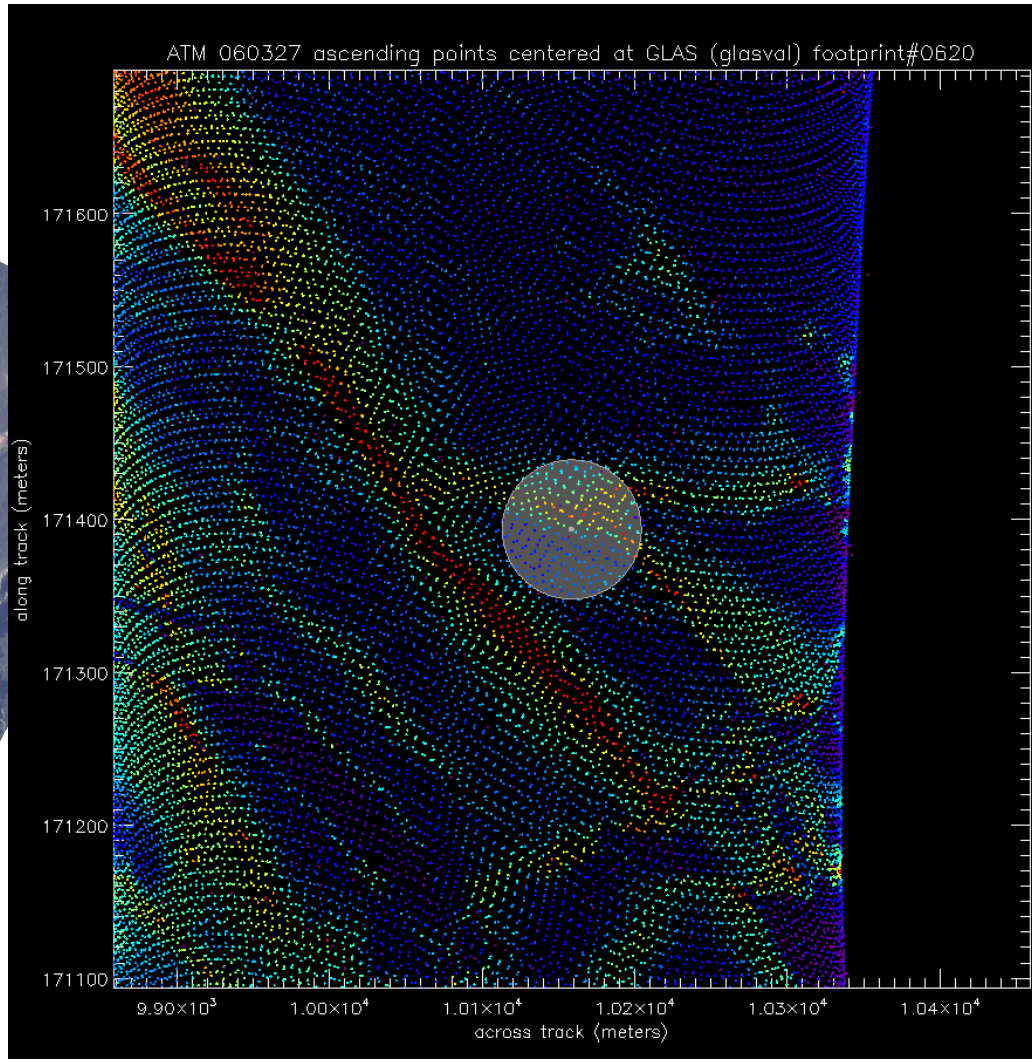

PREVIOUS YEAR'S SCAN SWATH

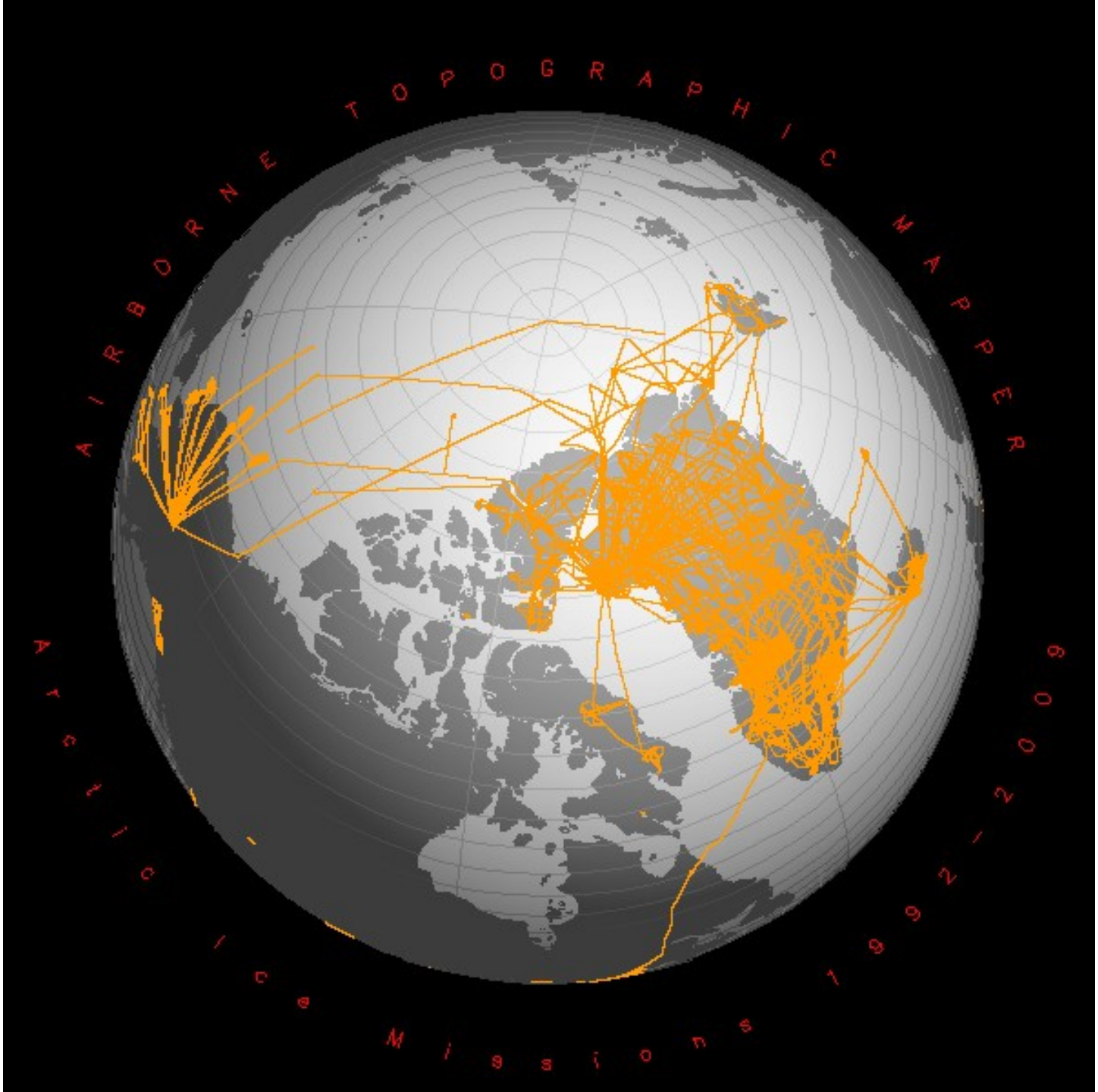
ATM underflight of ICESat 2006-Mar-27

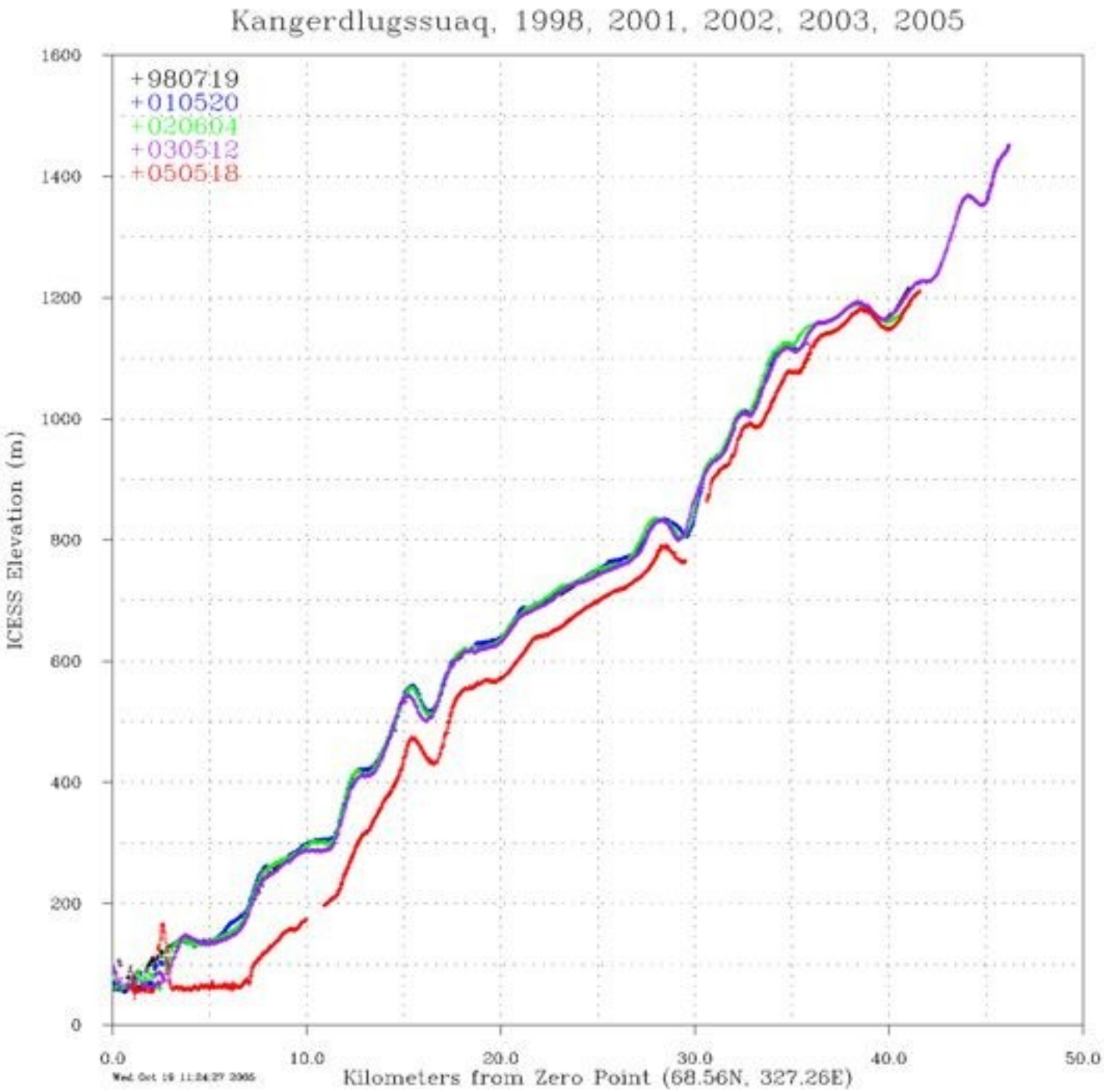
Aerial nadir photo

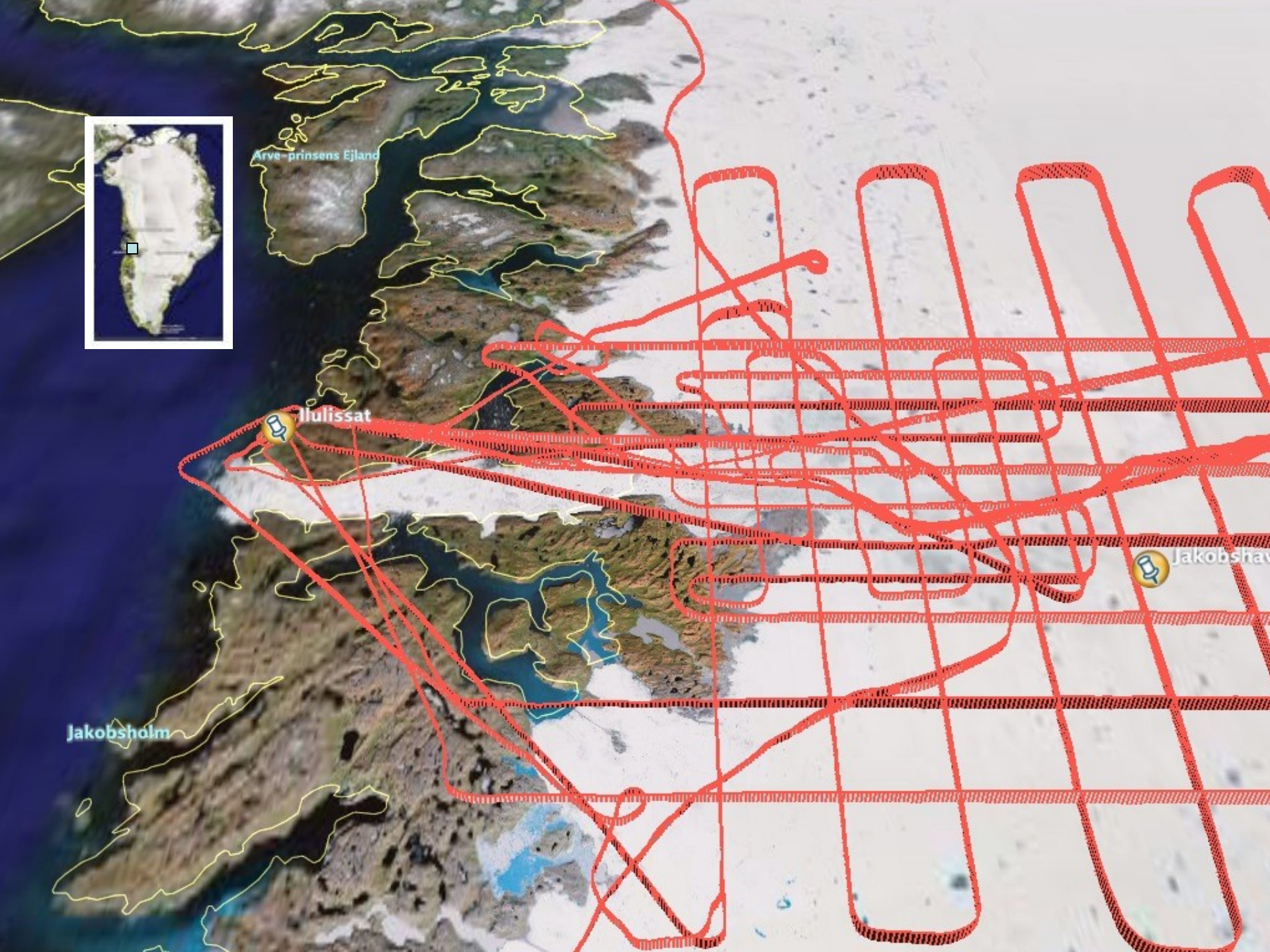


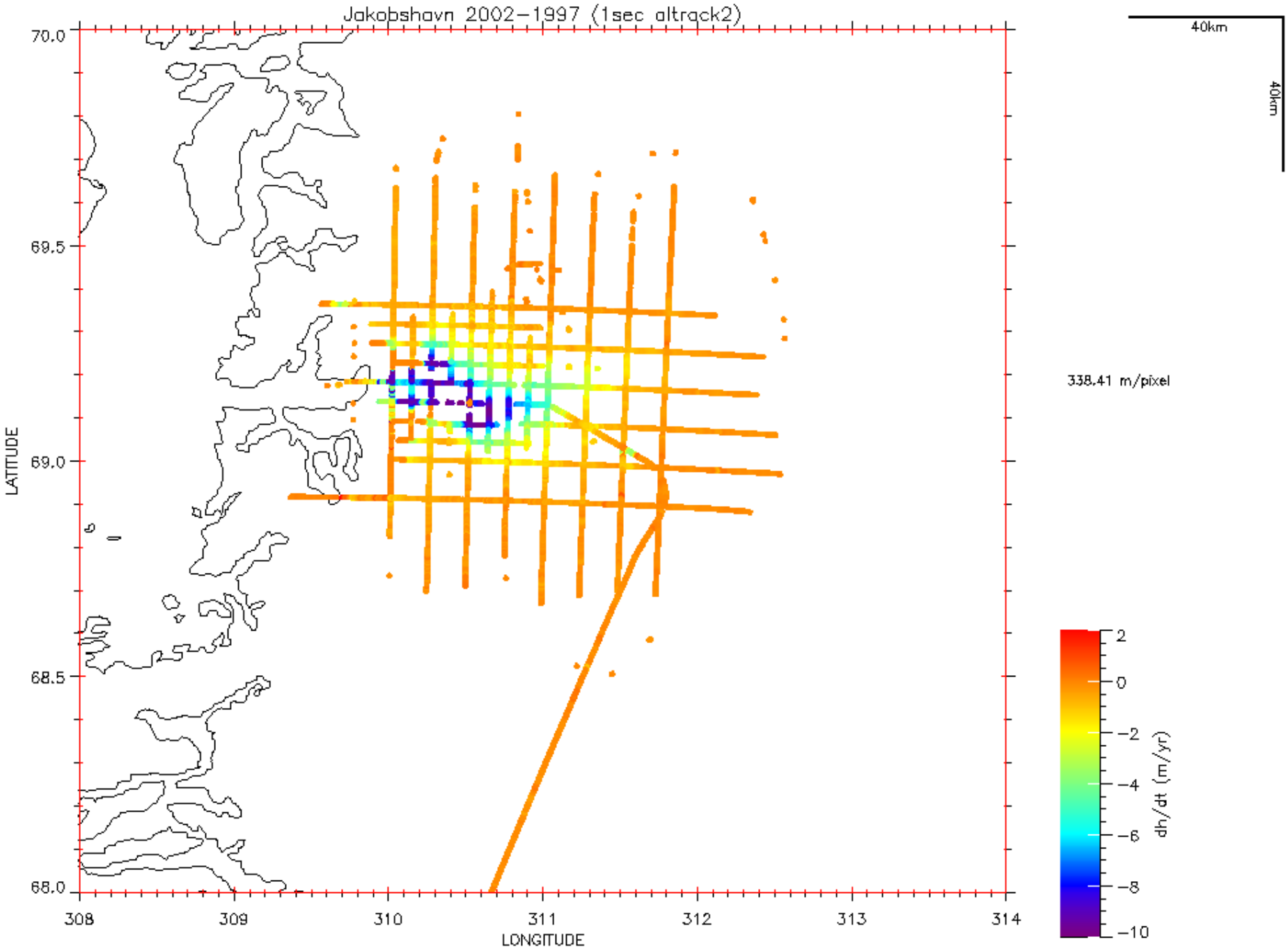
ATM topography

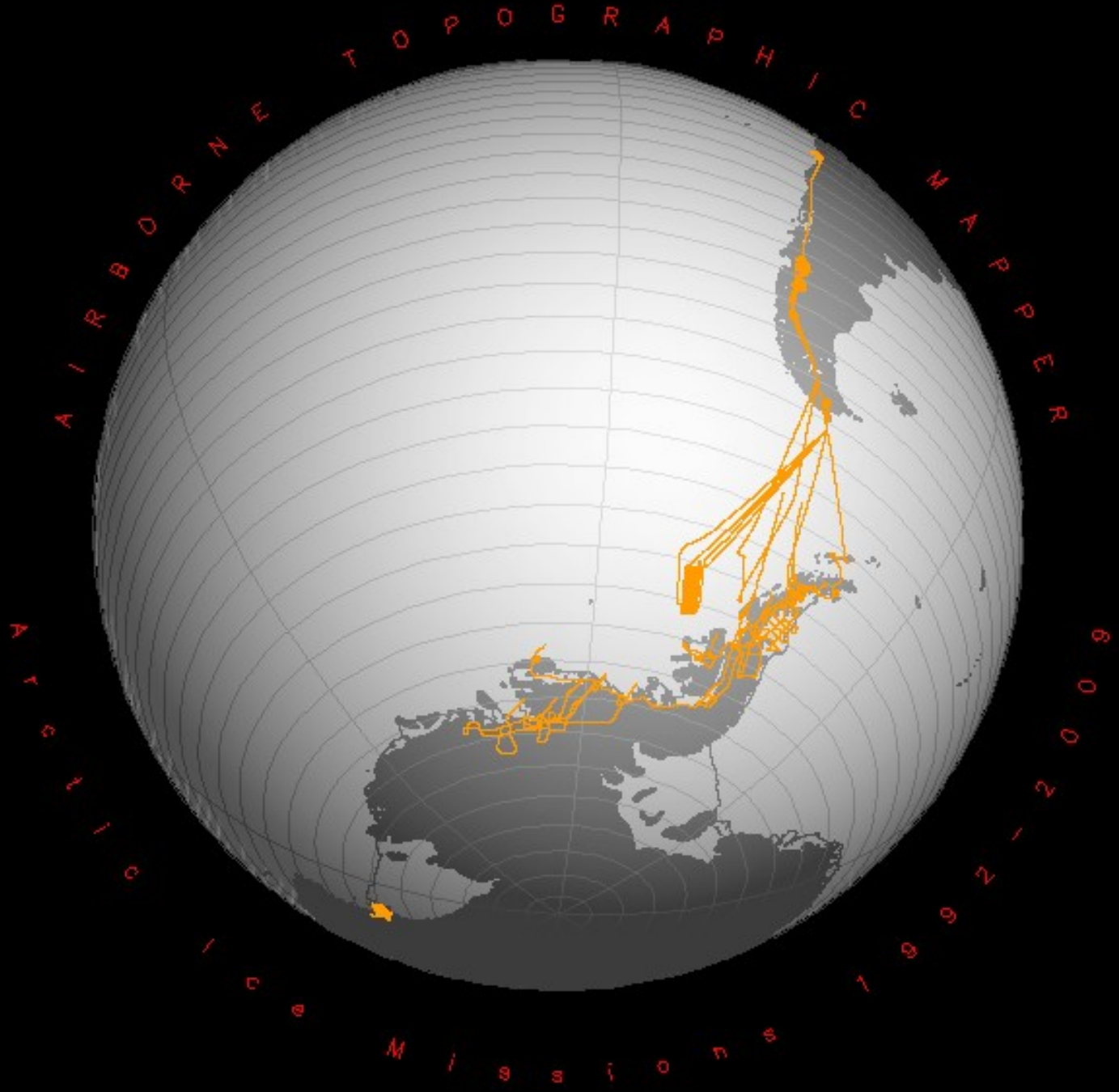



AIRBORNE TOPOGRAPHIC MAPPER
Arctic Ice Missions
1992-2006


Kangerdlugssuaq, 1998, 2001, 2002, 2003, 2005
+980719
+010520
+020604
+030512
+050518
ICESS Elevation (m)
1600
1400
1200
1000
800
600
400
200
0
0.0
10.0
20.0
30.0
40.0
50.0
Kilometers from Zero Point (68.56N, 327.26E)


Arve-prinsens Ejland
Ilulissat
Jakobsholm


Jakobshavn 2002-1997 (1sec altrack2)
40km
40km
338.41 m/pixel
70.0
69.5
69.0
68.5
68.0
LATITUDE
308
309
310
311
312
313
314
LONGITUDE
2
0
-2
-4
-6
-8
-10
dh/dt (m/yr)
Wed Oct 19 05:29:24 2005

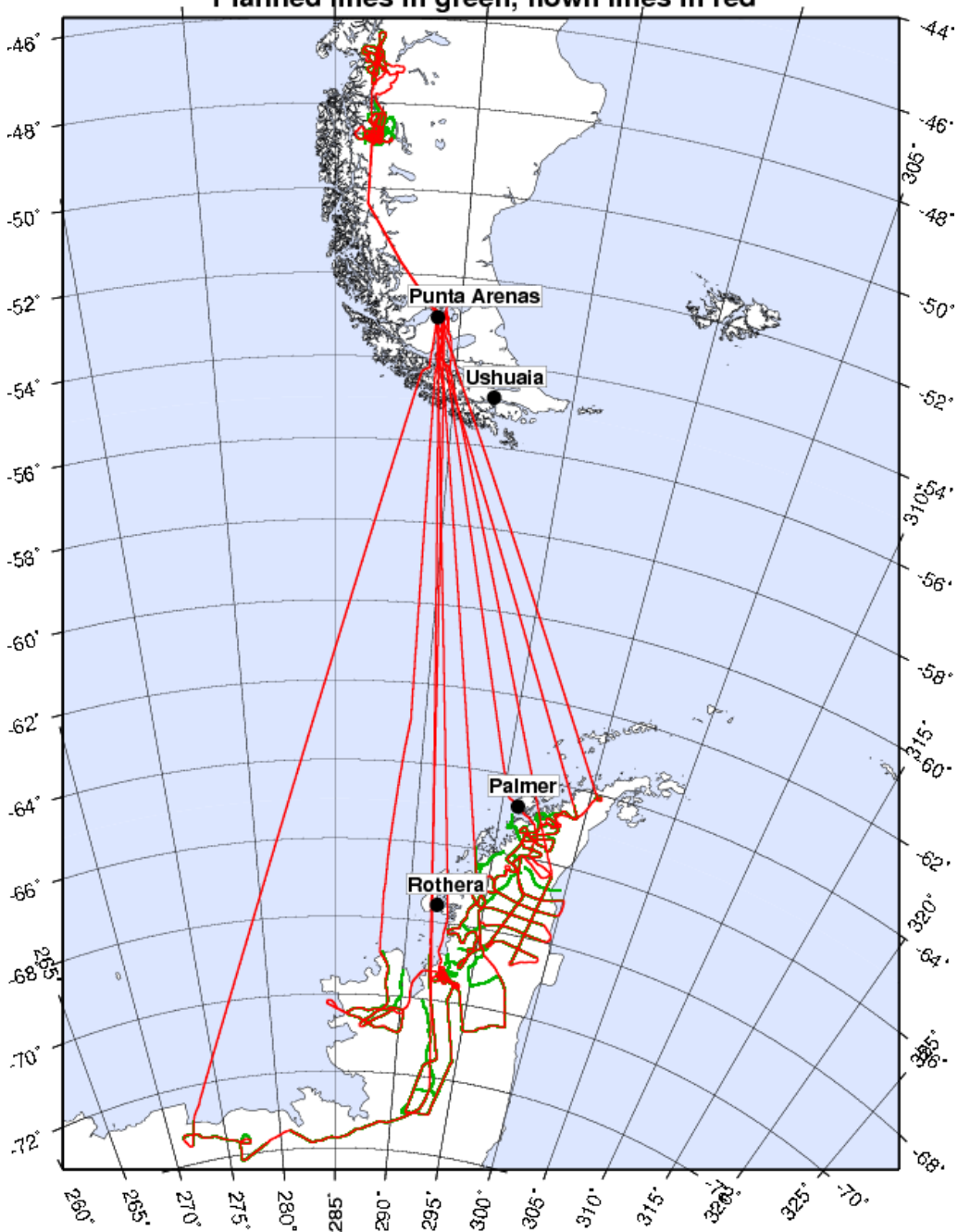

AIRBORNE TOPOGRAPHIC MAPPER
Arctic Ice Missions 1992-2002

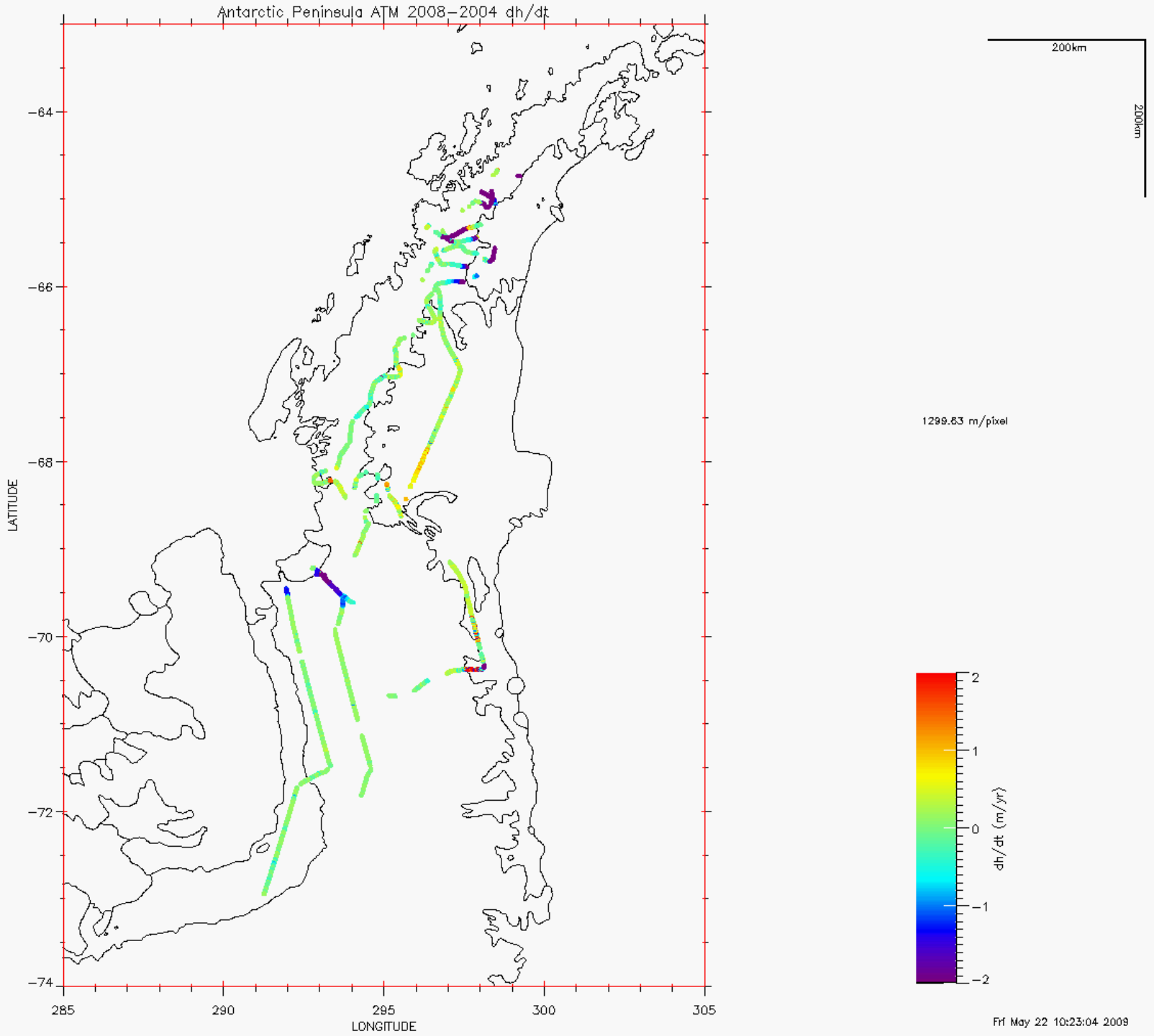
Chilean Navy P3 over Palmer Station

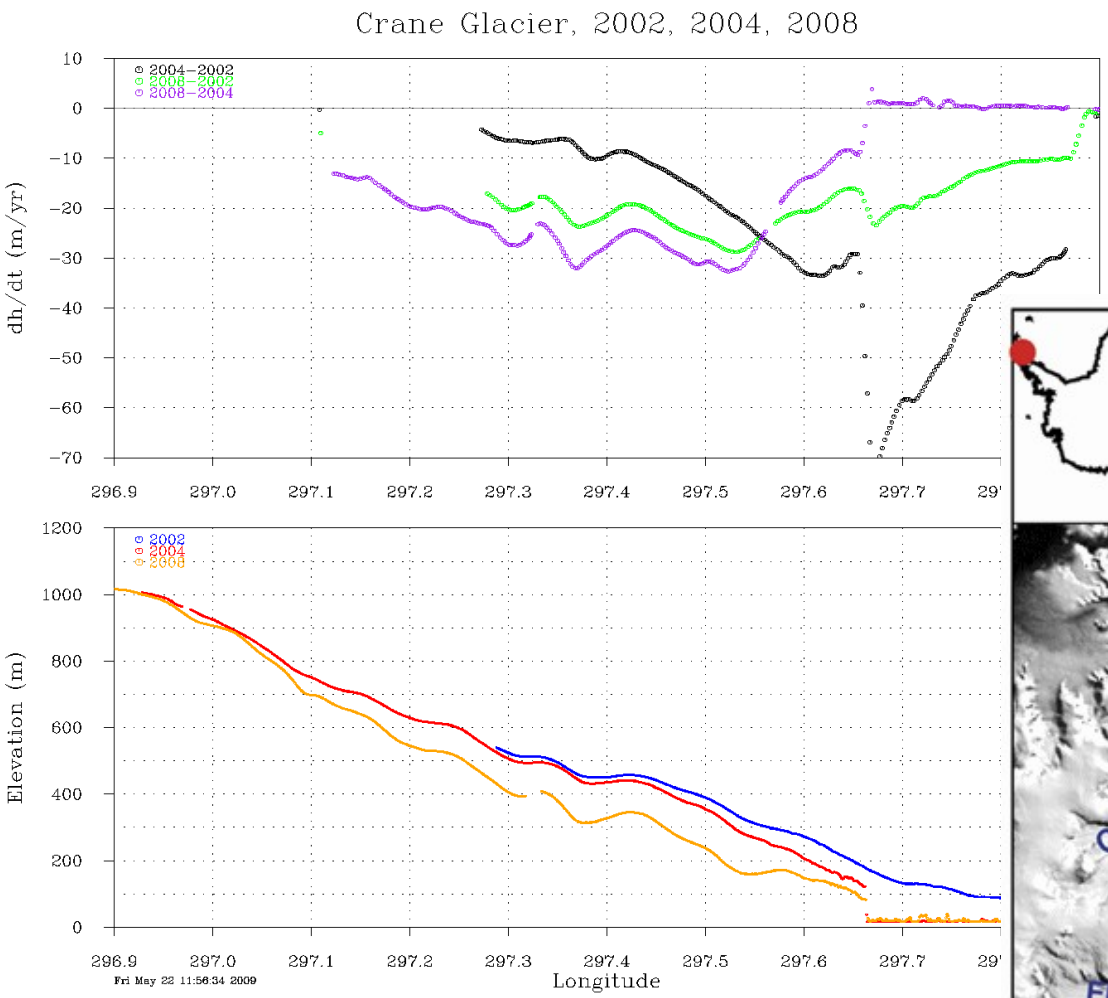
NASA/CECS/Chilean Navy

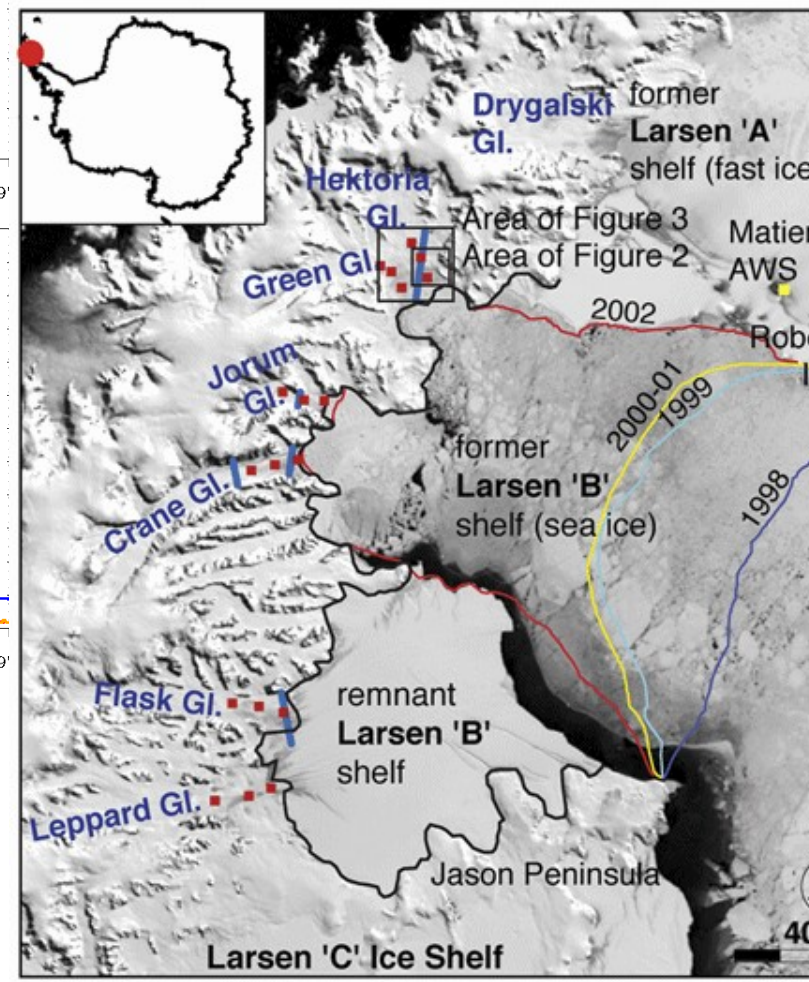
2008 Laser/Radar Flights

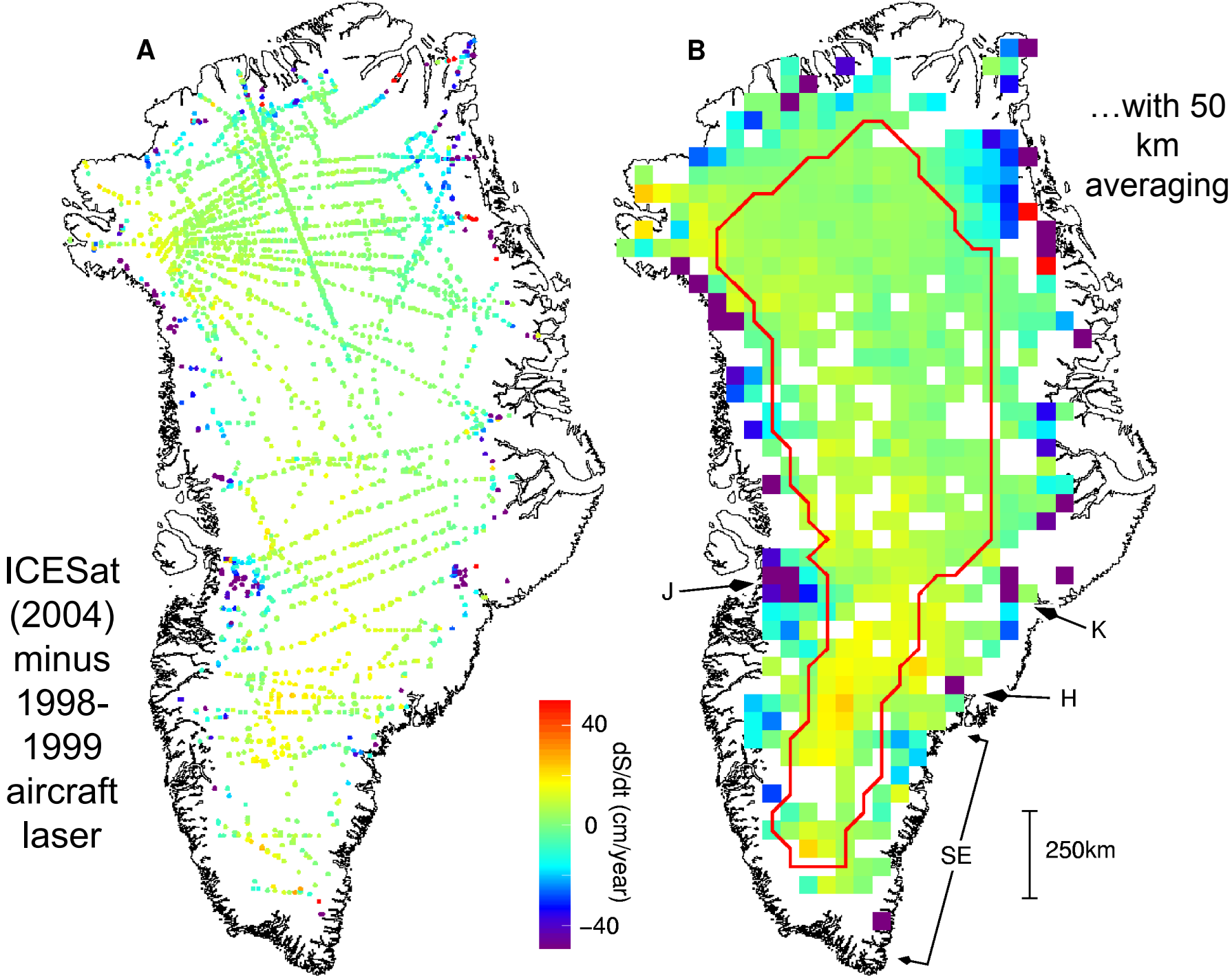
NASA / CECS / Armada de Chile
Planned lines in green, flown lines in red




Antarctic Peninsula ATM 2008-2004 dh/dt
200km
200km
1299.63 m/pixel
LATITUDE
-64
-66
-68
-70
-72
-74
285
290
295
300
305
LONGITUDE
2
1
0
-1
-2
dh/dt (m/yr)
Fri May 22 10:23:04 2009


Crane Glacier, 2002, 2004, 2008
2004−2002
2008−2002
2008−2004
dh/dt (m/yr)
10
0
−10
−20
−30
−40
−50
−60
−70
296.9
297.0
297.1
297.2
297.3
297.4
297.5
297.6
297.7
2002
2004
2008
Elevation (m)
1200
1000
800
600
400
200
0
Fri May 22 11:56:34 2009
Longitude

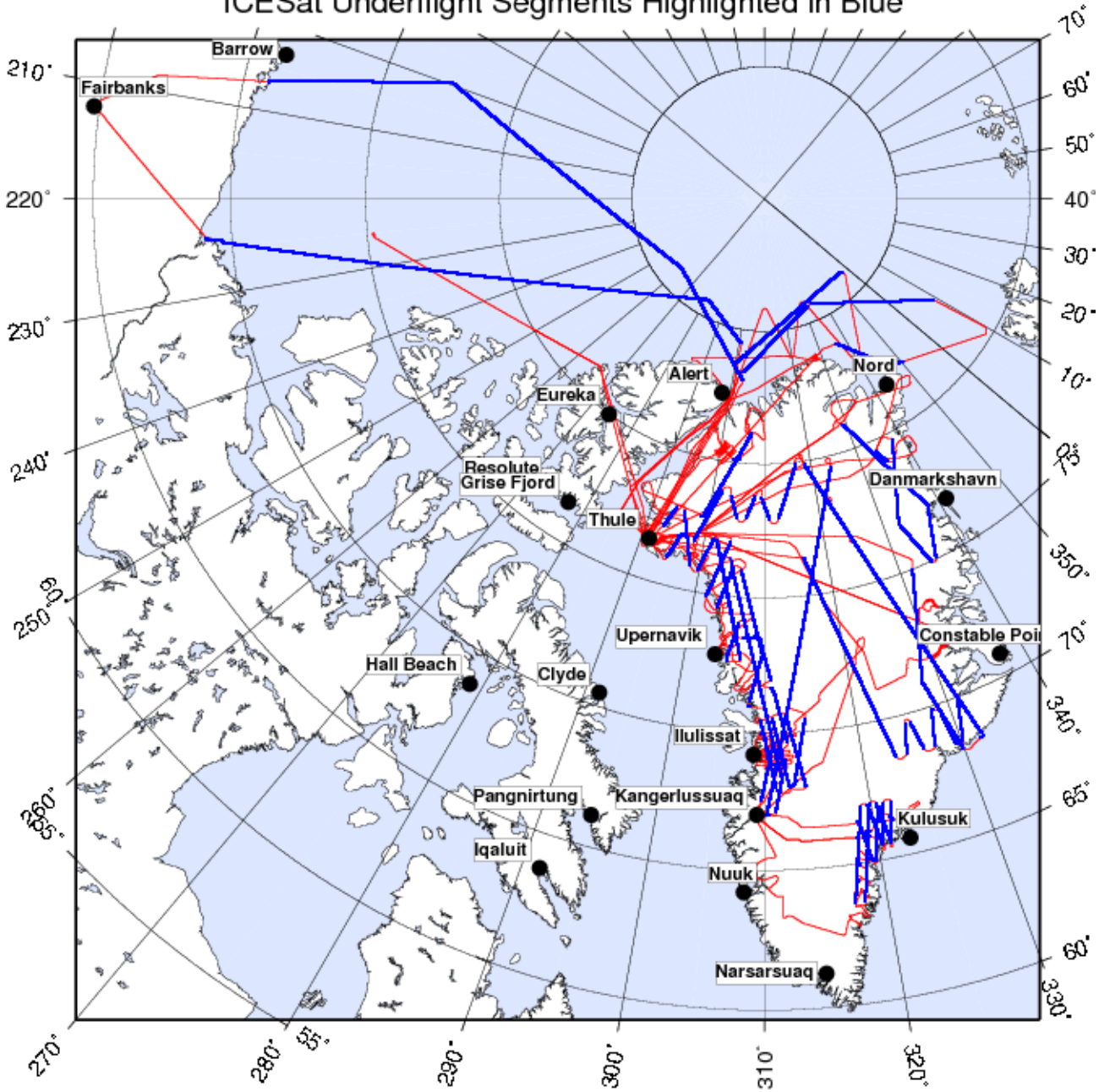

Drygalski Gl.
former
Larsen 'A'
shelf (fast ice
Hektoria Gl.
Area of Figure 3
Area of Figure 2
Green Gl.
2002
Jorum Gl.
2000-01
1999
former
Larsen 'B'
shelf (sea ice)
1998
Crane Gl.
Flask Gl.
remnant
Larsen 'B'
shelf
Leppard Gl.
Jason Peninsula
Larsen 'C' Ice Shelf


A
B
ICESat (2004) minus 1998-1999 aircraft laser
…with 50 km averaging
40
0
–40
dS/dt (cm/year)
J
K
H
SE
250km

2009 Spring Arctic Missions Flown

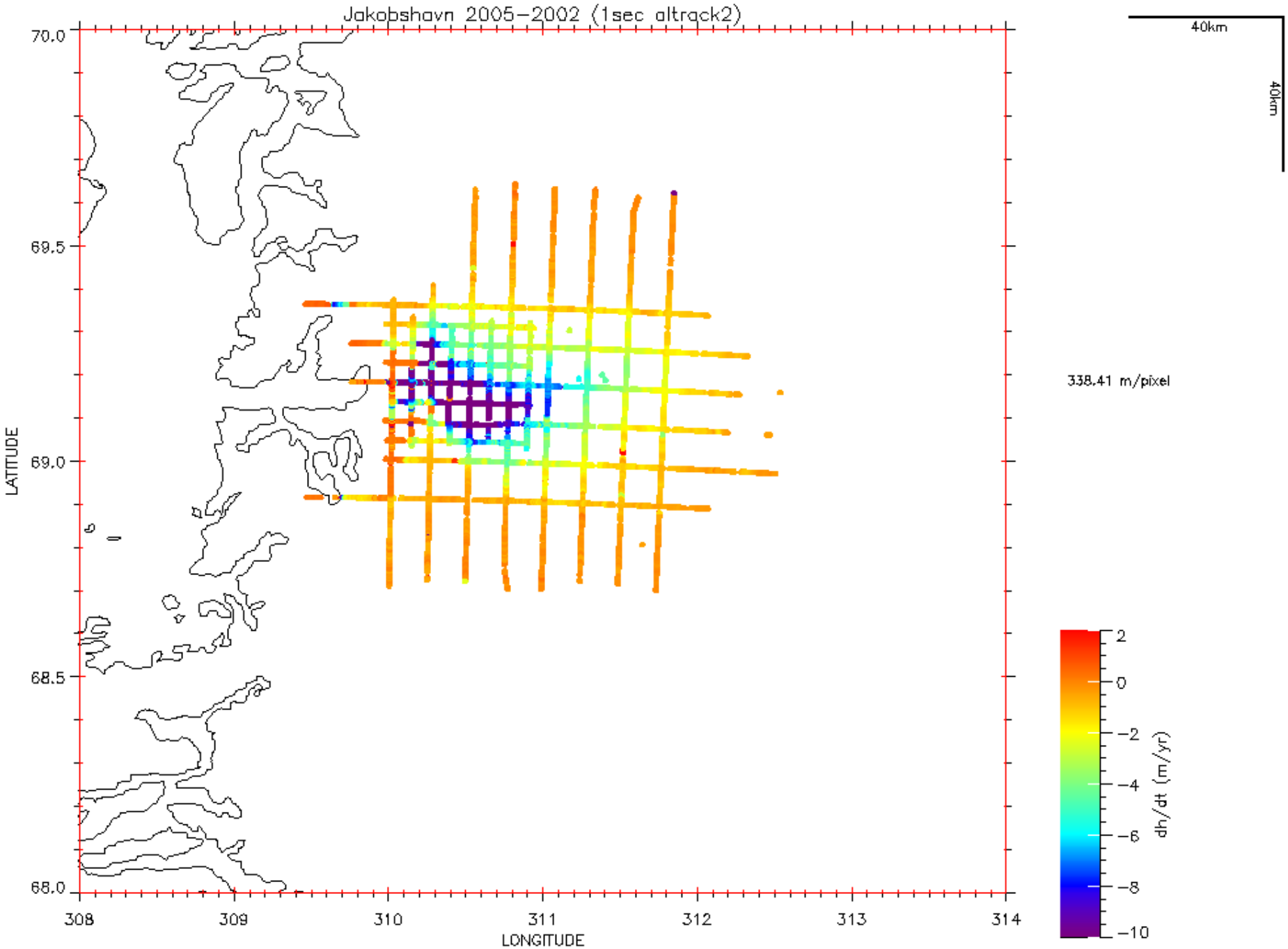
Final Update

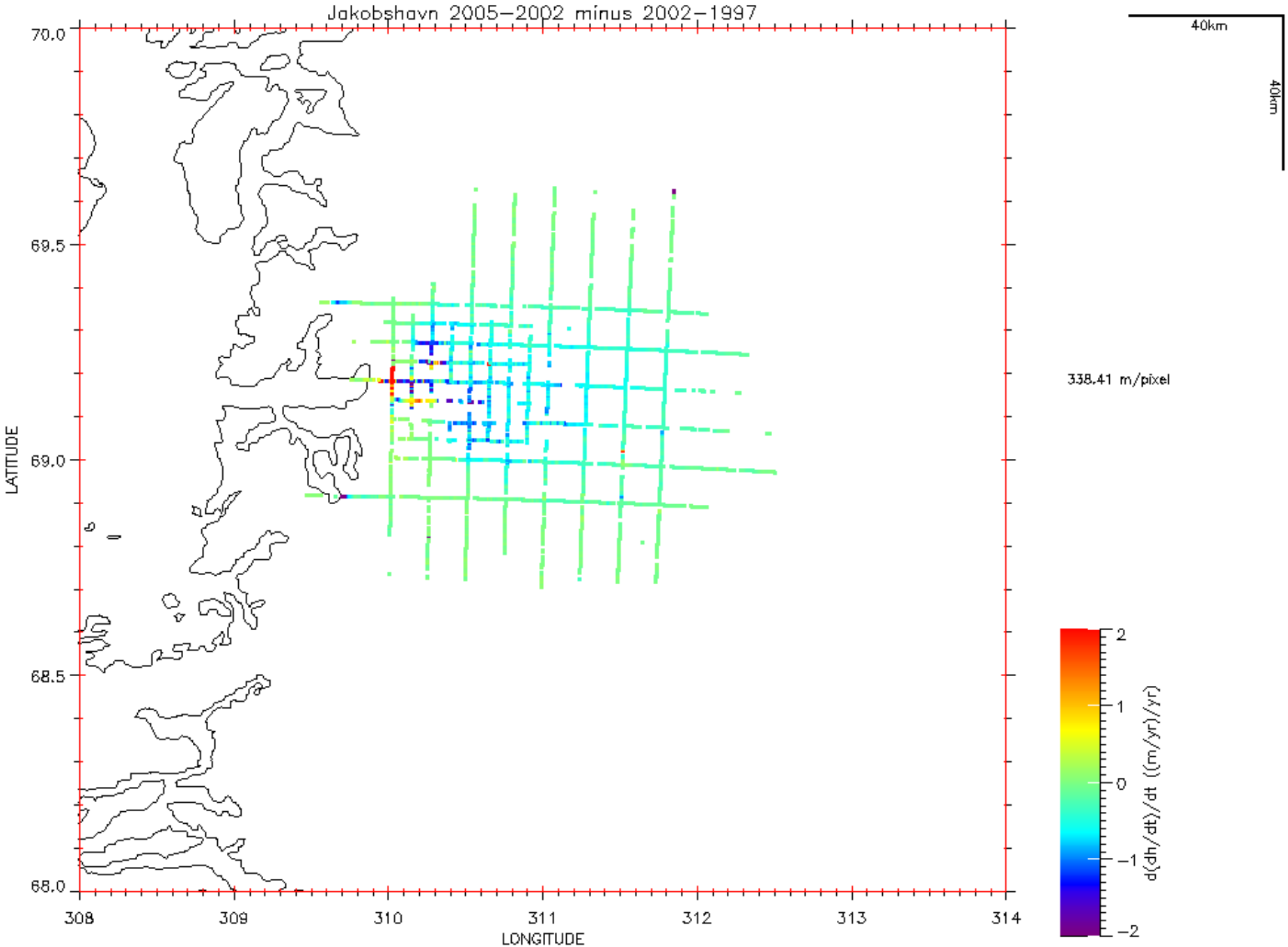
ICESat Underflight Segments Highlighted in Blue



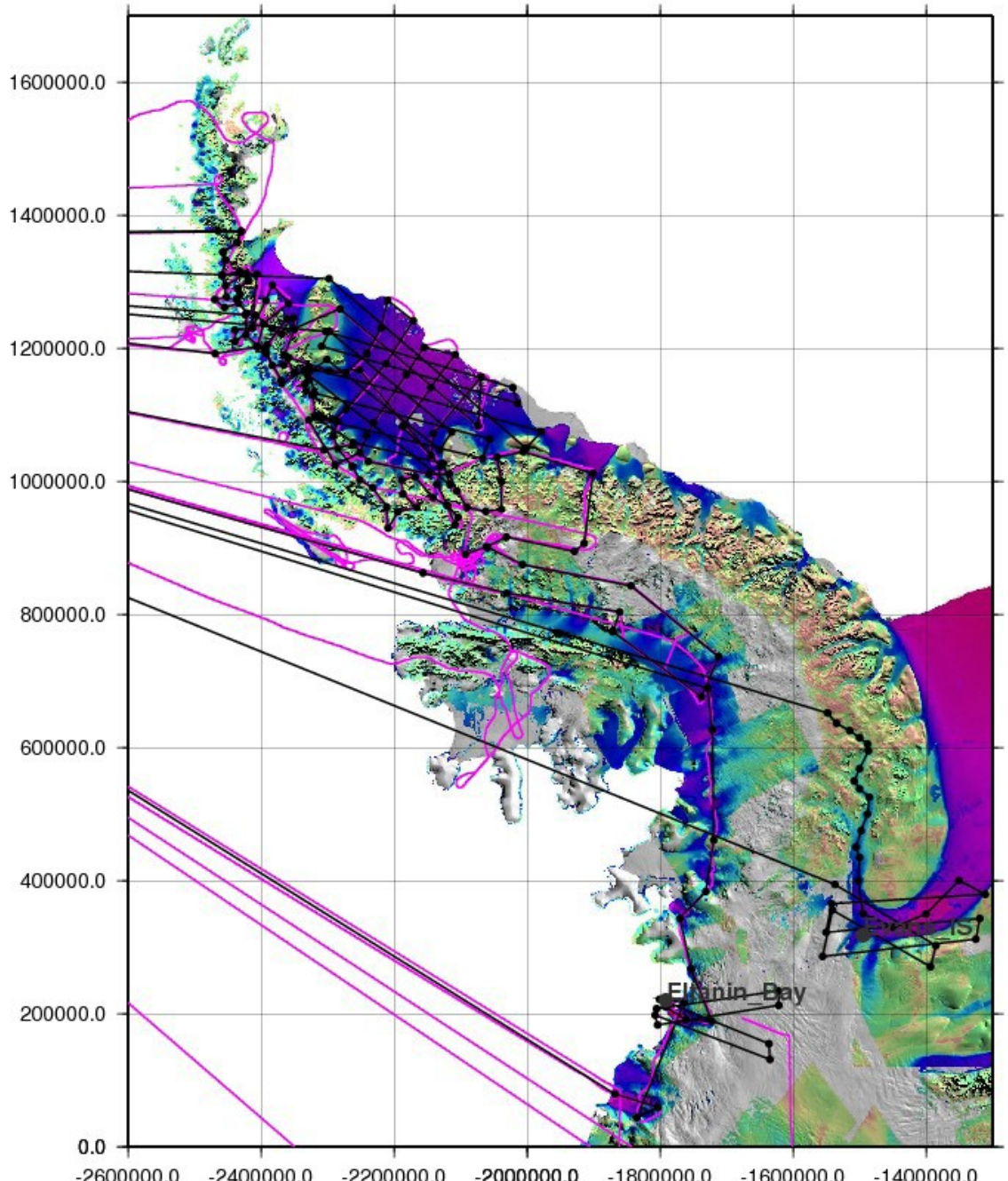
NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/Gallery/Photo/index.html
NASA Photo: EC04−0047−11 Date: February 24, 2004 Photo By: Tony Landis

NASA's DC−8 Airborne Science research aircraft, in new colors and markings, takes off Feb. 24, 2004.

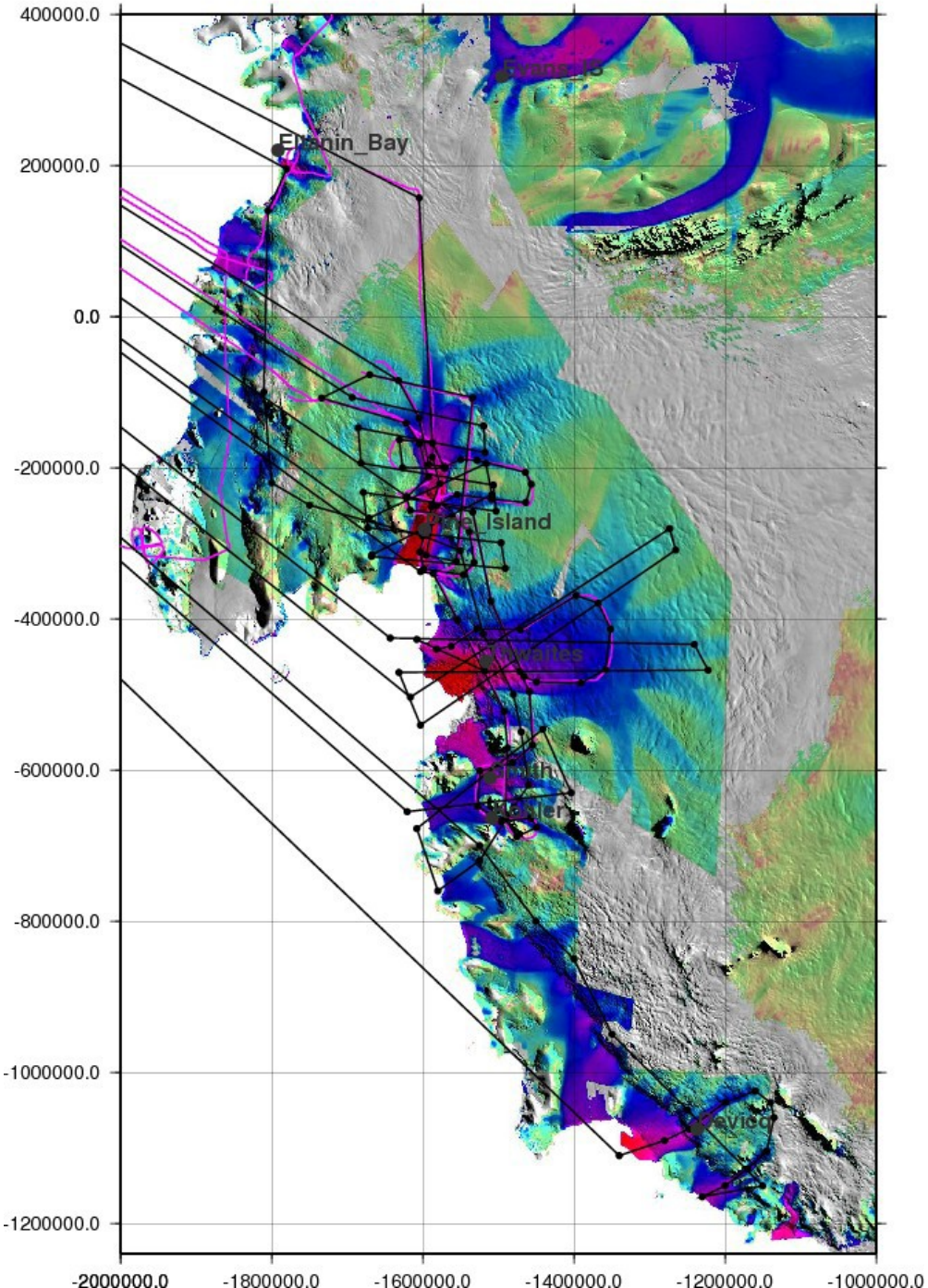

Jakobshavn 2005-2002 (1sec altrack2)
40km
40km
338.41 m/pixel
70.0
69.5
69.0
68.5
68.0
LATITUDE
308
309
310
311
312
313
314
LONGITUDE
2
0
-2
-4
-6
-8
-10
dh/dt (m/yr)
Wed Oct 19 08:30:03 2005


Jakobshavn 2005–2002 minus 2002–1997
40km
40km
338.41 m/pixel
70.0
69.5
69.0
68.5
68.0
LATITUDE
308
309
310
311
312
313
314
LONGITUDE
2
1
0
−1
−2
d(dh/dt)/dt ((m/yr)/yr)
Wed Oct 19 12:42:01 2005

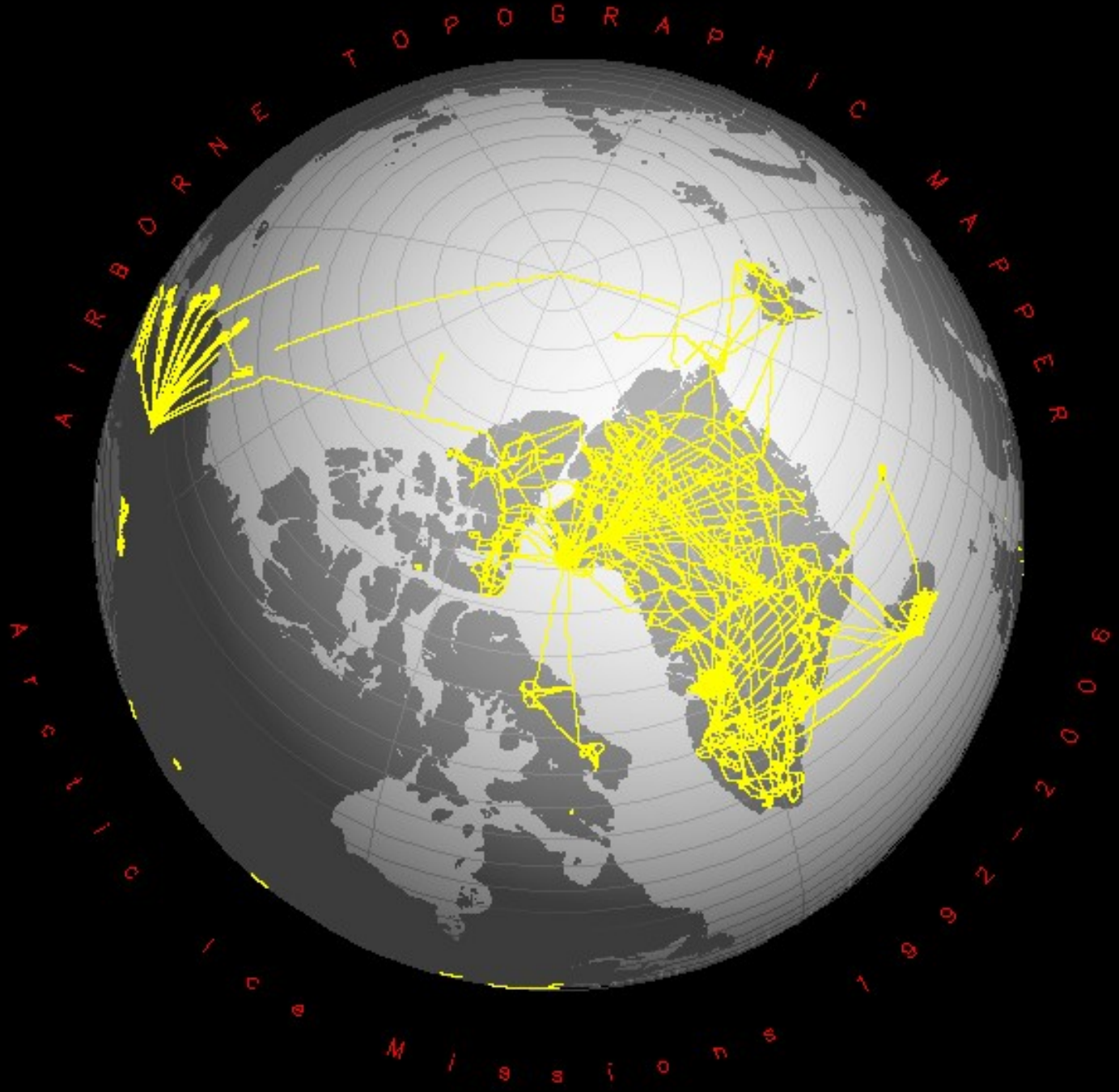
Antarctic Peninsula



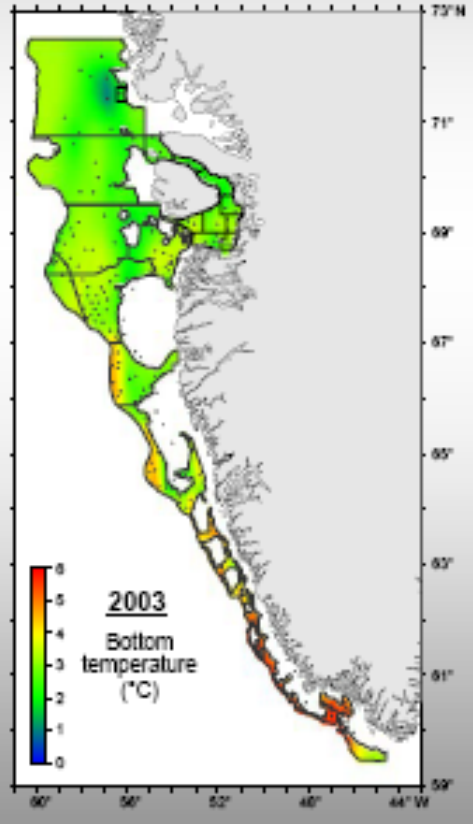
Amundsen Coast

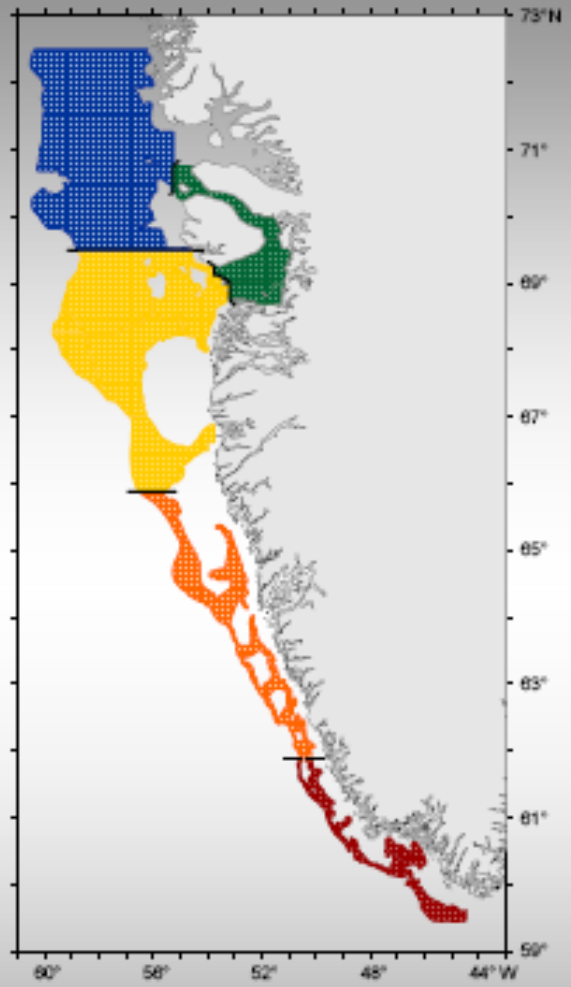


P-3 Airborne Research Platform
Thule, Greenland - Spring 2009
N426NA
NASA
2009
Operation ICE Bridge


AIRBORNE TOPOGRAPHIC MAPPER
Arctic Ice Missions 1992-2006

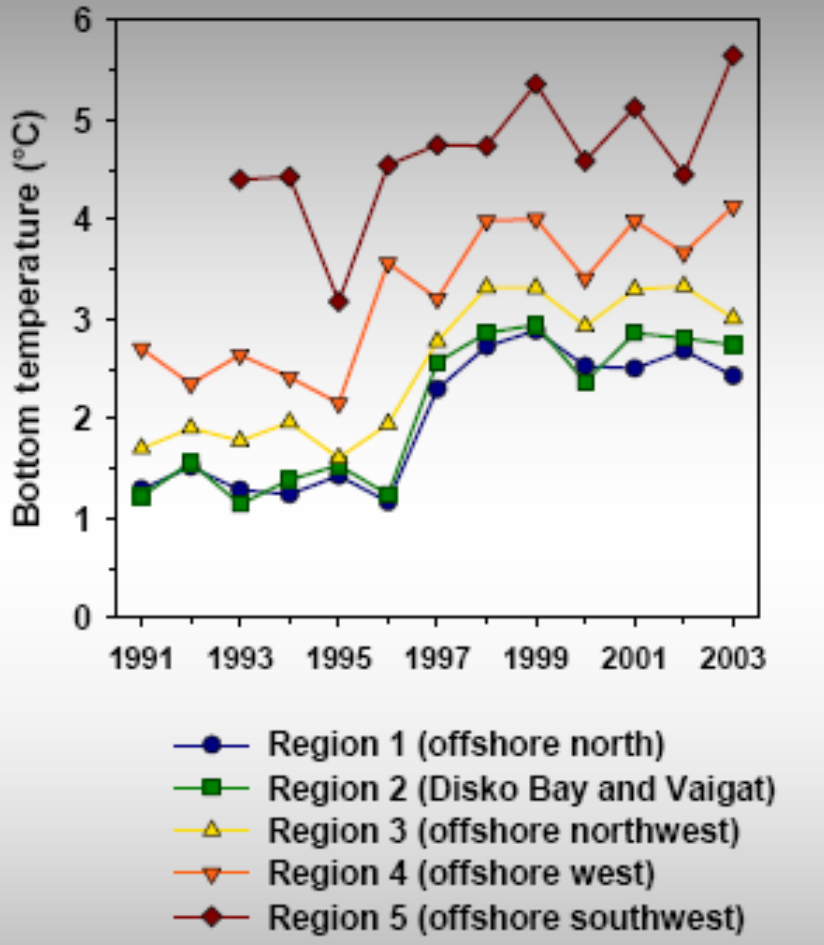
Bottom temperature at trawl stations (150 - 600 m)





survey strata → regions

Mean bottom temperature *



*: weighted for stratum areas

R. Thomas et al. (2004), Accelerated Sea-Level Rise from West Antarctica. **Science** 306 (5694), 255-258. [DOI: 10.1126/science.1099650]

Holland, D., R. Thomas, B de Young, M. Ribergaard, B Lyberth (2008) Acceleration of Jakobshavn Isbræ triggered by warm subsurface ocean waters, **Nature Geoscience** doi:10.1038/ngeo316

Joughin, I., I. M. Howat, M. Fahnestock, B. Smith, W. Krabill, R. B. Alley, H. Stern, and M. Truffer (2008), Continued evolution of Jakobshavn Isbrae following its rapid speedup, **J. Geophys. Res**., 113, F04006, doi:10.1029/2008JF001023.

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Rignot, E., G. Casassa, S. Gogineni, P. Kanagaratnam, W. Krabill, H. Pritchard, A. Rivera, R. Thomas, J. Turner, and D. Vaughan (2005), Recent ice loss from the Fleming and other glaciers, Wordie Bay, West Antarctic Peninsula, **Geophys. Res. Lett**., 32, L07502, doi:10.1029/2004GL021947.

Abdalati, W., W. Krabill, E. Frederick, S. Manizade, C. Martin, J. Sonntag, R. Swift, R. Thomas, J. Yungel, and R. Koerner (2004) Elevation changes of ice caps in the Canadian Arctic Archipelago. **J. Geophysical Research** 109, F04007, doi:10.1029/2003JF000045.

Rignot, E., G. Casassa, P. Gogineni, W. Krabill, A. Rivera, and R. Thomas (2004), Accelerated ice discharge from the Antarctic Peninsula following the collapse of the Larsen B ice shelf, **Geophys. Res. Lett**., 31, L18401, doi:10.1029/2004GL020697.

Mark Fahnestock	Univ. New Hampshire
Tavi Murray	Swansea Univ.
Ute Herzfeld	Univ. Colorado/NSIDC
Ian Howat	Byrd Polar Research Center, OSU
Bea Csatho	SUNY Buffalo & Byrd Polar Research Ctr/OSU
Marco Tedesco	City Univ. of New York
Ron Kwok	JPL
Ian Joughin	Univ. Washington
Prasad Gogineni	Univ. Kansas/ CReSIS
Eric Rignot	JPL
Slawek Tulaczyk	Univ. California
Nick Barrand	Univ. Alberta
Rachel Carr	St. Catharine's College
David Burgess	Canada Centre for Remote Sensing
Andrew Sole	Bristol Glaciology Centre
Ken Jezek	Byrd Polar Research Center, OSU
C. J. Van der Veen	Univ. Kansas
Carl Leuschen	Univ. Kansas & JHU/APL
Don Cavalieri	GSFC
Marian Klein	Univ. Colorado
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Martin Truffer	Univ. Alaska
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Meredith Payne	Oregon State Univ.
Anne Nolin	Oregon State Univ.
Chris Shuman	GSFC/UMBC
Michelle Hofton	GSFC/UMCP
James Garvin	GSFC

2007 ATM flights

May 1-12

resurveyed

Zacharaie

Nioghalvjerdsbrae

(79 North)

Storstrommen

L. Bistrup

Humbolt

Petermann

Steensby

Ryder

Igdlugldip

Giesecke

Upernavik

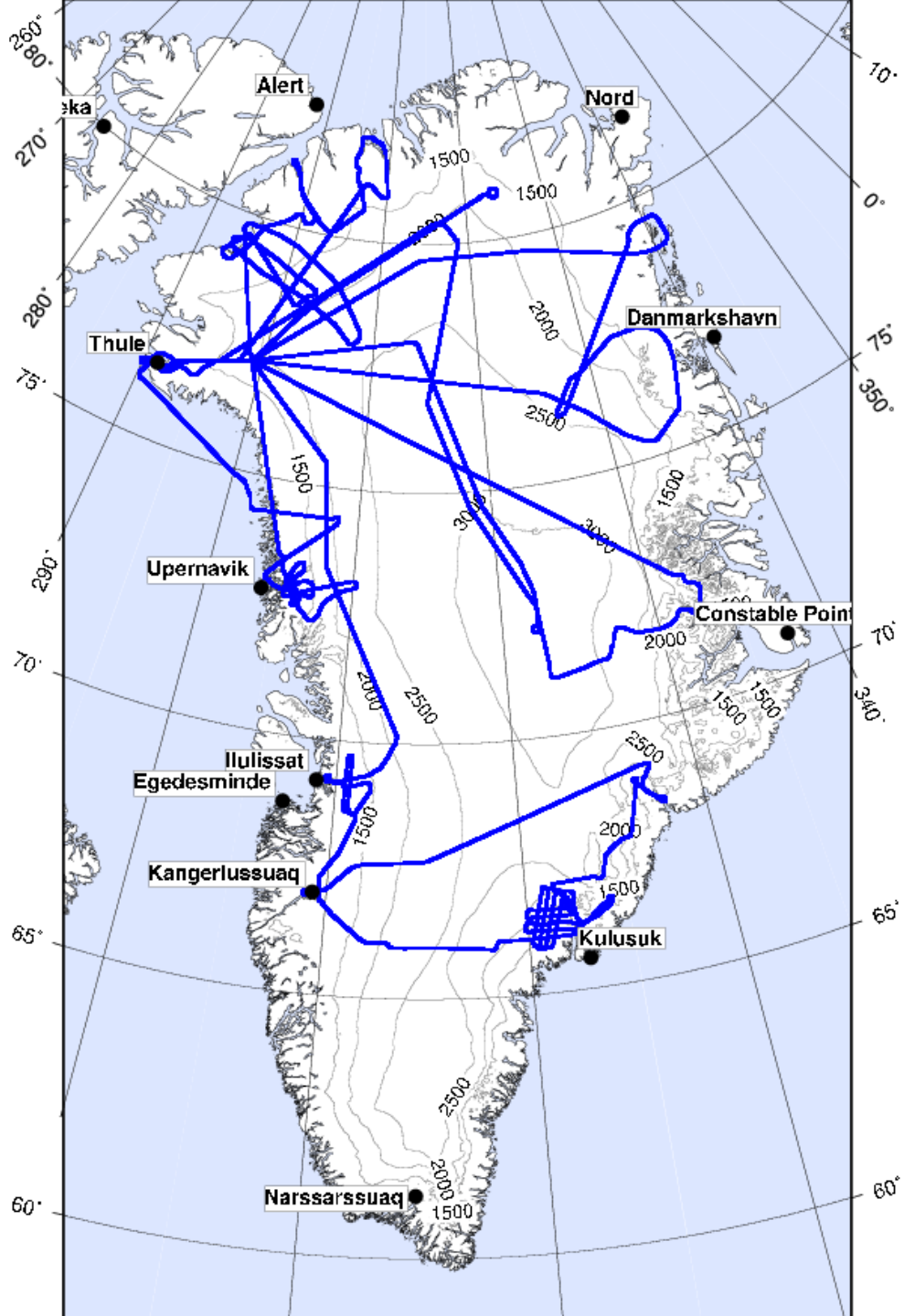
Jakobshavn

Helheim

Kangerdlugssuaq

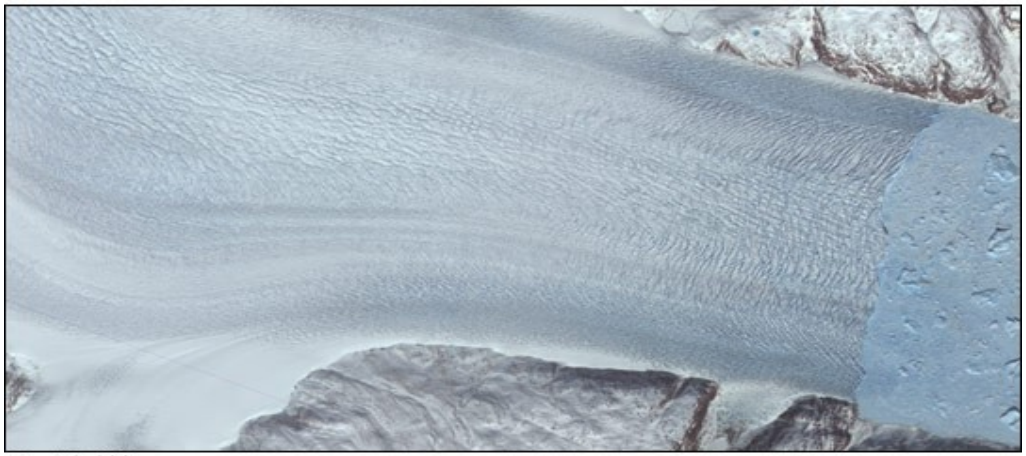
and, for the first time

Daugaard-Jensen

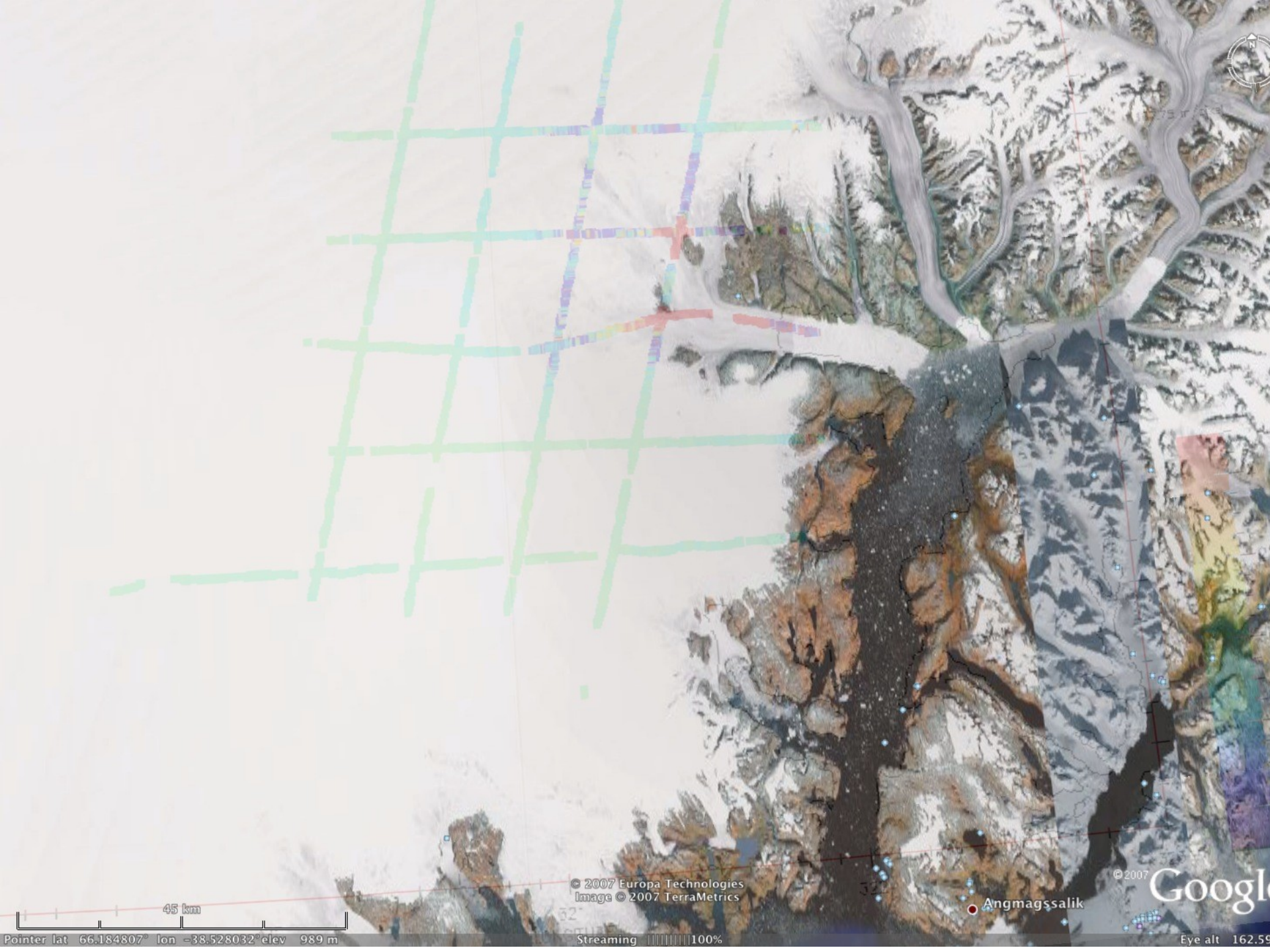


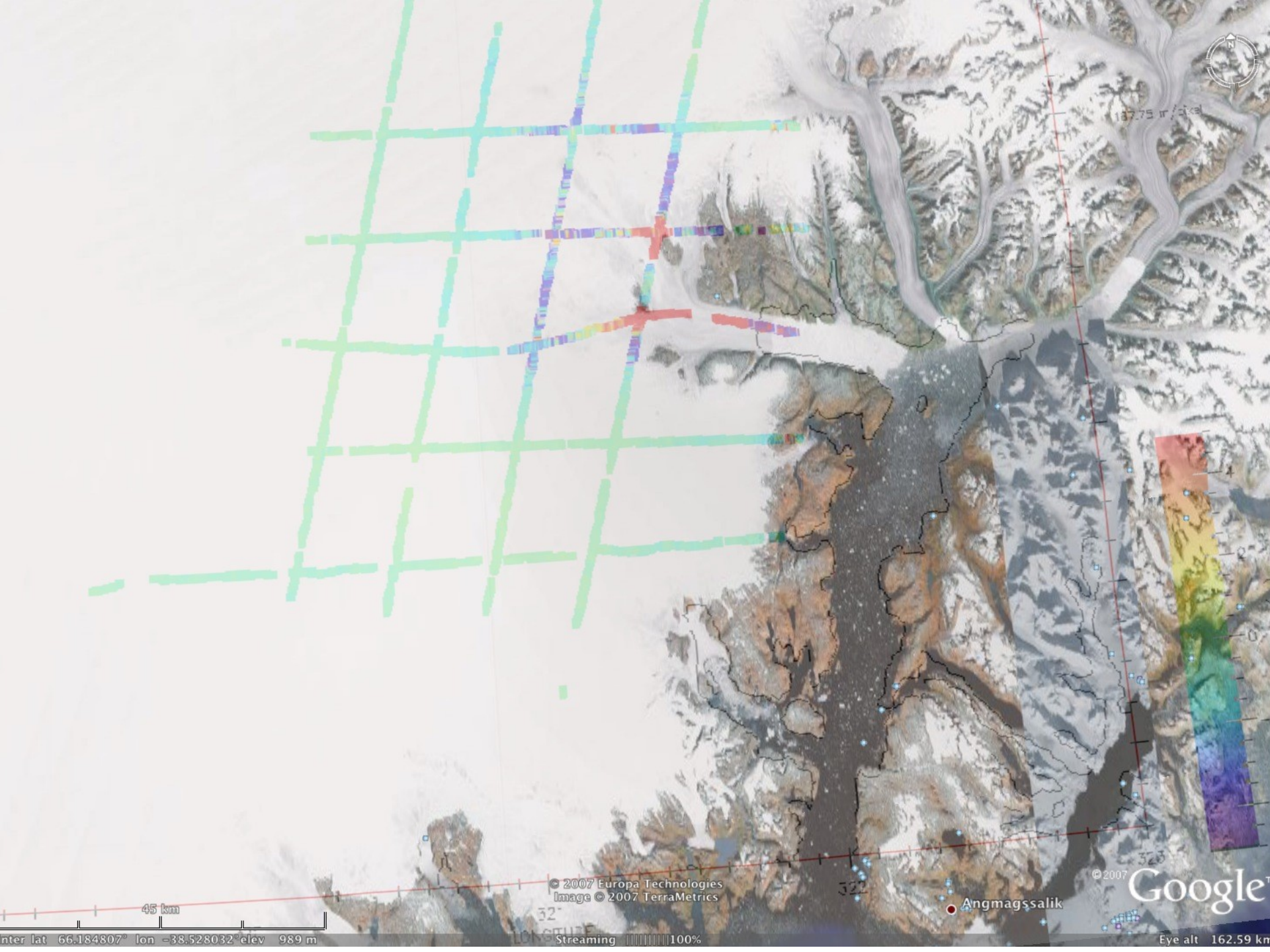
June 19, 2005

July 7, 2003



May 12, 2001


© 2007 Europa Technologies
Image © 2007 TerraMetrics
Angmagssalik
45 km
Pointer lat 66.184807° lon -38.528032° elev 989 m
Streaming 100%
Eye alt 162.59


© 2007 Europa Technologies
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Angmagssalik
45 km
Google
Streaming 100%
Eye alt 162.59 km

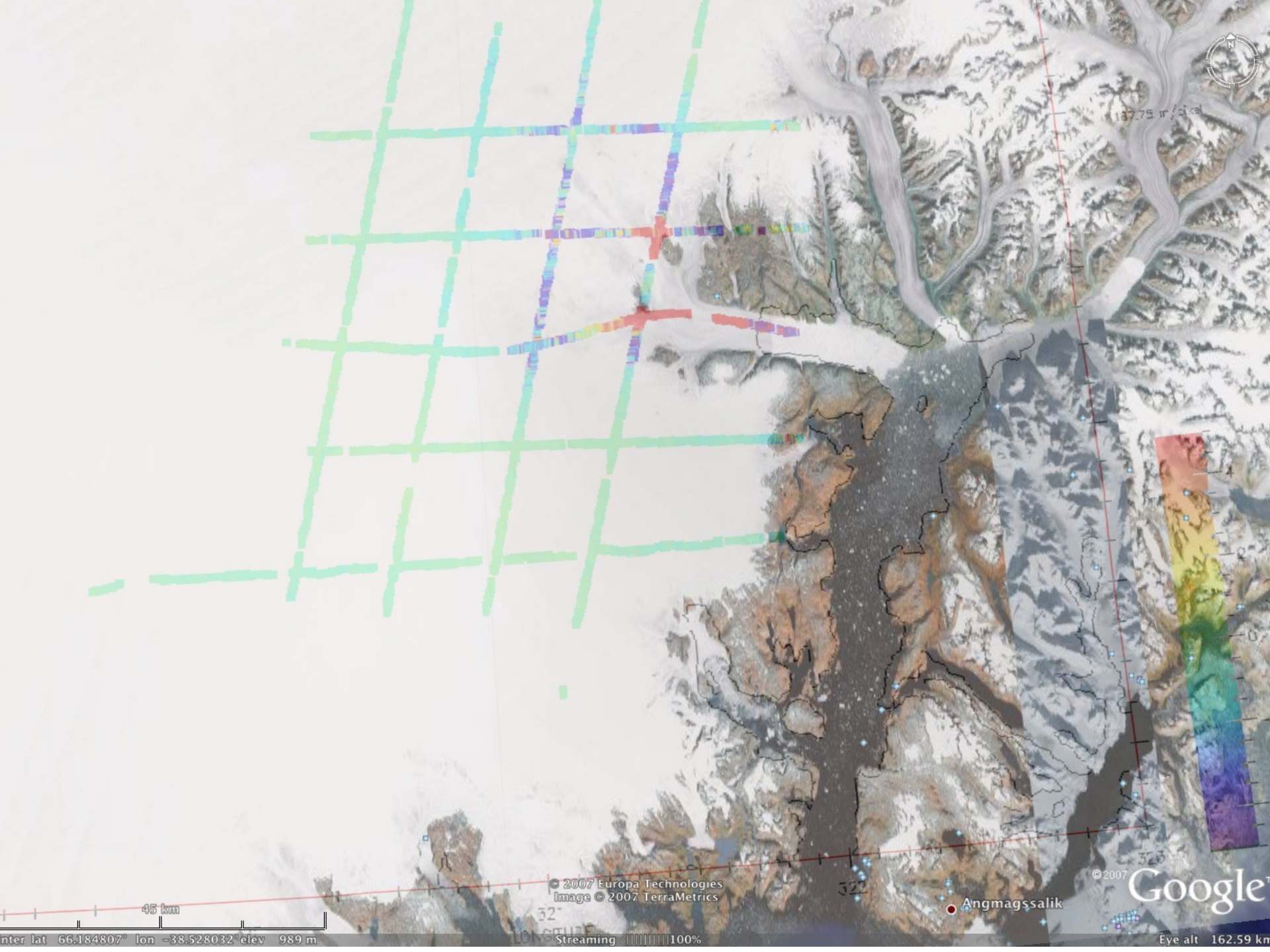
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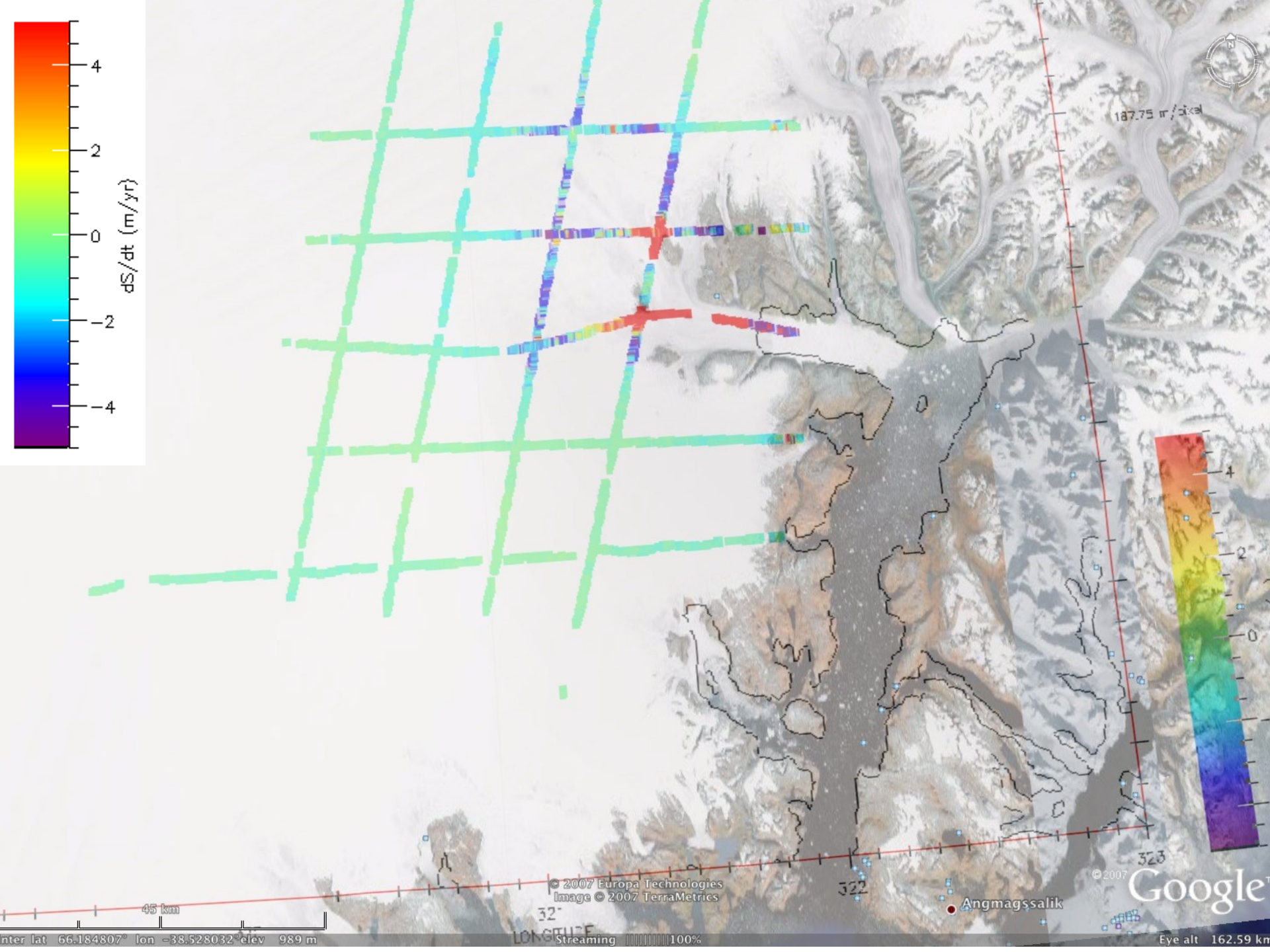
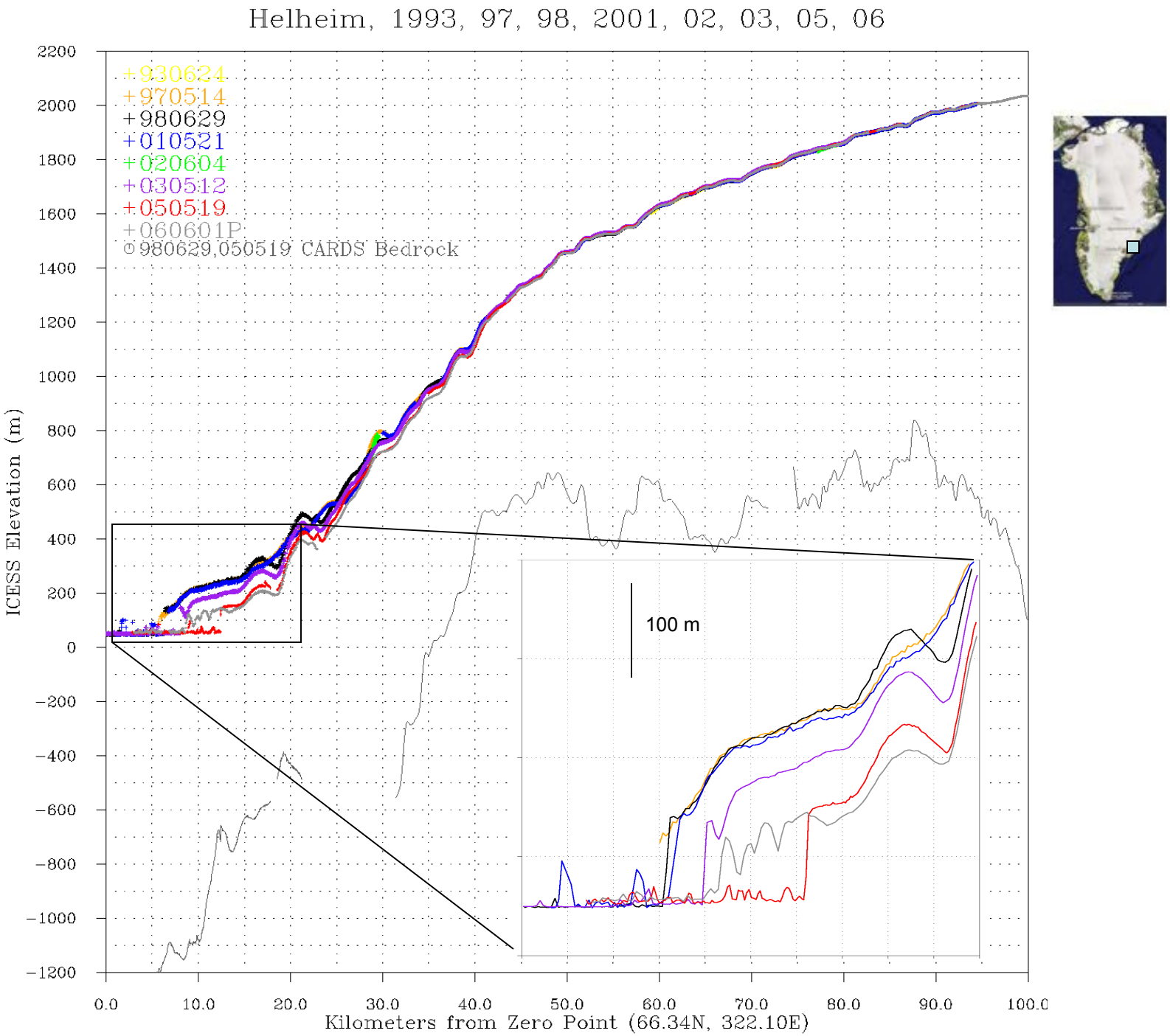
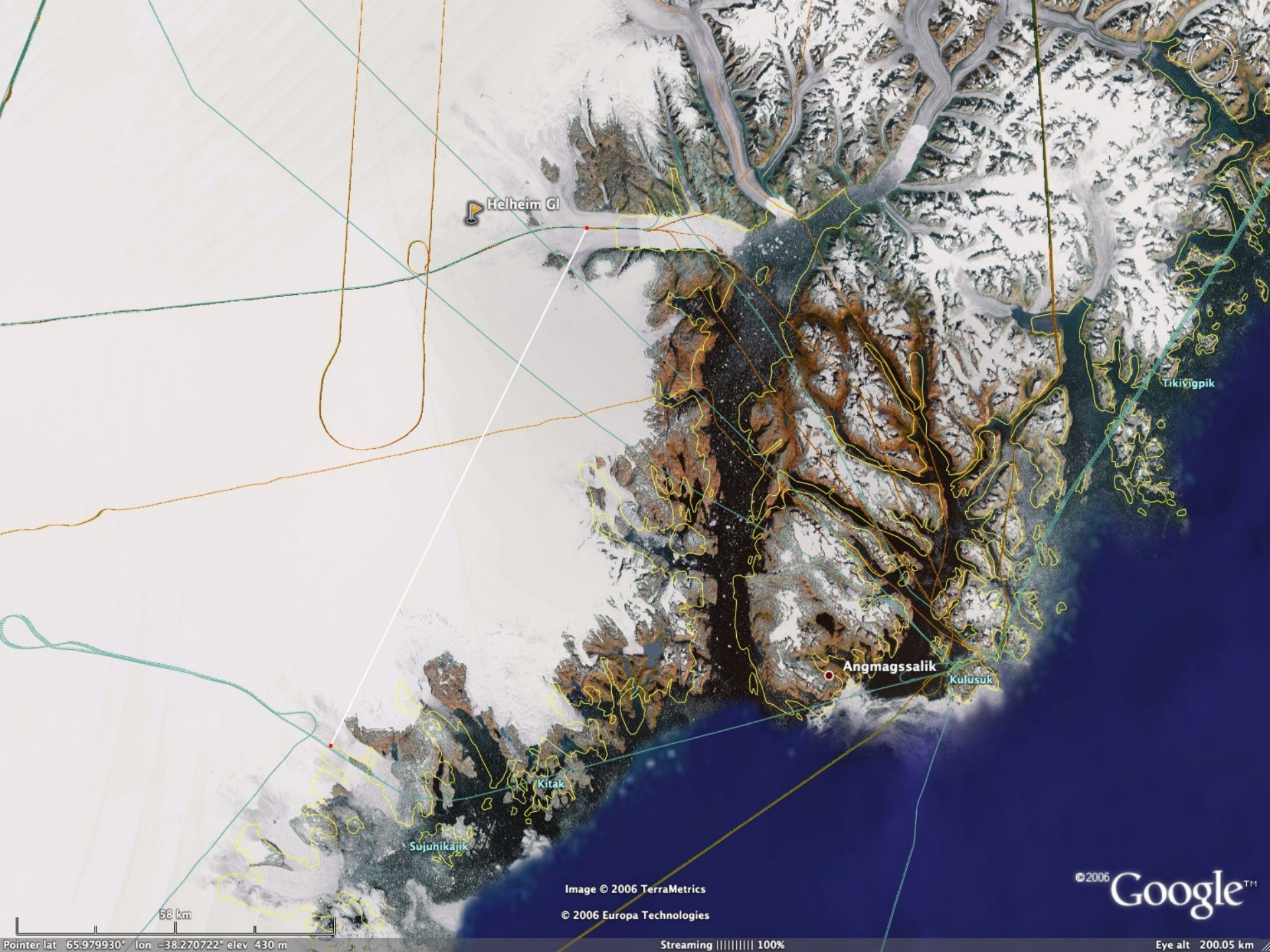
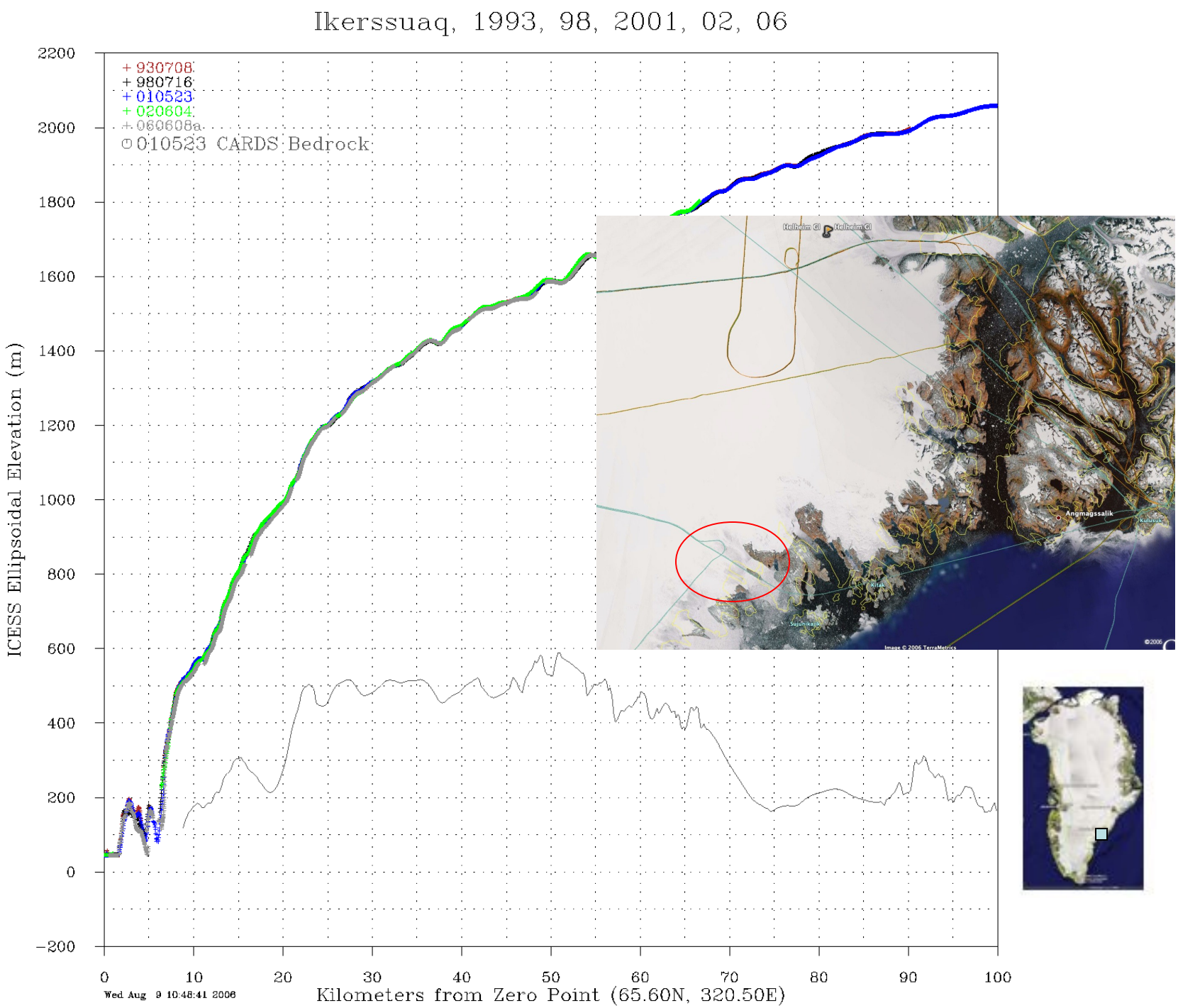
Image © 2007 TerraMetrics
Angmagssalik
45 km
Google
Streaming 100%
Eye alt 162.59 km


dS/dt (m/yr)
4
2
0
−2
−4
187.75 m/pixel
© 2007 Europa Technologies
Image © 2007 TerraMetrics
Angmagssalik
45 km
Google
Streaming 100%
Eye alt 162.59 km


Helheim, 1993, 97, 98, 2001, 02, 03, 05, 06
+930624
+970514
+980629
+010521
+020604
+030512
+050519
+060601P
©980629,050519 CARDS Bedrock
100 m
ICESS Elevation (m)
Kilometers from Zero Point (66.34N, 322.10E)
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
−200
−400
−600
−800
−1000
−1200
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0


Helheim Gl
Tikivigpik
Angmagssalik
Kulusuk
Kitak
Sujunikajik
Image © 2006 TerraMetrics
© 2006 Europa Technologies
©2006 Google™
58 km
Pointer lat 65.979930° lon -38.270722° elev 430 m
Streaming |||||||||| 100%
Eye alt 200.05 km


Ikerssuaq, 1993, 98, 2001, 02, 06
+ 930708
+ 980716
+ 010523
+ 020604
+ 060608a
010523 CARDS Bedrock
ICESS Ellipsoidal Elevation (m)
Kilometers from Zero Point (65.60N, 320.50E)
Wed Aug 9 10:48:41 2006
Angmagssalik
Image © 2006 TerraMetrics

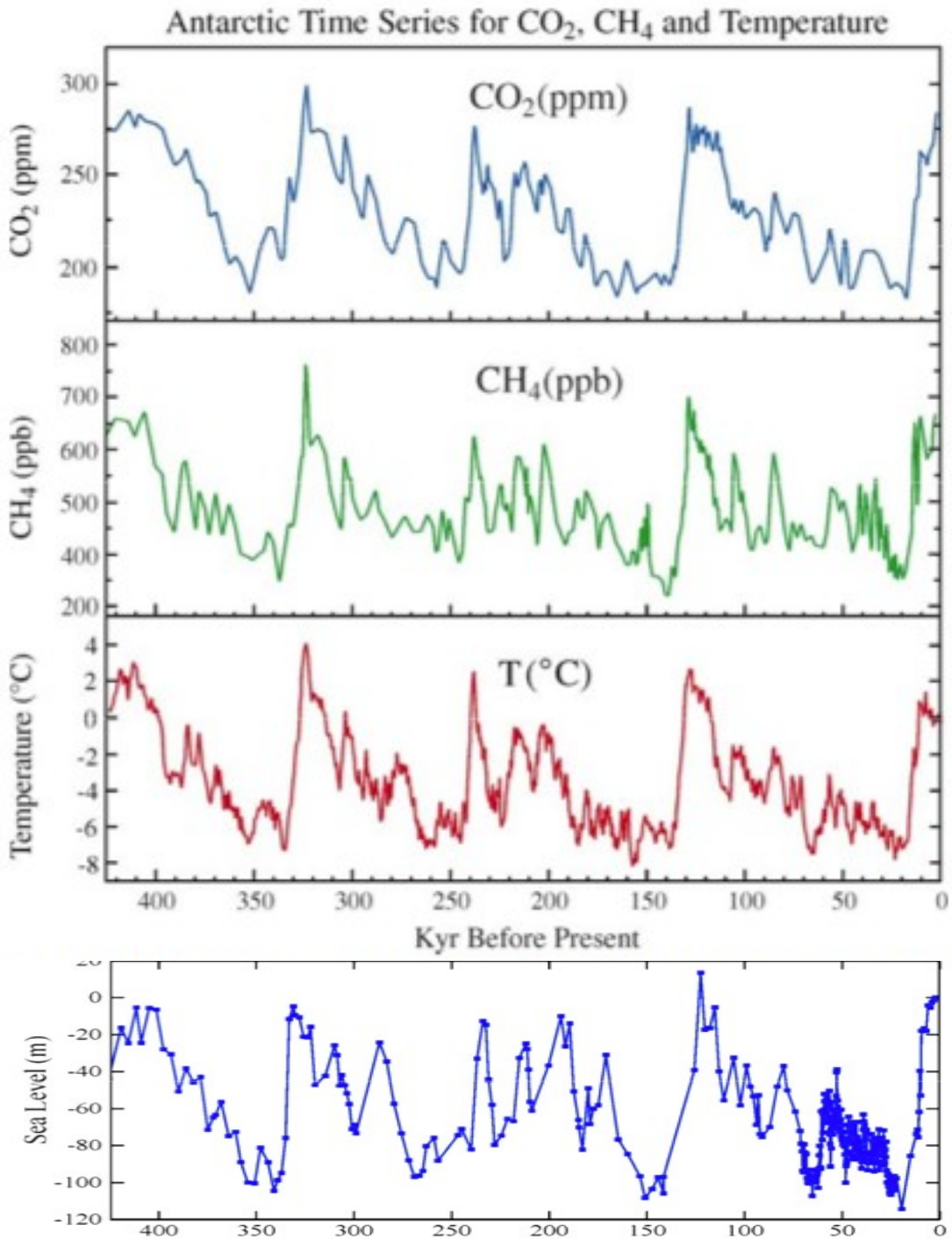
APPLICATIONS OF AIRCRAFT LASER ALTIMETRY TO CRYOSPHERIC SCIENCE

John Sonntag Serdar Manizade Richard Mitchell Bob Swift
Bill Krabill Rob Russell Earl Fredrick Jim Yungel

Bob Thomas Chreston Martin Johnny Scott

Bullet number one from the recent Earth Sciences Decadal Survey Prepared by the National Academy Of Sciences

"Will there be catastrophic collapse of the major ice sheets, including Greenland and West Antarctic and, if so, how rapidly will this occur? What will be the time patterns of sea level rise as a result?"


Antarctic Time Series for CO_2, CH_4 and Temperature
CO_2(ppm)
CO_2 (ppm)
300
250
200
CH_4(ppb)
CH_4 (ppb)
800
700
600
500
400
200
T(°C)
Temperature (°C)
4
2
0
-2
-4
-6
-8
400
350
300
250
200
150
100
50
0
Kyr Before Present
Sea Level (m)
0
-20
-40
-60
-80
-100
-120
400
350
300
250
200
150
100
50
0

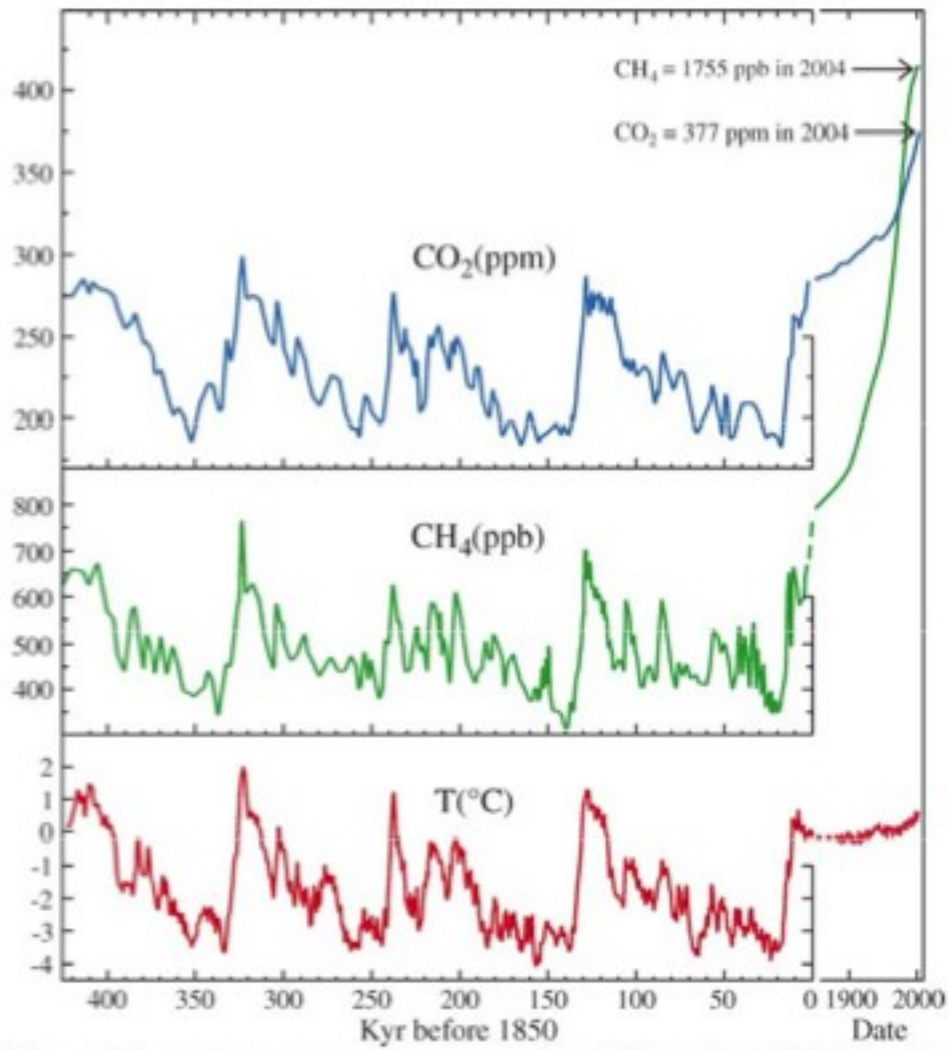


Fig. 9. Extension of CO_2, CH_4 and temperature records of Fig. 4 to 2004. Temperature change since 1880 is the land-ocean temperature index (Fig. 1), with the 1880-1899 mean defined as zero, while the earlier temperature is the Vostok Antarctica temperature change divided by two. Source: Hansen, Amer. Geo. Union, U23D-01, Dec. 6, http://www.columbia.edu/~jeh1, 2005.

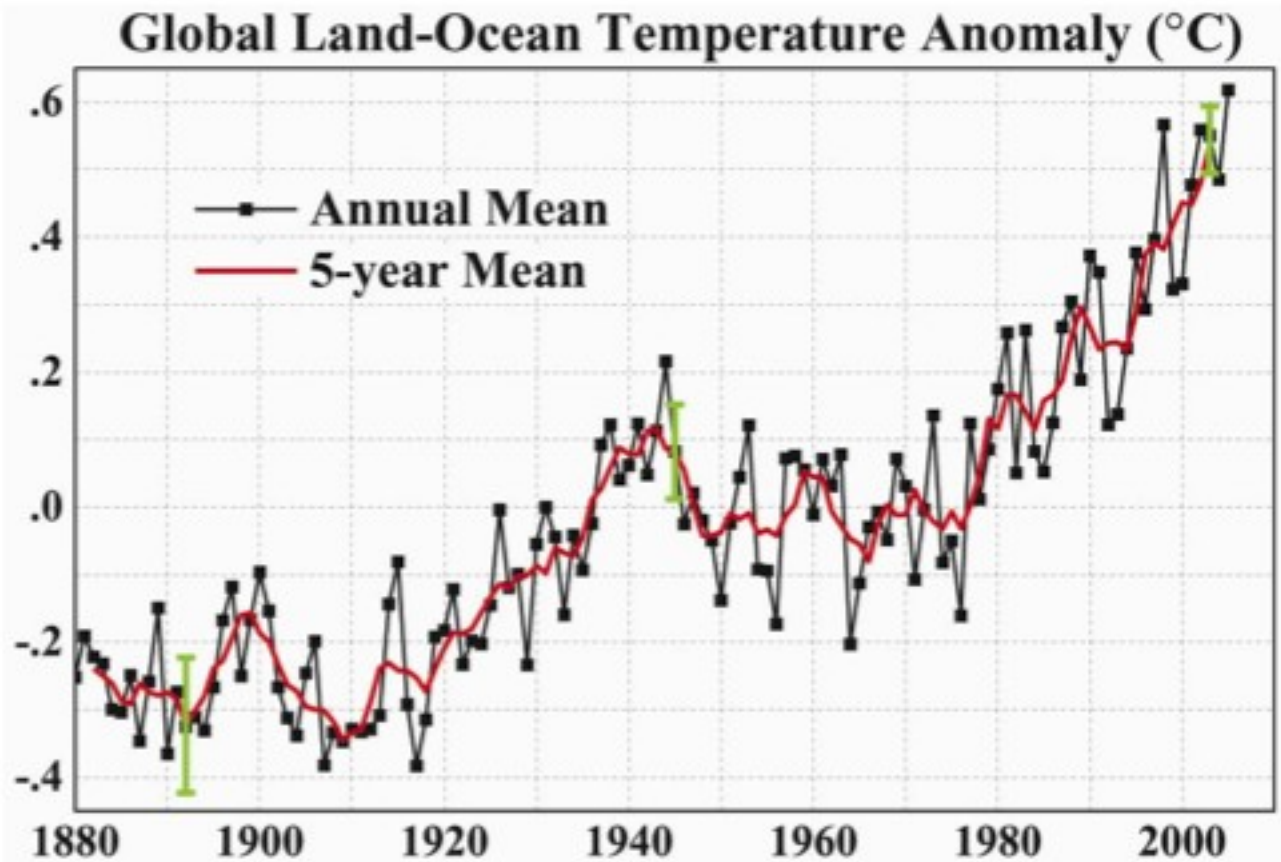
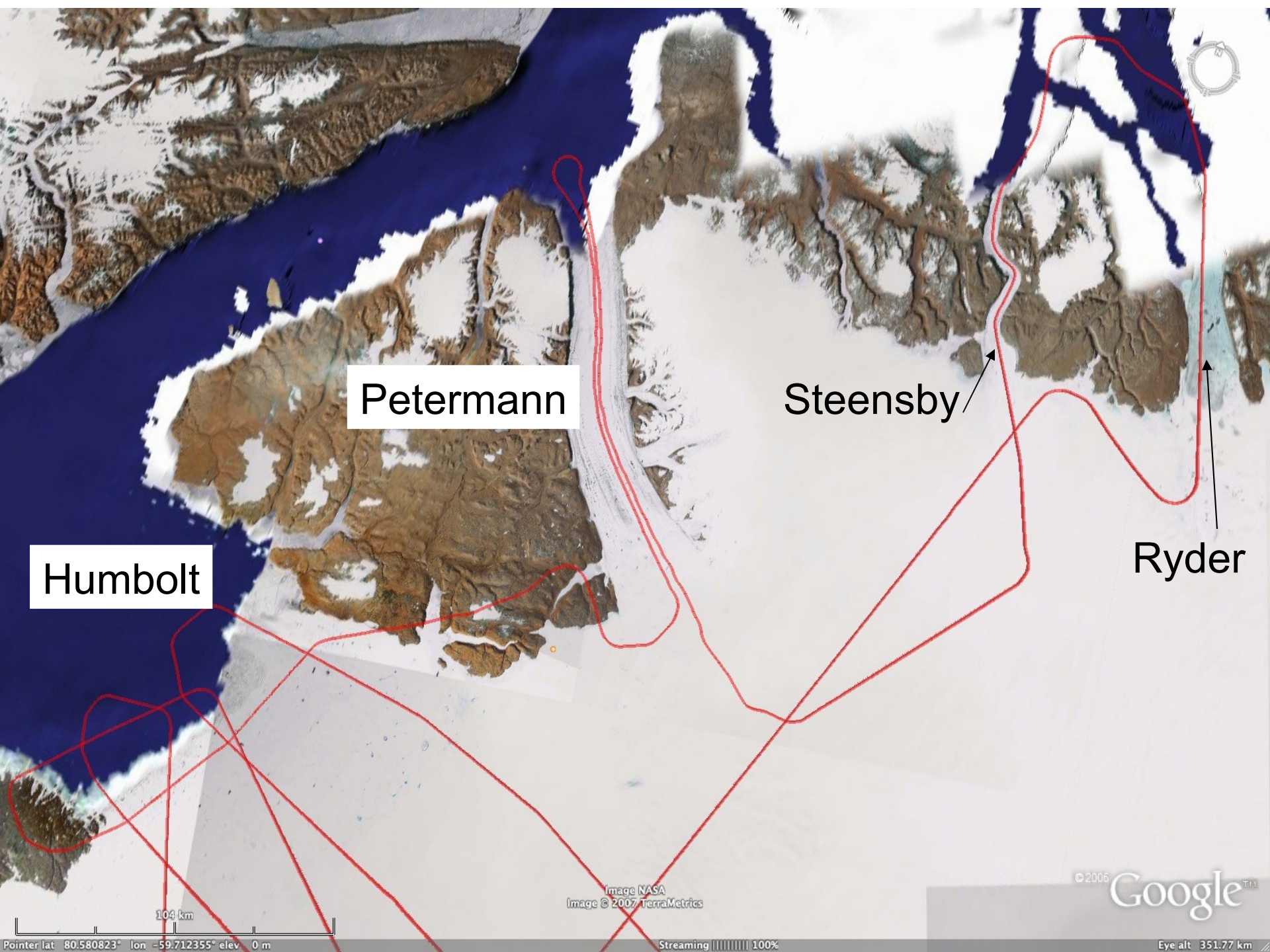
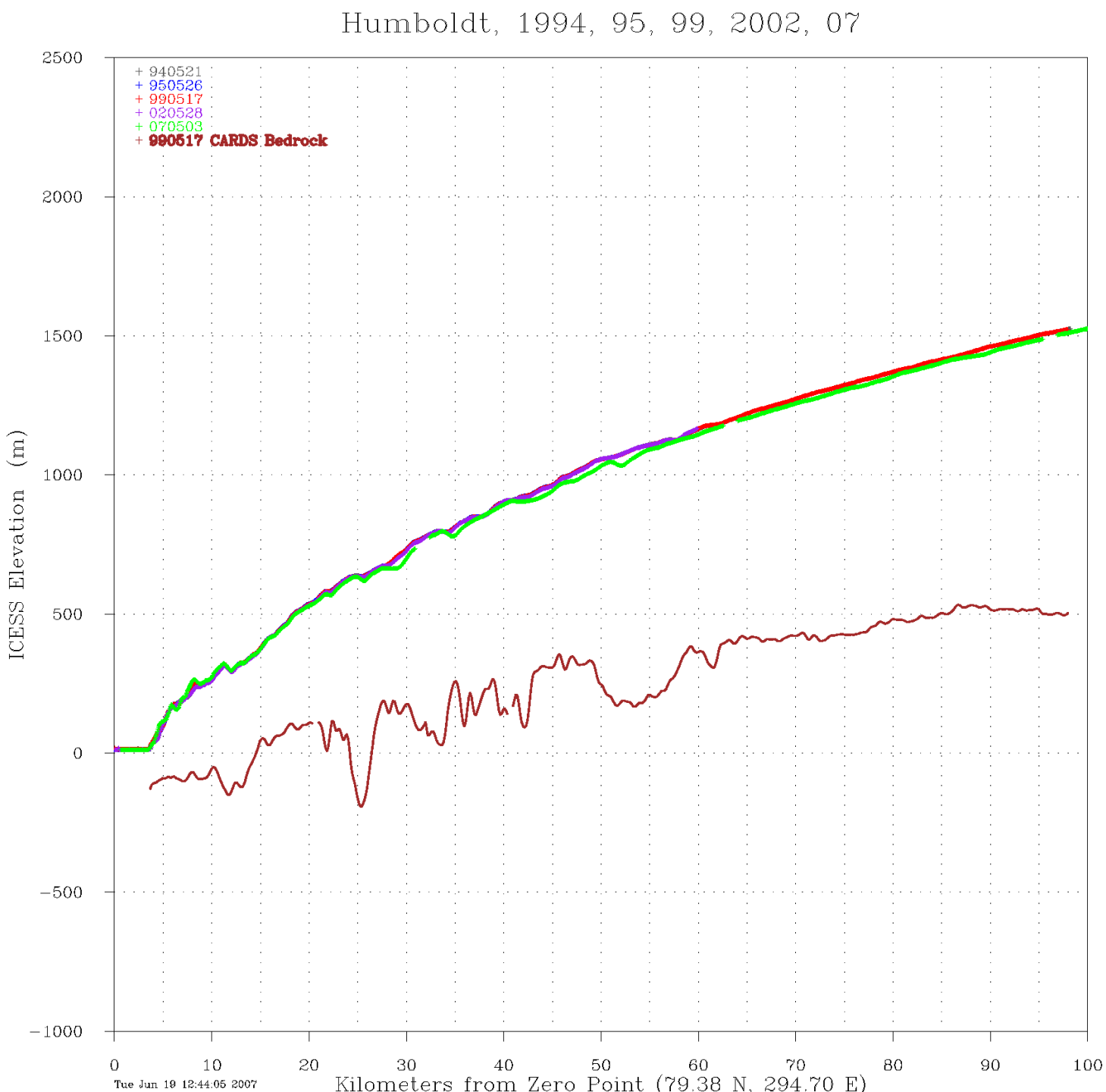
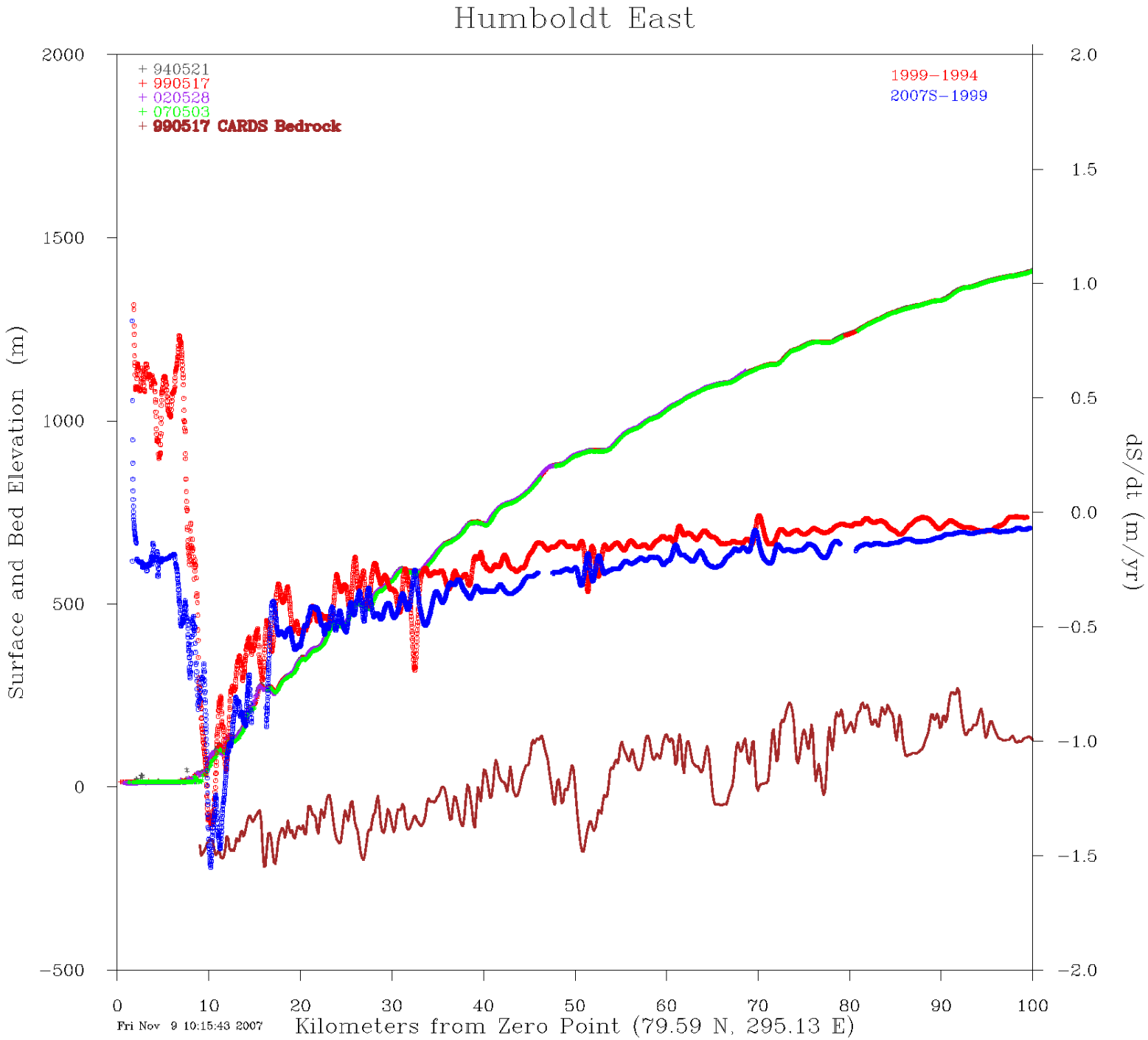
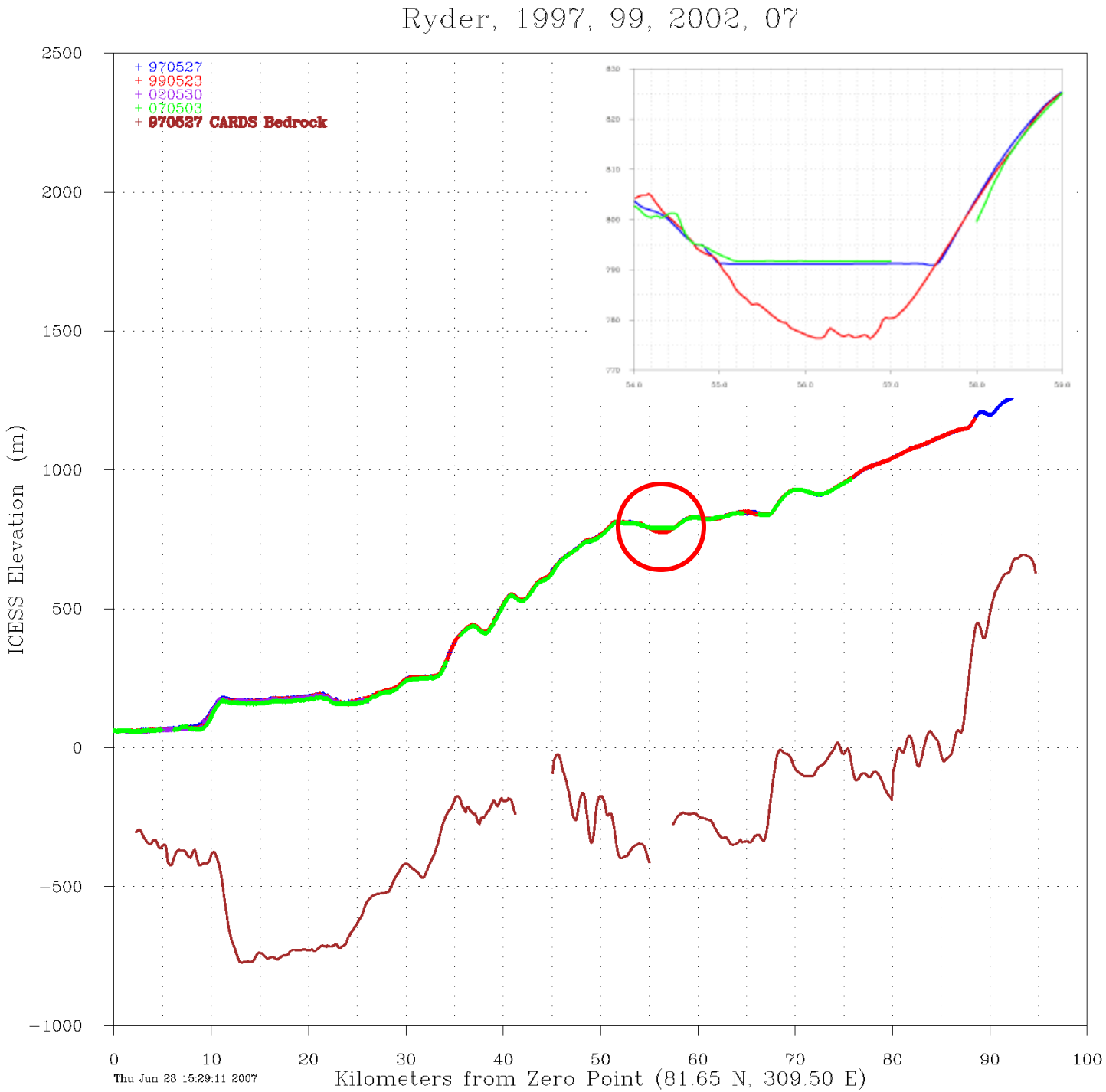


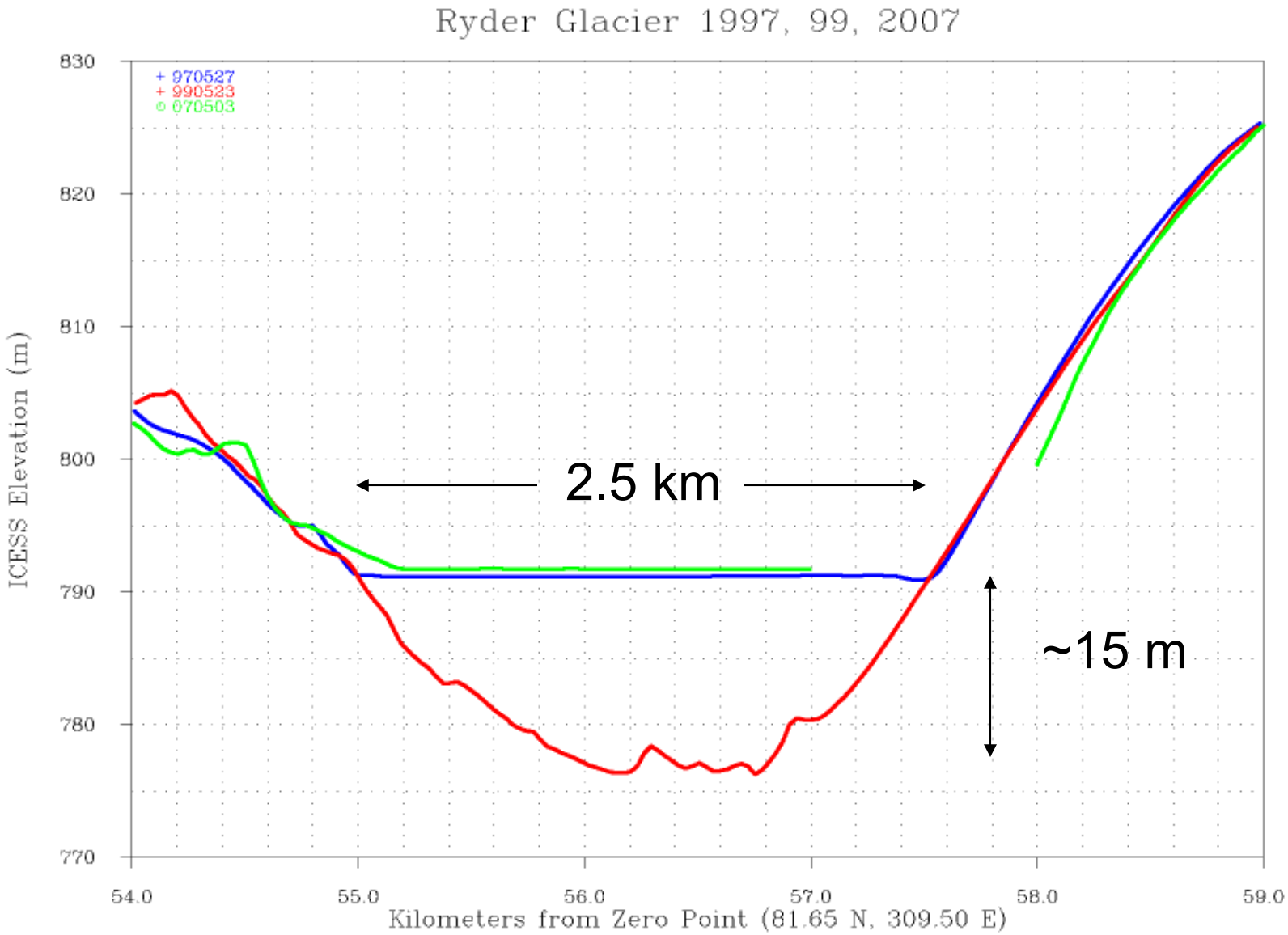
Fig. 1. Global mean surface temperature change based on surface air measurements over land and SSTs over ocean. Source: update of Hansen et al., JGR, 106, 23947, 2001; Reynolds and Smith, J. Climate, 7, 1994; Rayner et al., JGR, 108, 2003.


Petermann
Steensby
Ryder
Humbolt
104 km
Image NASA
Image © 2007 TerraMetrics
©2005 Google
Pointer lat 80.580823° lon -59.712355° elev 0 m
Streaming 100%
Eye alt 351.77 km

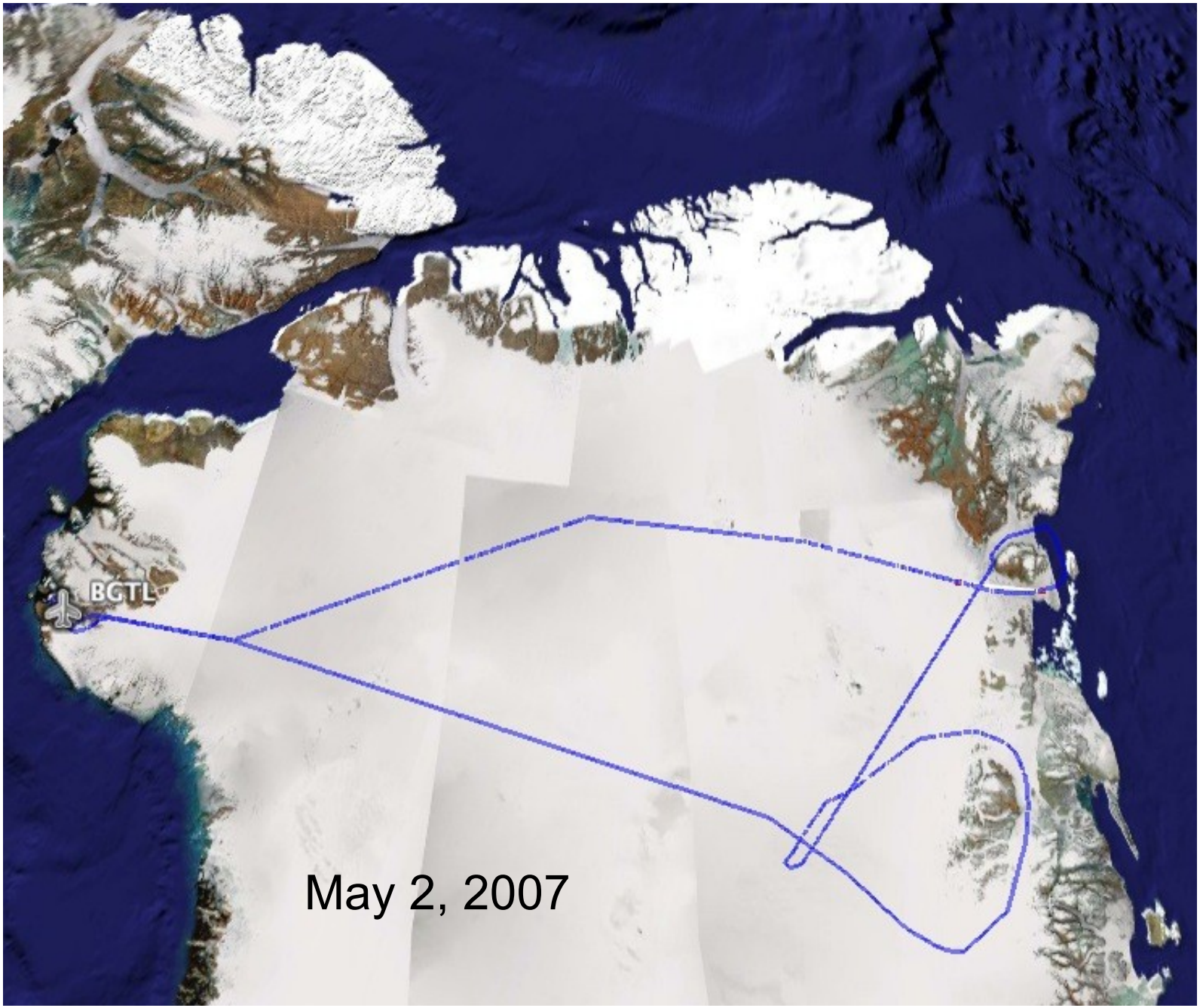

Humboldt, 1994, 95, 99, 2002, 07
+ 940521
+ 950526
+ 990517
+ 020528
+ 070503
+ 990517 CARDS Bedrock
ICESS Elevation (m)
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70
80
90
100
Tue Jun 19 12:44:05 2007
Kilometers from Zero Point (79.38 N, 294.70 E)

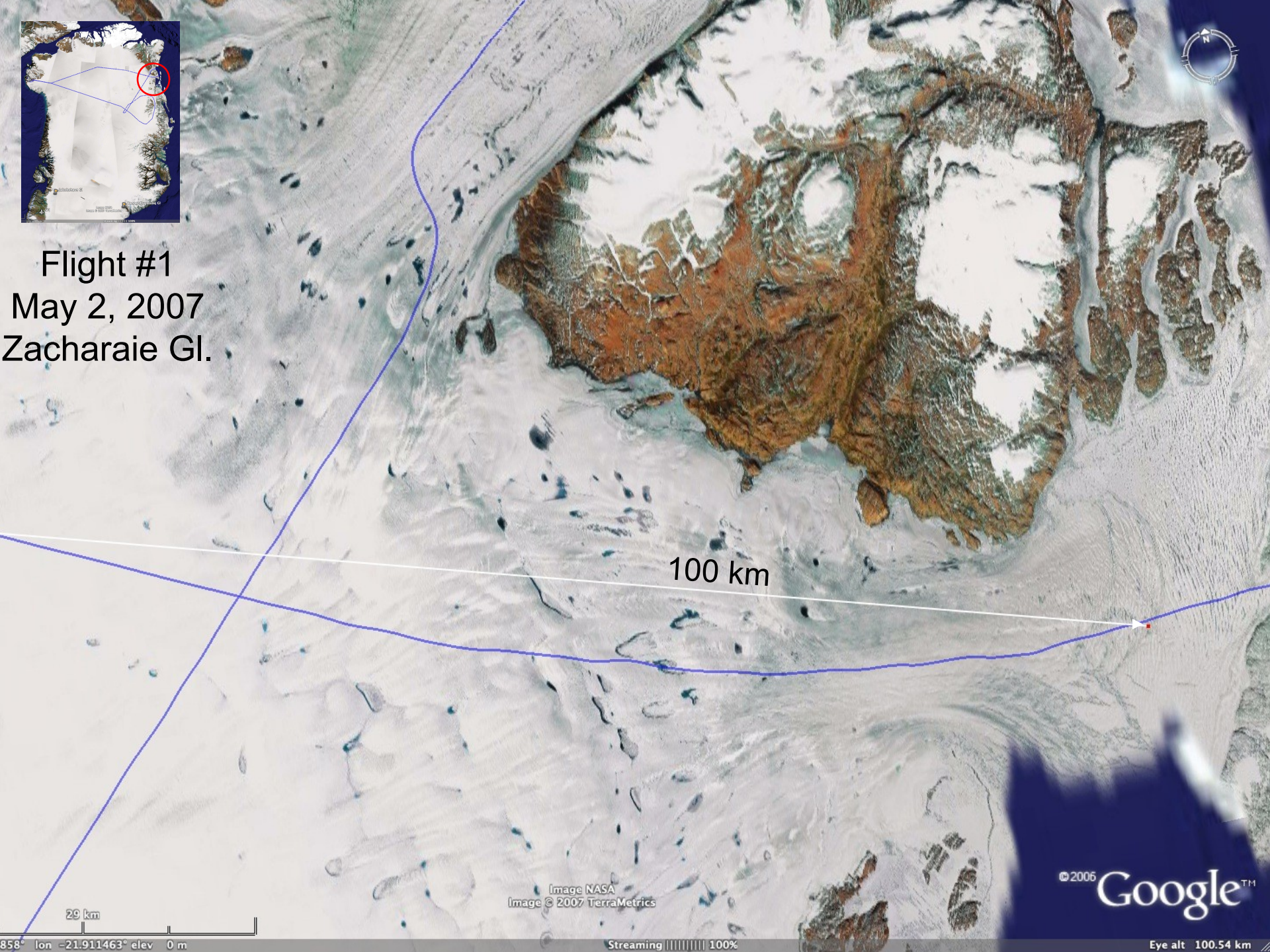

Humboldt East
+ 940521
+ 990517
+ 020528
+ 070503
+ 990517 CARDS Bedrock
1999−1994
2007S−1999
Surface and Bed Elevation (m)
dS/dt (m/yr)
Kilometers from Zero Point (79.59 N, 295.13 E)
Fri Nov 9 10:15:43 2007
2000
1500
1000
500
0
−500
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
0
10
20
30
40
50
60
70
80
90
100

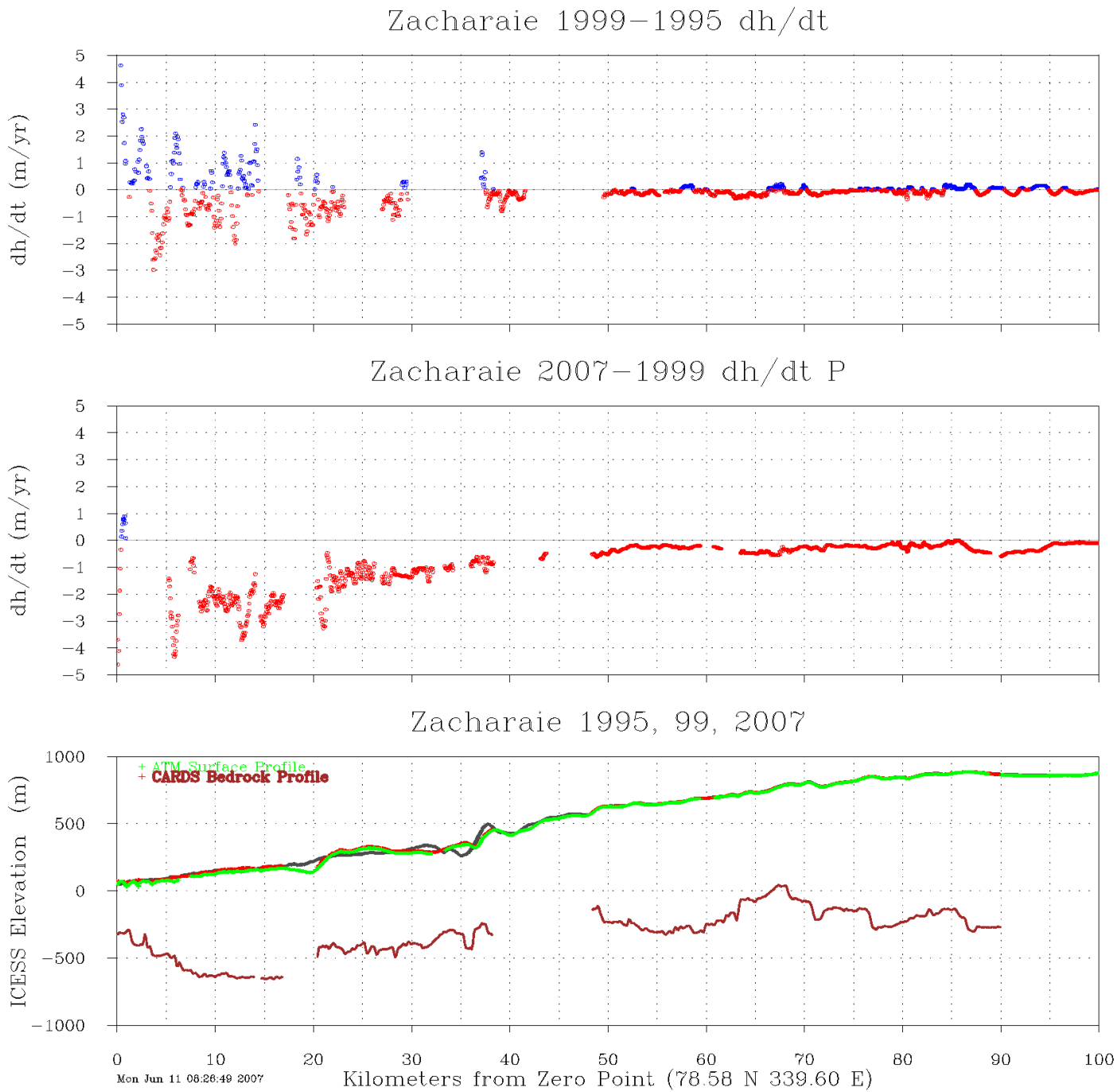

Ryder, 1997, 99, 2002, 07
+ 970527
+ 990523
+ 020530
+ 070503
+ 970527 CARDS Bedrock
ICESS Elevation (m)
2500
2000
1500
1000
500
0
−500
−1000
0
10
20
30
40
50
60
70
80
90
100
Thu Jun 28 15:29:11 2007
Kilometers from Zero Point (81.65 N, 309.50 E)

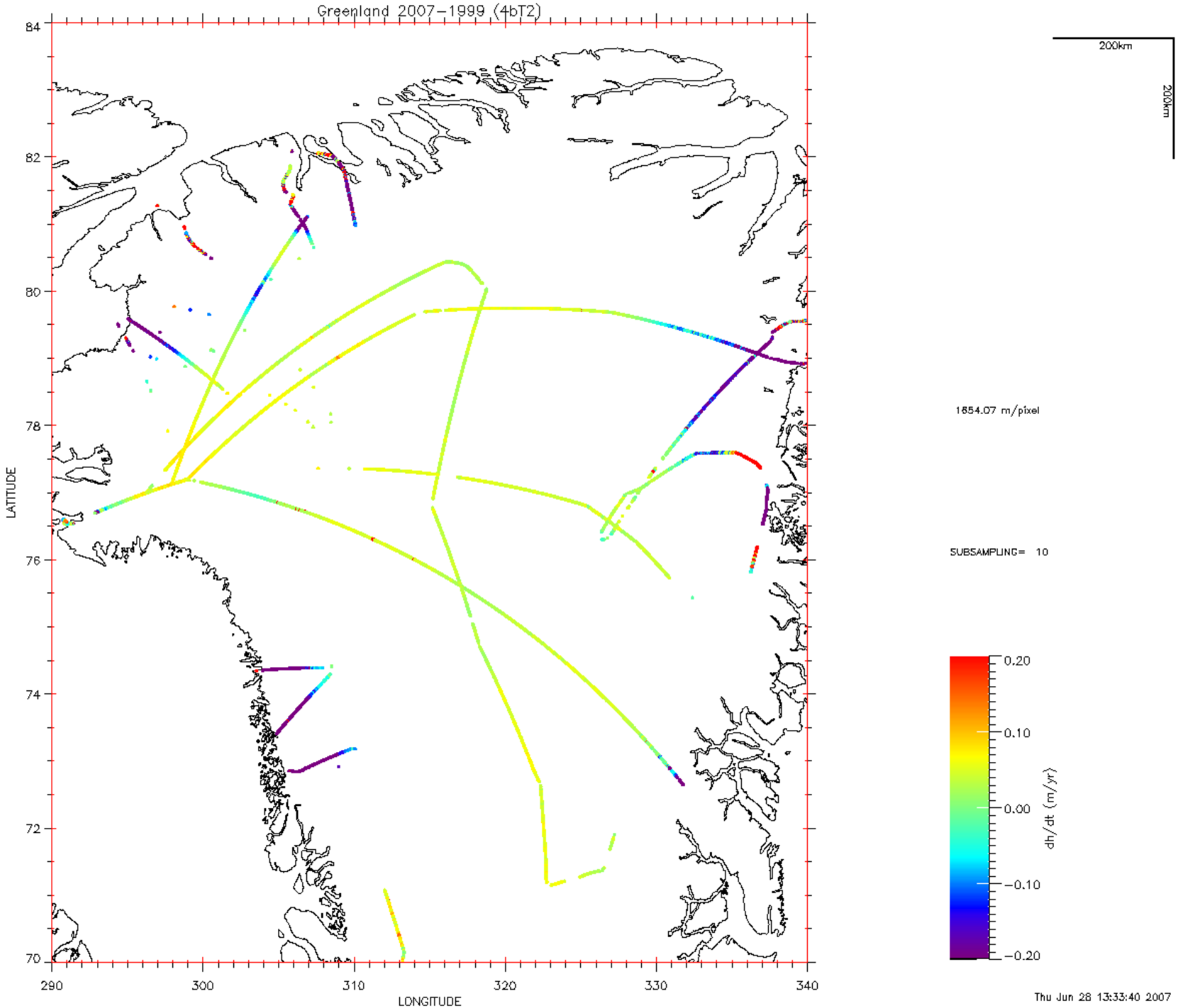

Ryder Glacier 1997, 99, 2007
+ 970527
+ 990523
○ 070503
830
820
810
800
790
780
770
ICESS Elevation (m)
54.0
55.0
56.0
57.0
58.0
59.0
Kilometers from Zero Point (81.65 N, 309.50 E)
2.5 km
~15 m

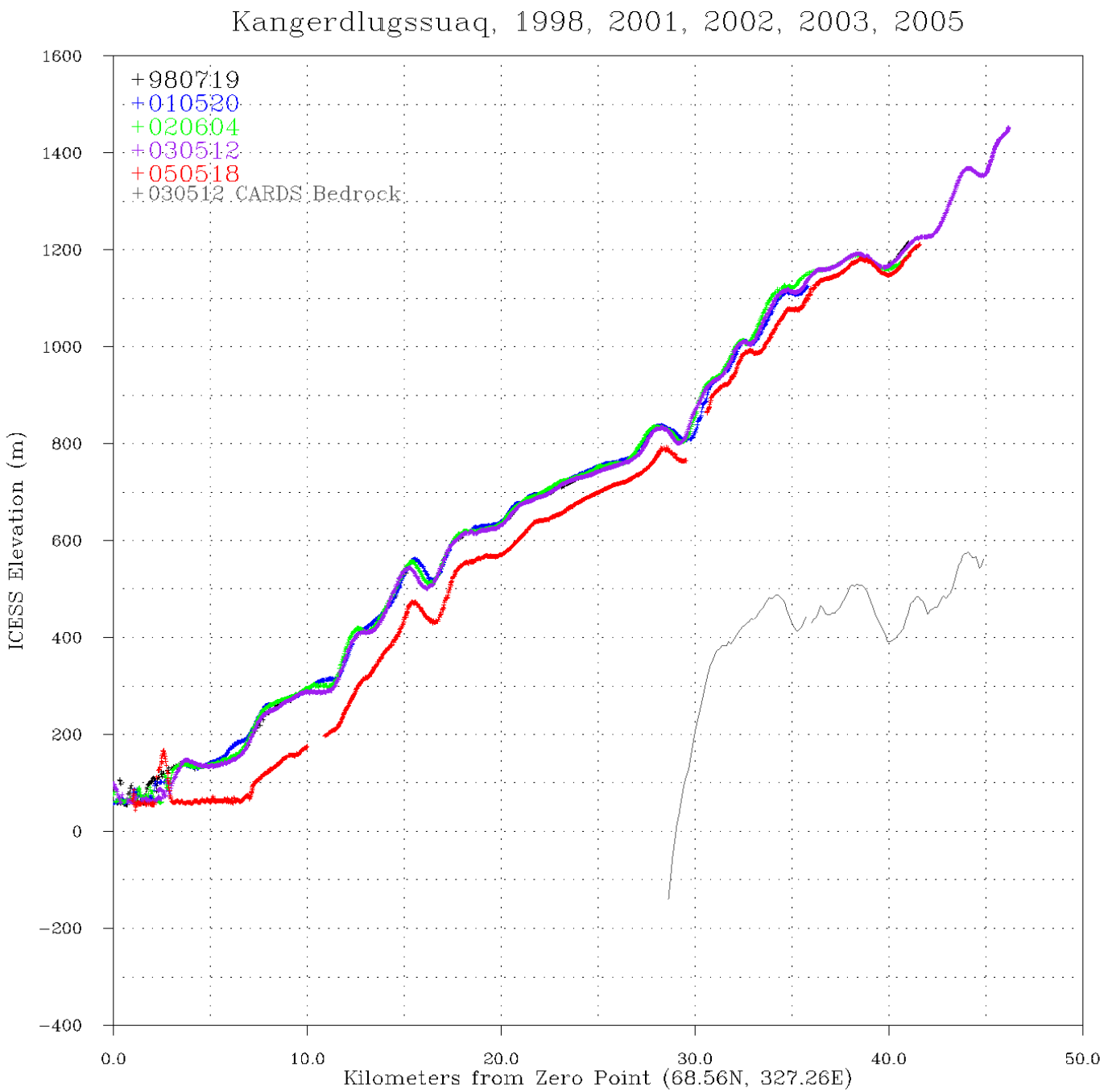
Kenn Borek Air Ltd.

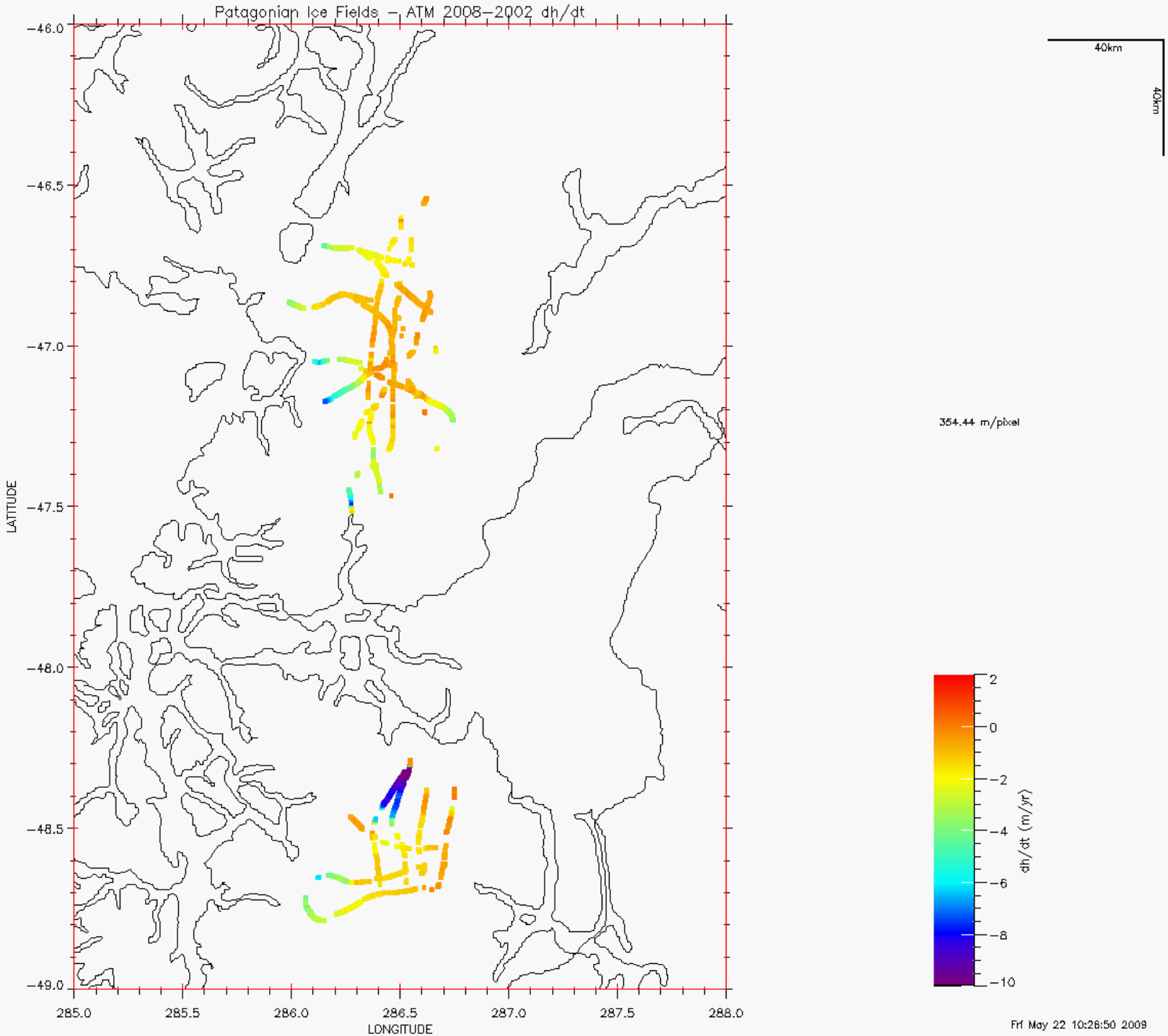

BGTL
May 2, 2007

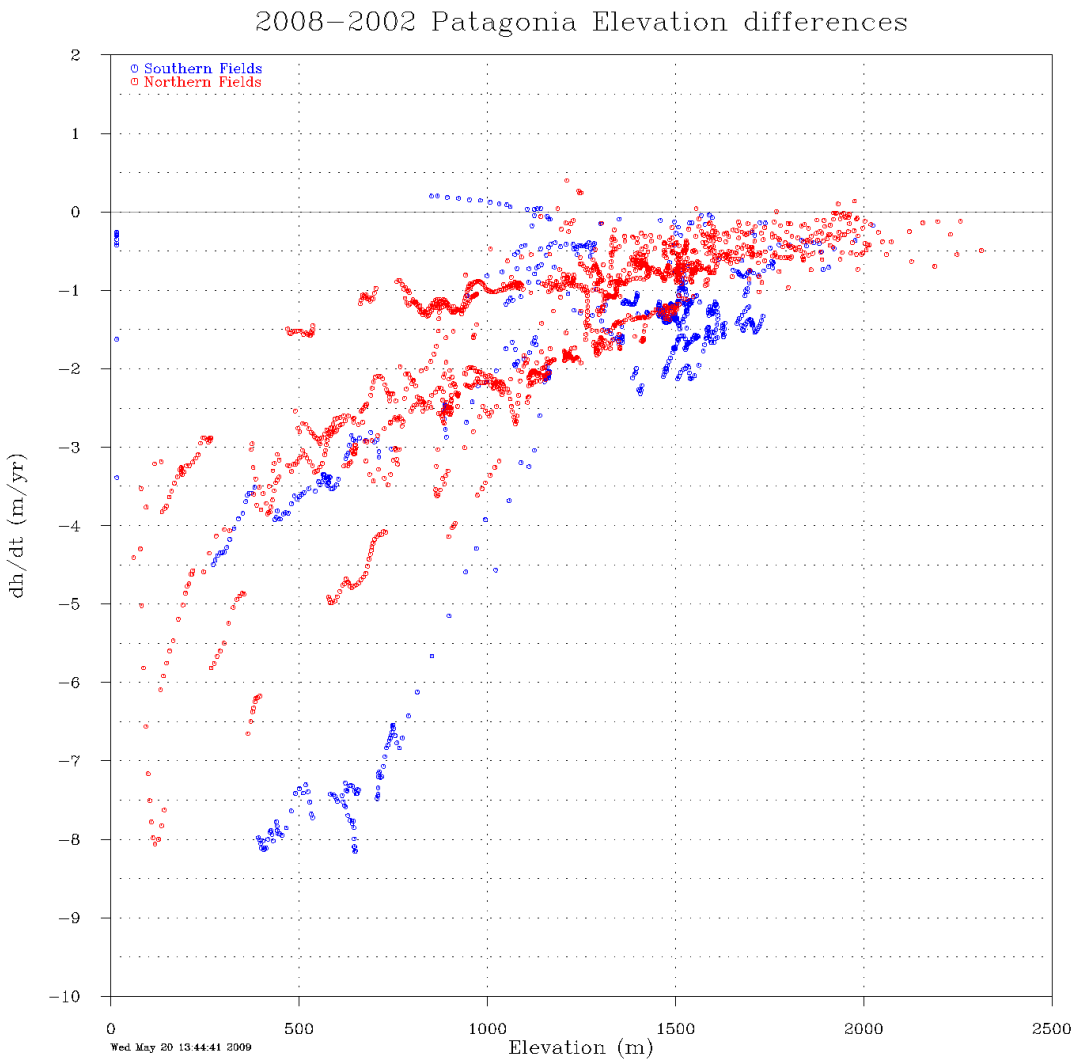

Flight #1
May 2, 2007
Zacharaie Gl.
100 km
Image NASA
Image © 2007 TerraMetrics
29 km
©2006 Google™
858° lon -21.911463° elev 0 m
Streaming 100%
Eye alt 100.54 km


Zacharaie 1999−1995 dh/dt
dh/dt (m/yr)
5
4
3
2
1
0
−1
−2
−3
−4
−5
Zacharaie 2007−1999 dh/dt P
dh/dt (m/yr)
Zacharaie 1995, 99, 2007
ICESS Elevation (m)
1000
500
0
−500
−1000
+ ATM Surface Profile
+ CARDS Bedrock Profile
0
10
20
30
40
50
60
70
80
90
100
Mon Jun 11 08:26:49 2007
Kilometers from Zero Point (78.58 N 339.60 E)

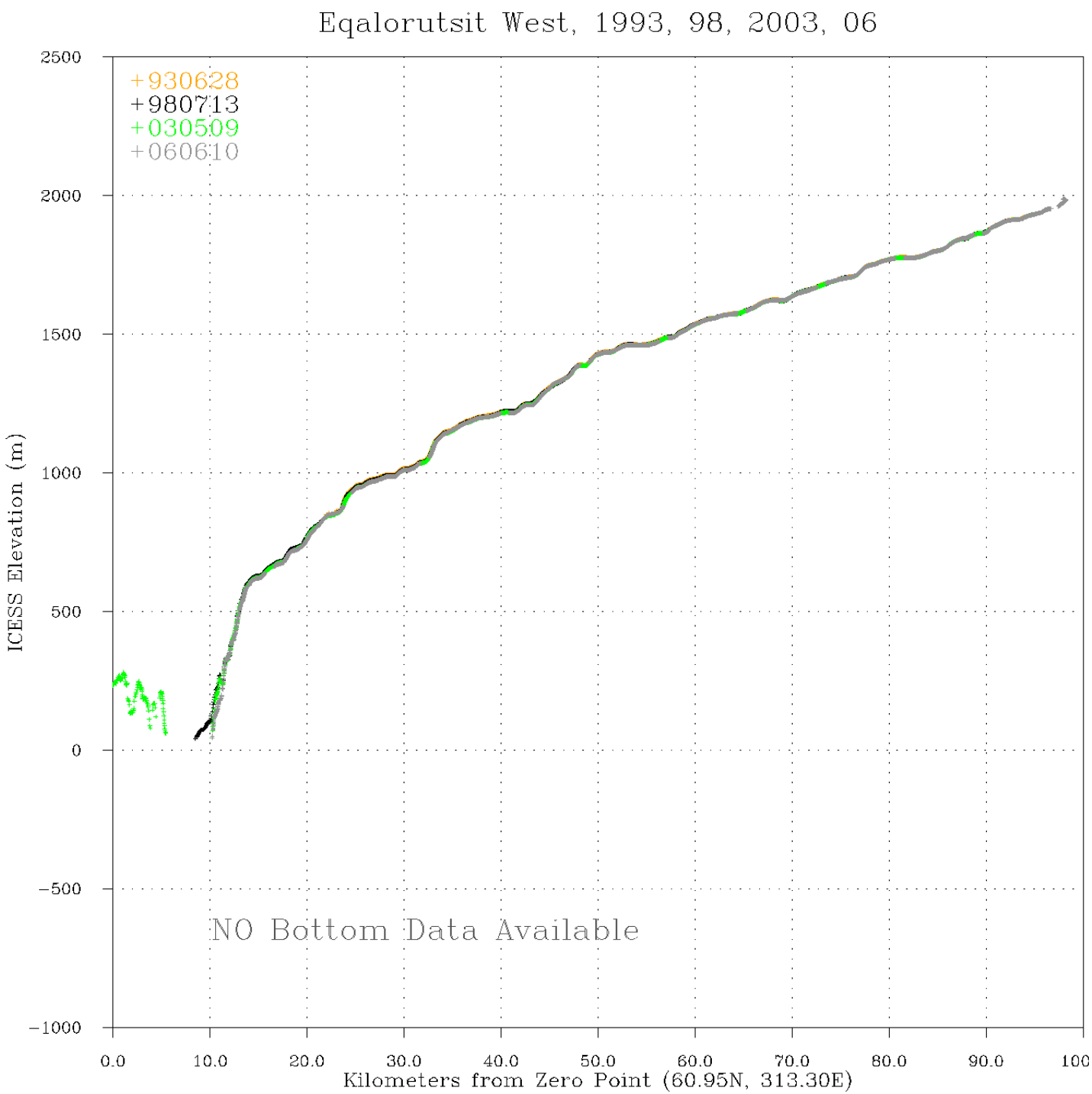

Greenland 2007-1999 (4bT2)
LATITUDE
LONGITUDE
84
82
80
78
76
74
72
70
290
300
310
320
330
340
200km
200km
1654.07 m/pixel
SUBSAMPLING= 10
0.20
0.10
0.00
-0.10
-0.20
dh/dt (m/yr)
Thu Jun 28 13:33:40 2007

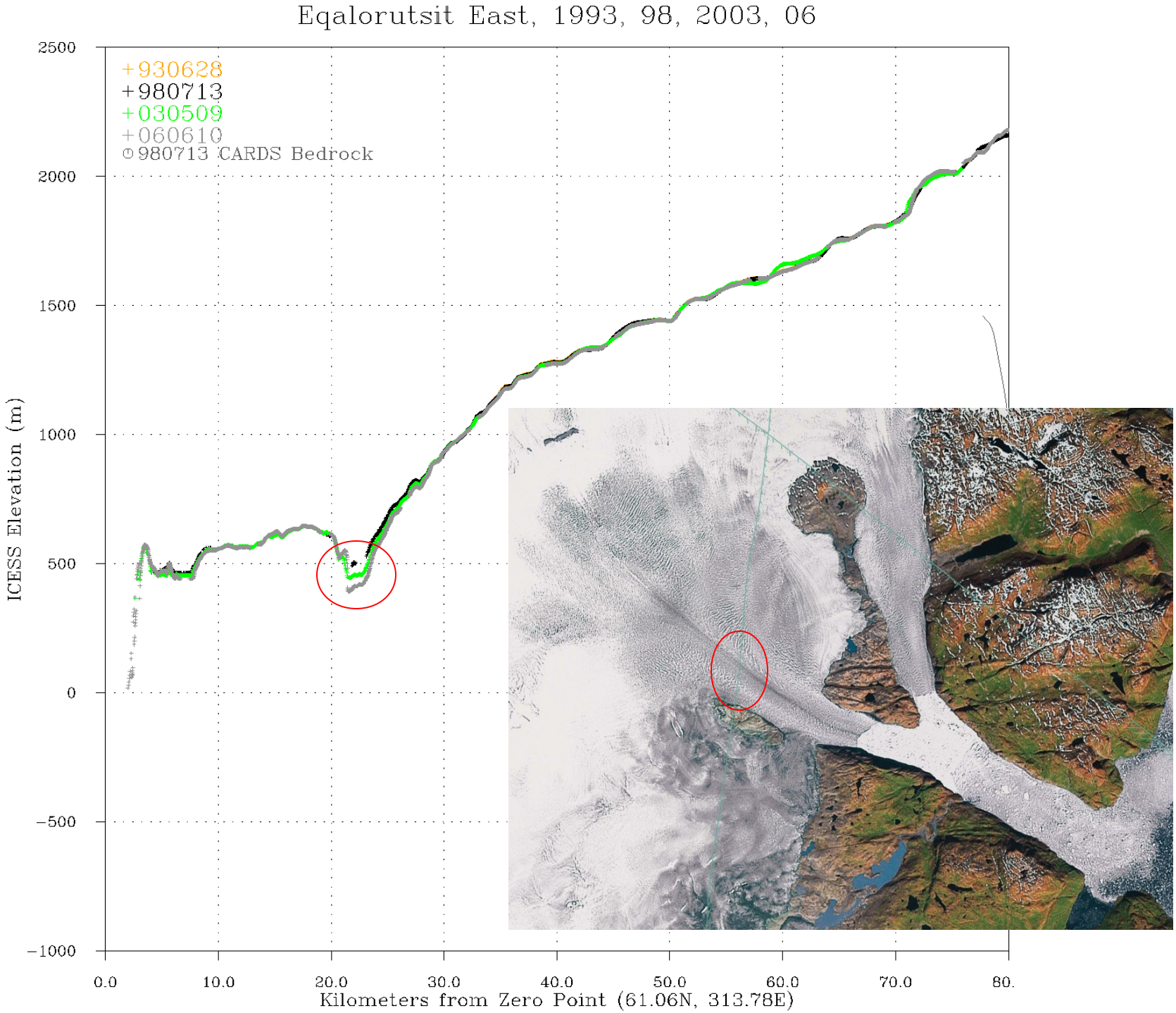

Kangerdlugssuaq, 1998, 2001, 2002, 2003, 2005
+980719
+010520
+020604
+030512
+050518
+030512 CARDS Bedrock
ICESS Elevation (m)
1600
1400
1200
1000
800
600
400
200
0
−200
−400
0.0
10.0
20.0
30.0
40.0
50.0
Kilometers from Zero Point (68.56N, 327.26E)

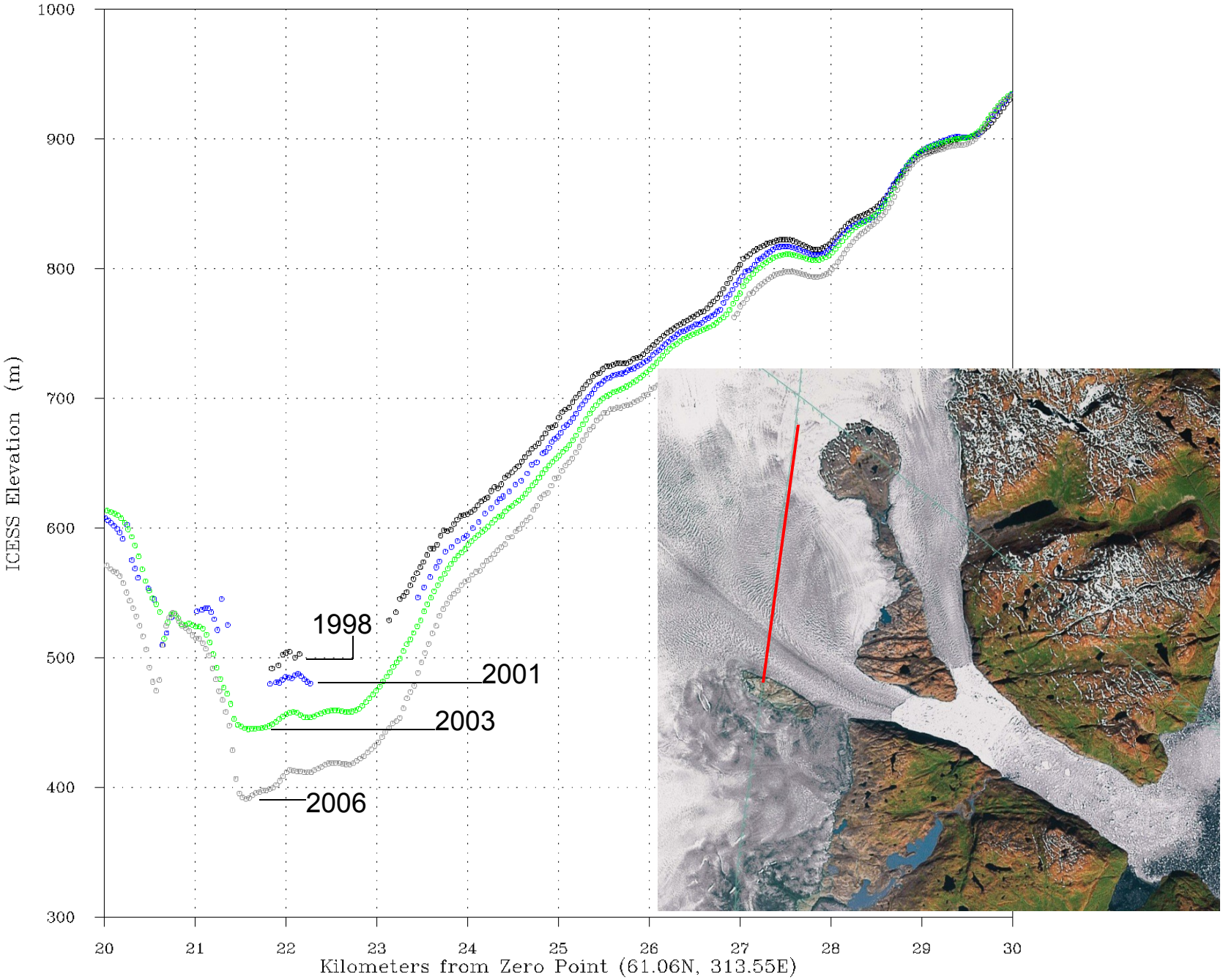

Patagonian Ice Fields – ATM 2008–2002 dh/dt
40km
40km
354.44 m/pixel
LATITUDE
LONGITUDE
−46.0
−46.5
−47.0
−47.5
−48.0
−48.5
−49.0
285.0
285.5
286.0
286.5
287.0
287.5
288.0
dh/dt (m/yr)
2
0
−2
−4
−6
−8
−10
Fri May 22 10:26:50 2009

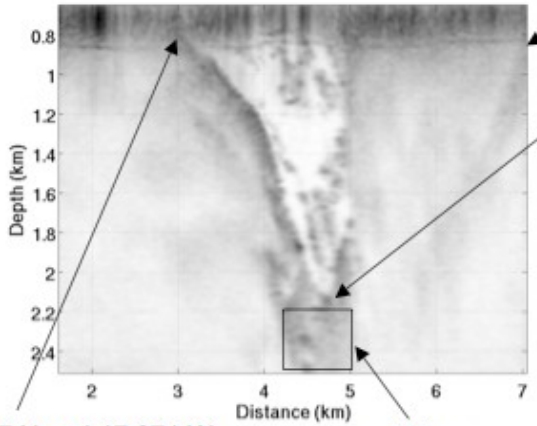

2008−2002 Patagonia Elevation differences
Southern Fields
Northern Fields
dh/dt (m/yr)
Elevation (m)
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
0
500
1000
1500
2000
2500
Wed May 20 13:44:41 2009

Nunarssit


Eqalorutsit West, 1993, 98, 2003, 06
+930628
+980713
+030509
+060610
NO Bottom Data Available
ICESS Elevation (m)
2500
2000
1500
1000
500
0
−500
−1000
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100
Kilometers from Zero Point (60.95N, 313.30E)


Eqalorutsit East, 1993, 98, 2003, 06
+930628
+980713
+030509
+060610
©980713 CARDS Bedrock
ICESS Elevation (m)
2500
2000
1500
1000
500
0
−500
−1000
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.
Kilometers from Zero Point (61.06N, 313.78E)


1000
900
800
700
600
500
400
300
ICESS Elevation (m)
20
21
22
23
24
25
26
27
28
29
30
Kilometers from Zero Point (61.06N, 313.55E)
1998
2001
2003
2006

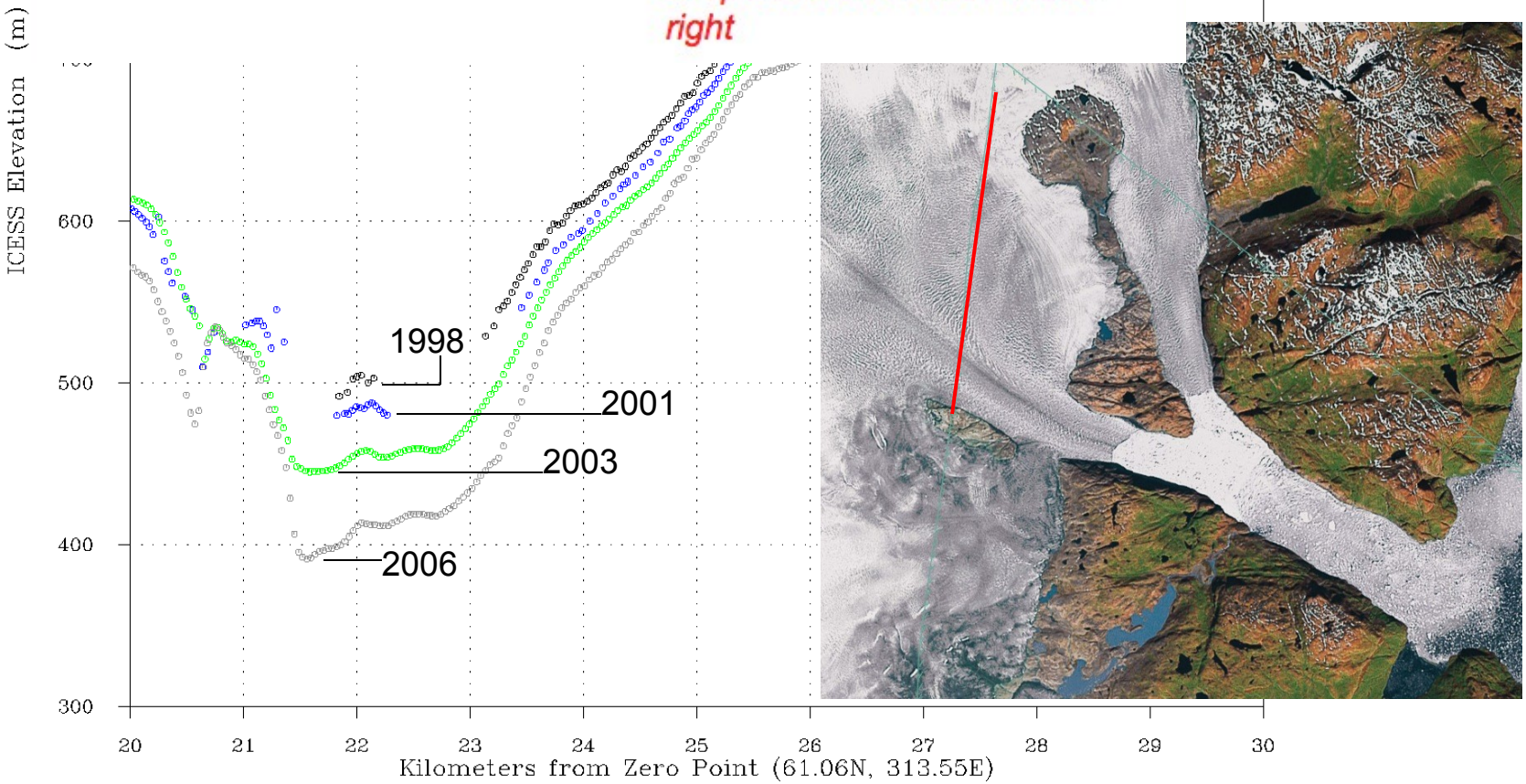


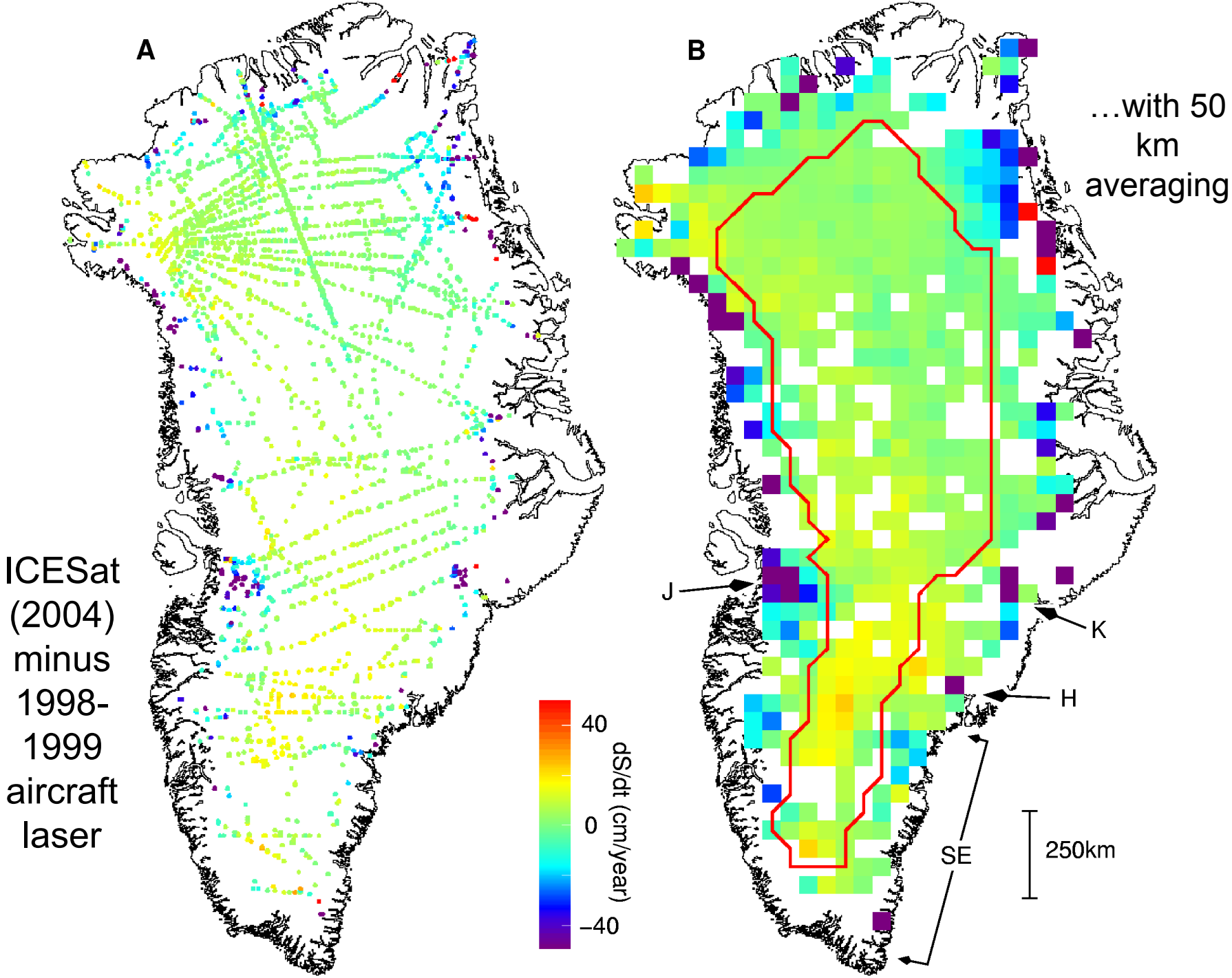
Deepest bed return

Thickness ~ 2.2 km and width at bed < 1km

Right side echoes are masked by surface clutter

Clutter rejection algorithm is being refined to obtain the shape of the channel on the right




A
B
ICESat (2004) minus 1998-1999 aircraft laser
…with 50 km averaging
40
0
–40
dS/dt (cm/year)
J
K
H
SE
250km

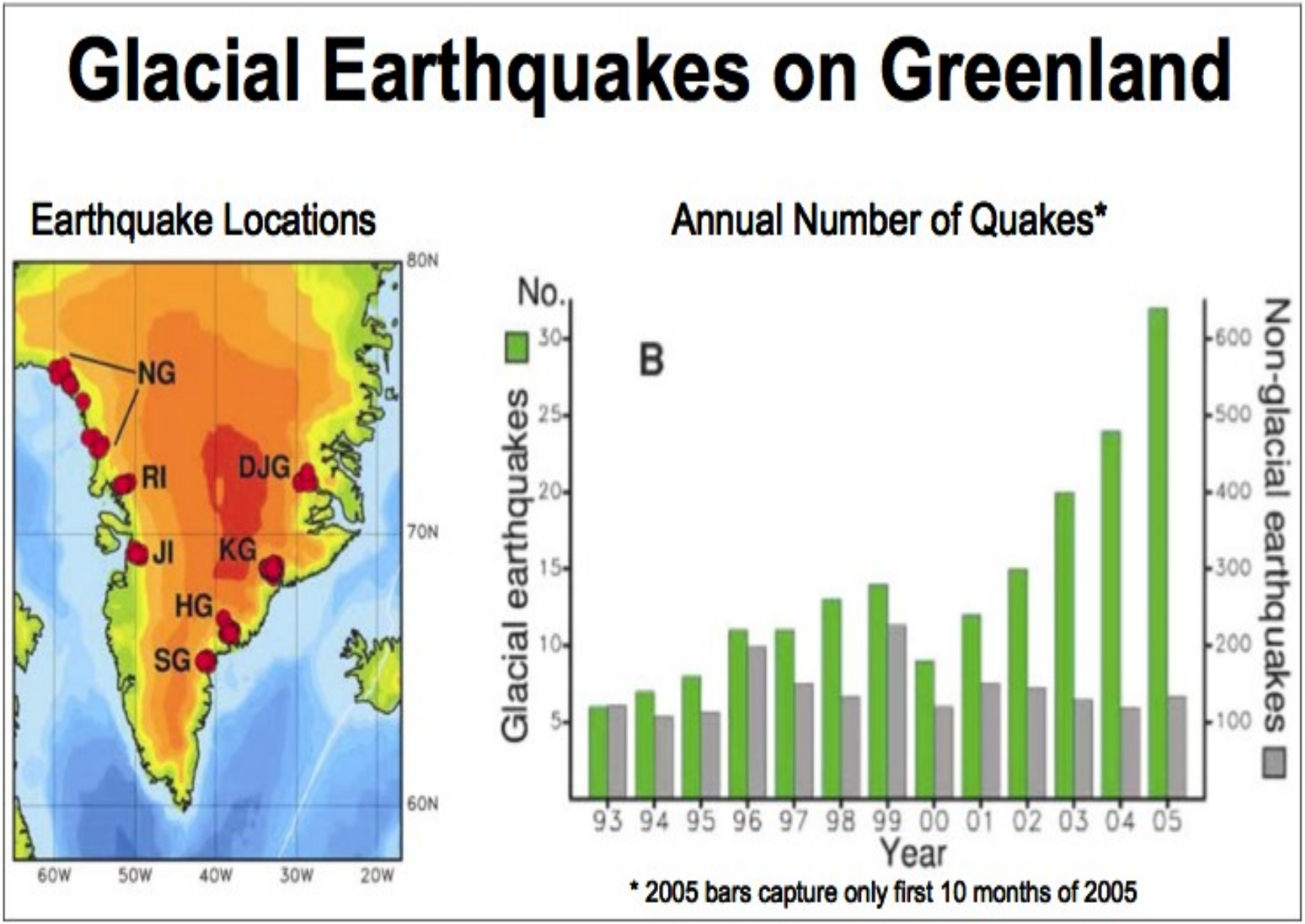
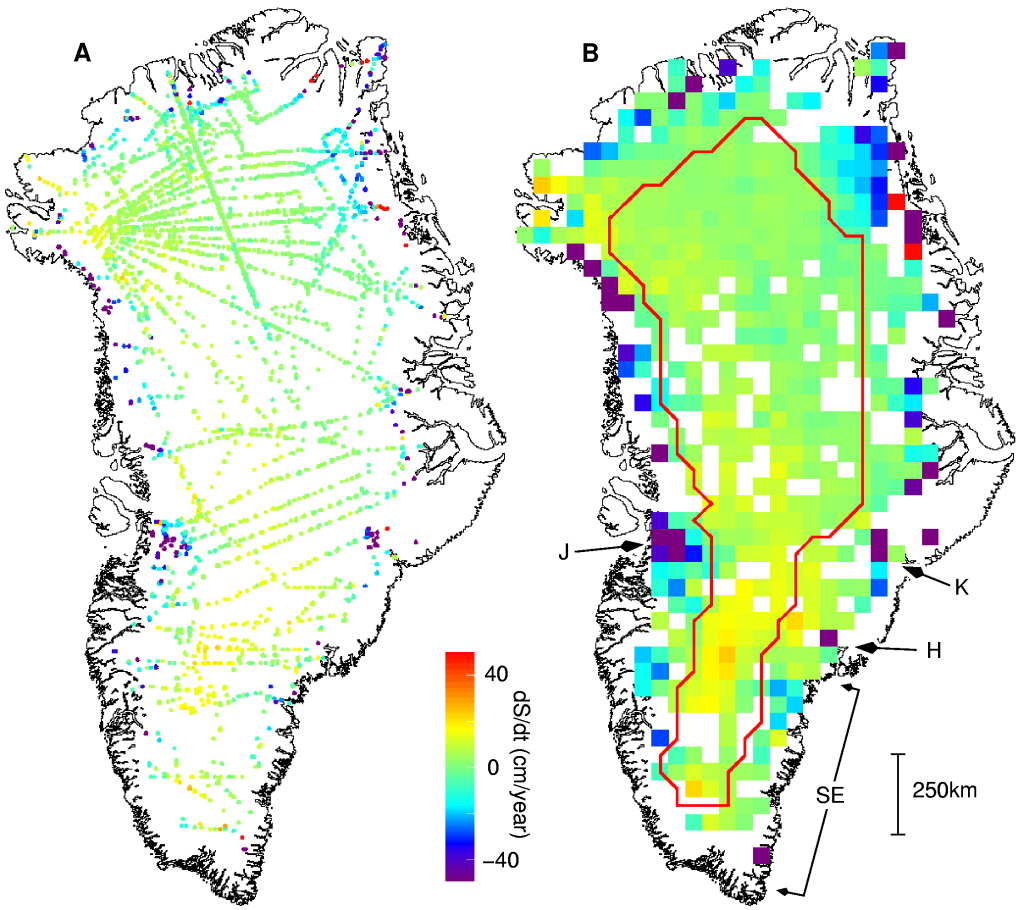
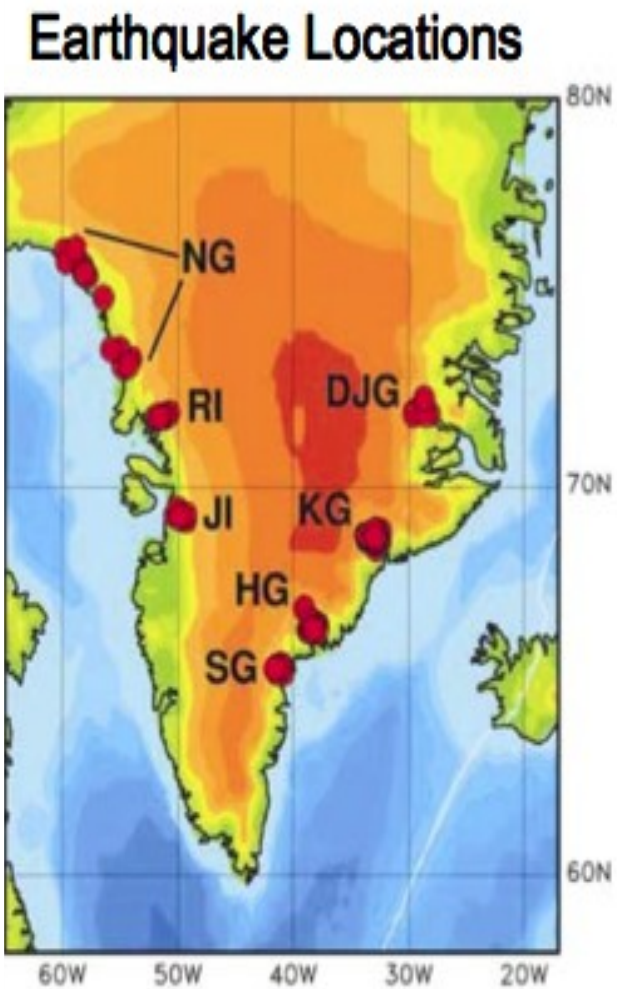
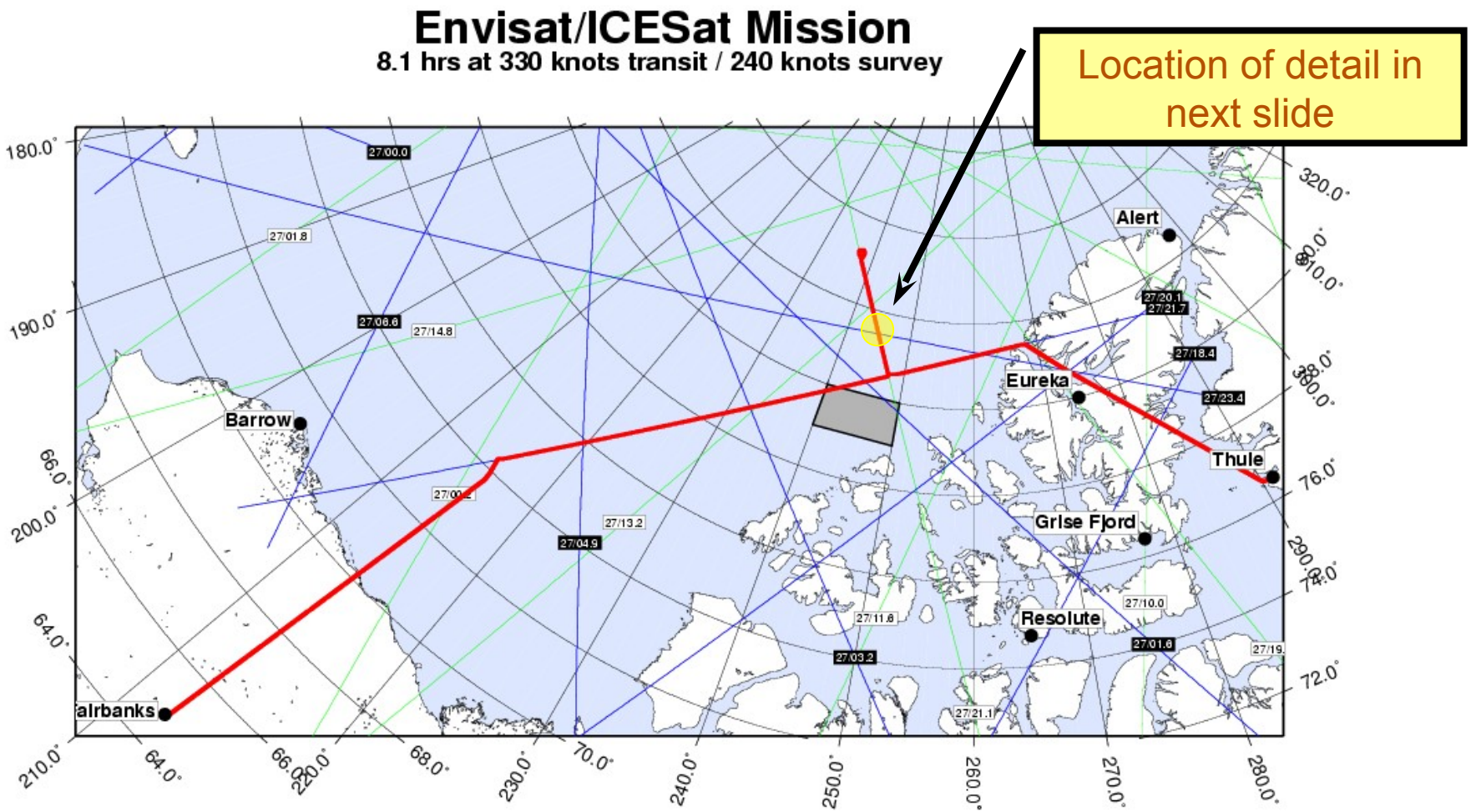


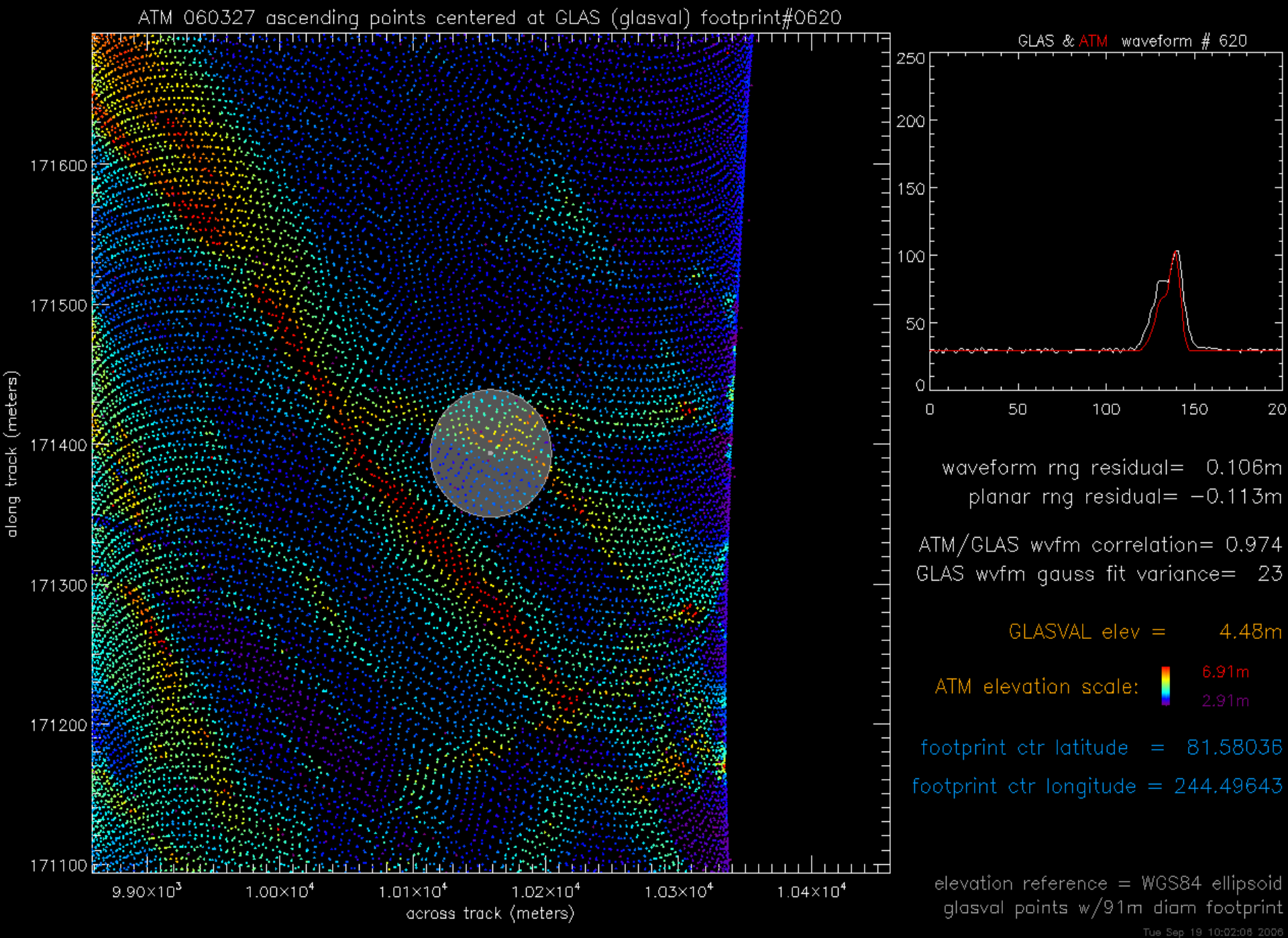
Fig. 22. Location and frequency of earthquakes on Greenland. Magnitudes of the earthquakes are in the range 4.6 to 5.1. Source: Ekstrom, Nettles and Tsai, Science, 311, 1756, 2006.


A
B
40
0
−40
dS/dt (cm/year)
J
K
H
SE
250km


Earthquake Locations
NG
RI
DJG
JI
KG
HG
SG
80N
70N
60N
60W
50W
40W
30W
20W

ATM seaice survey 2006-Mar-27




ATM 060327 ascending points centered at GLAS (glasval) footprint#0620
along track (meters)
171600
171500
171400
171300
171200
171100
9.90×10³
1.00×10⁴
1.01×10⁴
1.02×10⁴
1.03×10⁴
1.04×10⁴
across track (meters)
GLAS & ATM waveform # 620
250
200
150
100
50
0
0
50
100
150
20
waveform rng residual= 0.106m
planar rng residual= −0.113m
ATM/GLAS wvfm correlation= 0.974
GLAS wvfm gauss fit variance= 23
GLASVAL elev = 4.48m
ATM elevation scale:
6.91m
2.91m
footprint ctr latitude = 81.58036
footprint ctr longitude = 244.49643
elevation reference = WGS84 ellipsoid
glasval points w/91m diam footprint
Tue Sep 19 10:02:06 2006

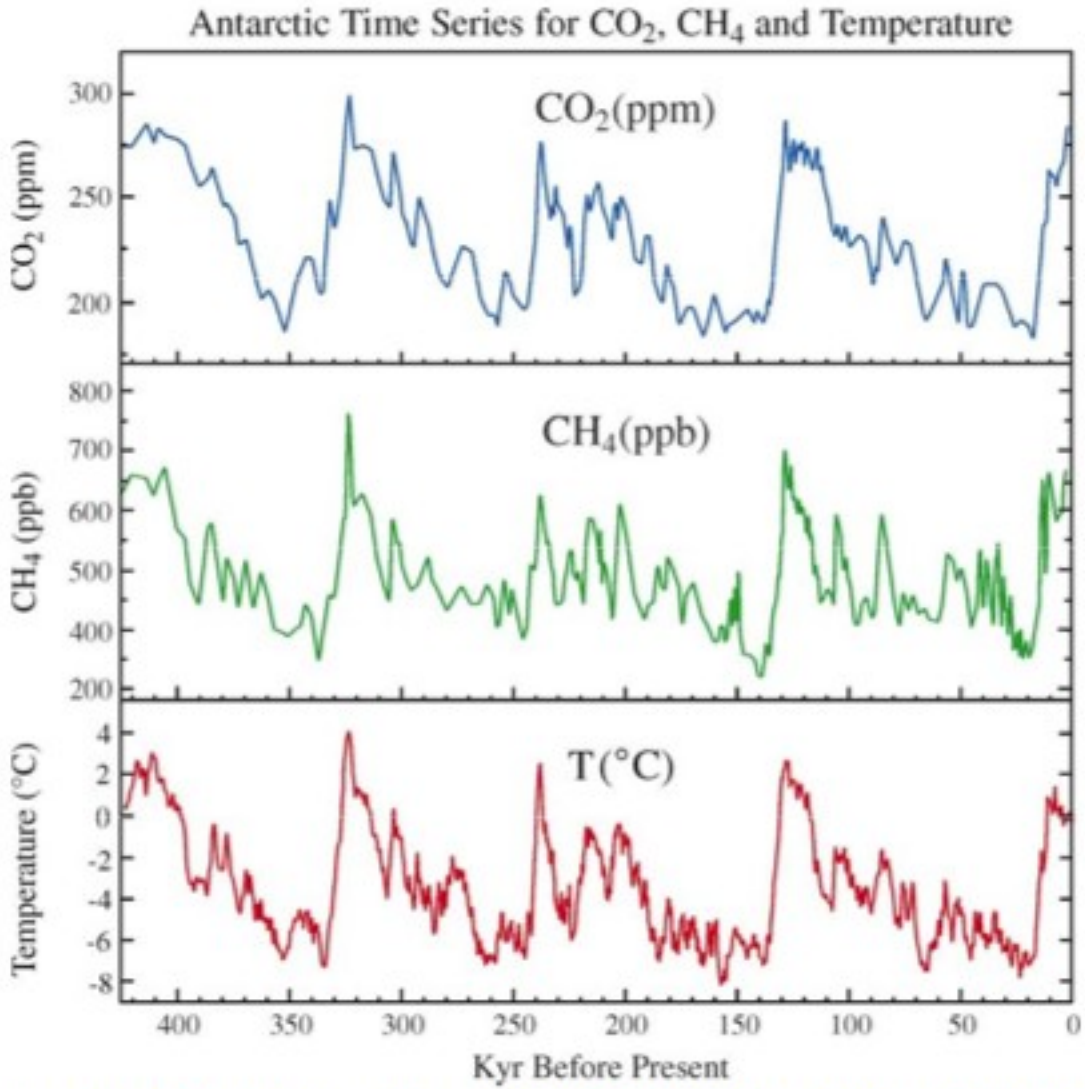


Fig. 4. CO_2, CH_4 and temperature records from Antarctic ice core data. Source: Vimeux et al., Earth Plan. Sci. Lett., 203, 829, 2002.

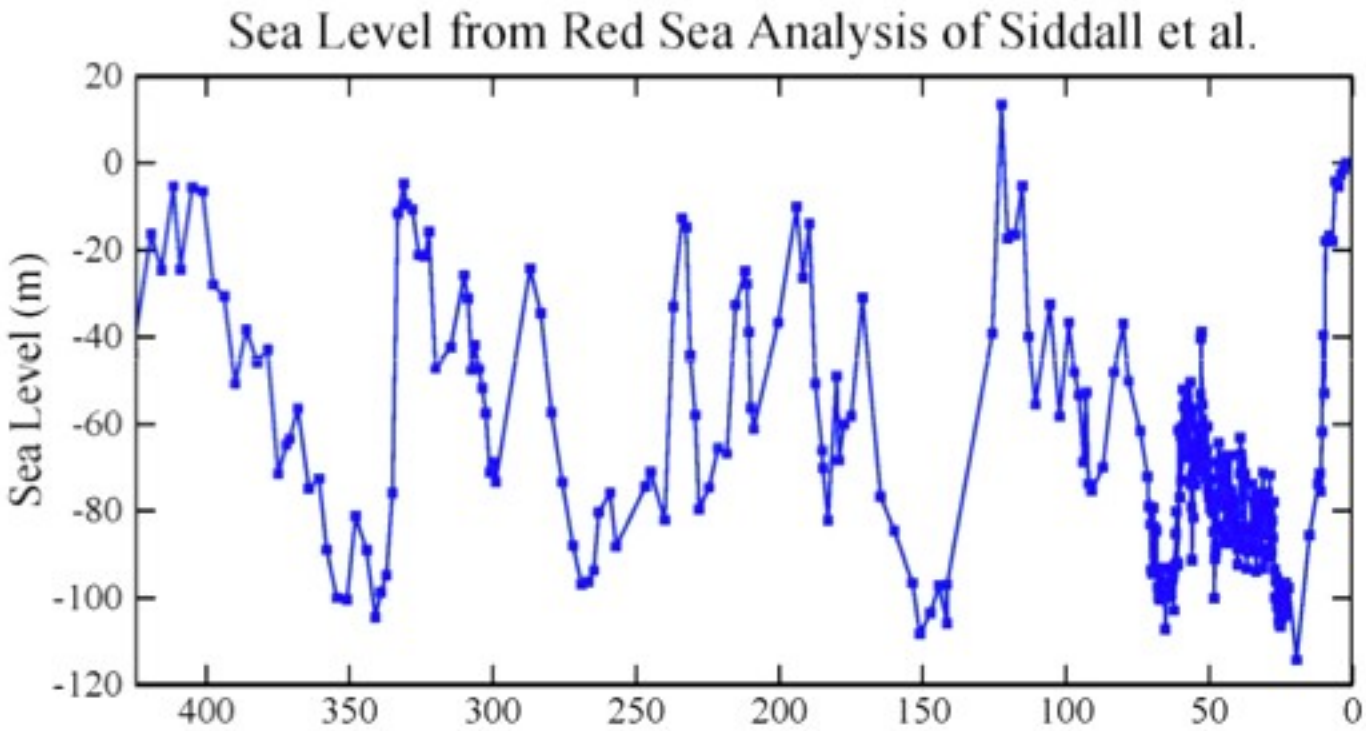
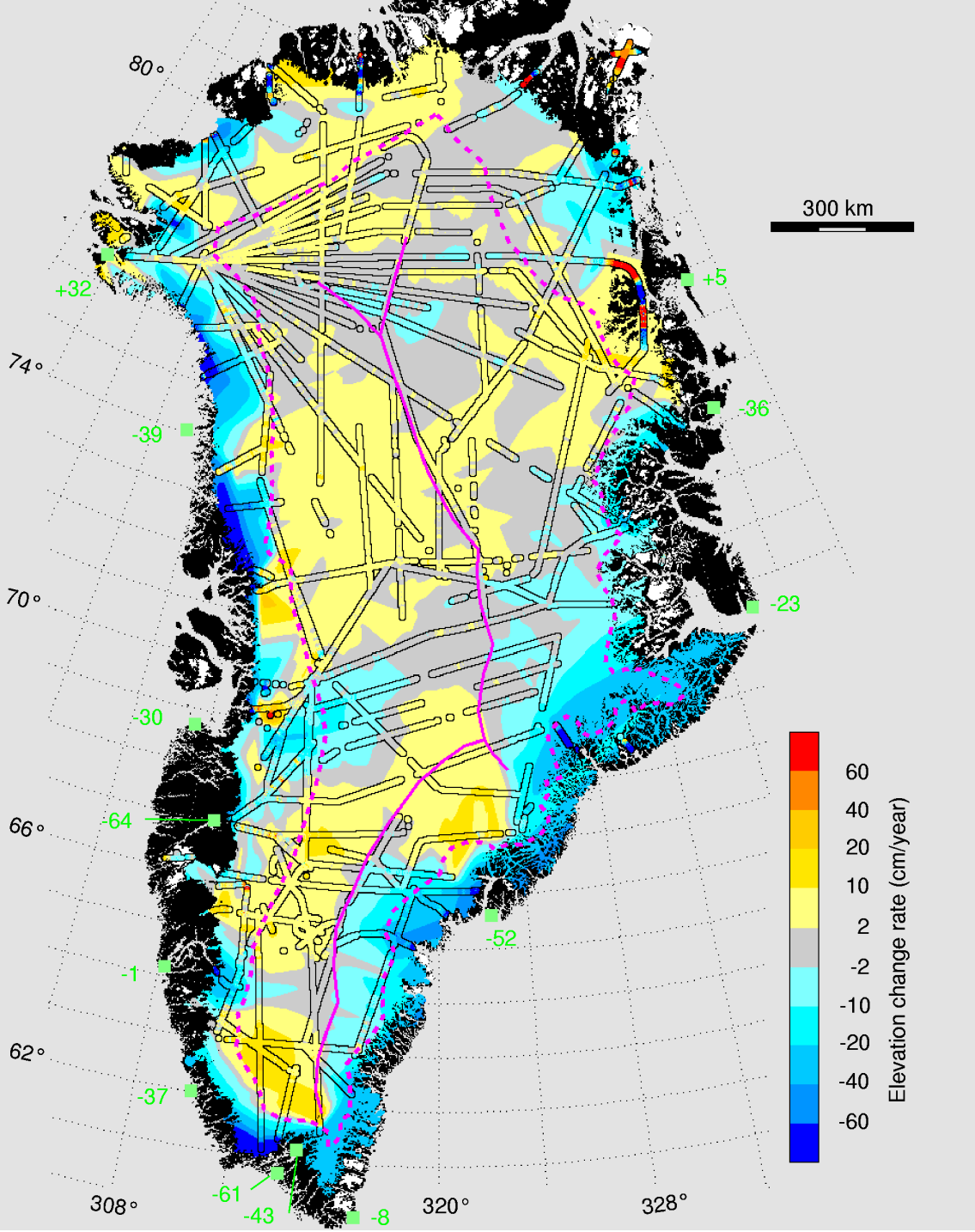


Fig. 6. Global sea level extracted, via a hydraulic model, from an ozygen isotope record for the Red Sea over the past 470 kyr (concatenates Siddall's MD921017, Byrd, & Glacial Recovery data sets; AMS radiocarbon dating). Source: Siddall et al., Nature, 423, 853, 2003.



…from *Science*, 2000