Remote Sensing of the Bering Glacier Region

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Bering Glacier Background

- Largest and longest glacier in continental North America (area 5,175 km^2, length 190 km)
- 6% area of glacier ice in Alaska (15-20% of total ice in Alaska)
- Largest surging glacier in America (last surge 1993-95)
- Rapid ongoing retreat of the glacier and expansion of Vitus Lake has established new flora and fauna habitats
- Post-surge retreat of glacier has created a dynamic landscape of reticulated and fluted surfaces with subtidal invertebrate fossils, lake sediments, and previous overrun forests.
- Given current climate change scenarios, Bering may undergo a dramatic retreat, giving a dramatically different landscape.

Why Remote Sensing at Bering Glacier?

- Data is collected year-round and can provide information about the system when field data collection is not possible due to extreme weather conditions (i.e. non-summer months).
- The Glacier's remote location limits on-the-ground access. In general, remote sensing can offer insight into areas that have not or cannot be accessed.
- Remote sensing provides useful tools for determining and quantifying landscape change.
- For certain applications there may be reduced costs when compared to traditional field data collection methods in remote environments (for example, land cover classification).
- Given the geographic extent of the Glacier, in situ observations alone cannot adequately characterize glacial dynamics. Remote sensing systems can capture a synoptic view of the landscape.
- Remote sensing provides additional information that can supplement more intensive sampling efforts and help extrapolate findings.

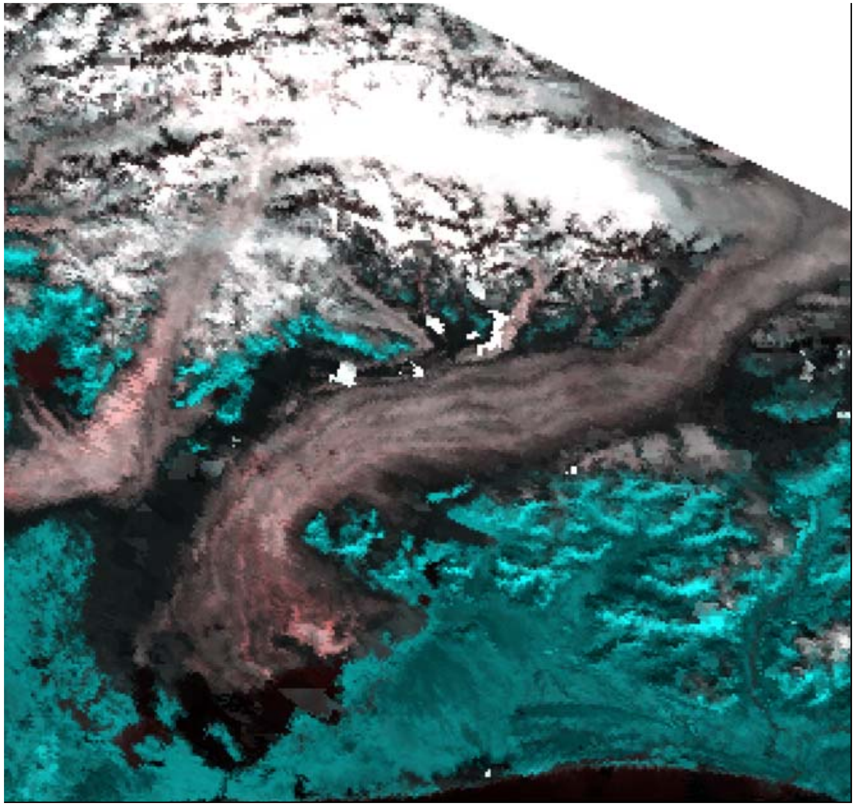
In-Situ Studies of the Bering Glacier Region

Satellite Sensors for Glacier Study

Optical Sensors	Temporal range	Resolution	Applications	Description
MODIS: Aqua/Terra	2000 - present	250-1000 m 2 platforms 1-2 day revisit interval 36 spectral Bands	Snow Line, Terminus positions, Water Quality, Albedo derived product, Vegetation Map, Landcover	Pros: 40 data products that combine different spectral, temporal, and spatial resolutions. Perhaps the most prudent to the Bering Glacier area is the 8 day reflectance product that has a spatial resolution of 250 meters and combines 8 days of reflectance data into one image making it ideal for the cloudy tendencies of the area. Free, Collected every day, and Free Cons: Spatial Resolution
ASTER	2000 - present	15, 30, 90 m 16 day revisit interval 14 spectral bands	Snow Line, Terminus positions, DEM generation, Landcover, Vegetation Map, Glacier Features	Pros: multispectral allows for observing contrasts, resolution, DEM creation, inexpensive to free Cons: Temporal extent, The long repeat time coupled with the cloudy tendencies of the area make it hard to find useful data especially for when you want it
Landsat	1973 - present	30 m, 15 m panchromatic 2 platform 16 day repeat time 8 spectral bands	Snow Line, Terminus positions, Landcover mapping	Pros: temporal extent, multispectral allows for observing contrasts, resolution Cons: The long repeat time coupled with the cloudy tendencies of the area make it hard to find useful data especially for when you want it, the data is expensive, recent issues with Landsat 7
QuickBird/Ikonos/ OrbView (commercial satellites)	2001- present	2-4 m, 60 cm panchromatic 1-3.5 revisit interval 5 spectral bands	Ice berg monitoring, Seal monitoring, Water quality	Pros: spatial resolution, revisit interval Cons: expensive, suffers same problems as other optical sensors
Radar Sensors	**Temporal range**	**Resolution**	**Applications**	**Description**
ERS-1 ERS-2 Envisat Radarsat	1992 - present	25 meter pixel size 2 platforms 35 day revisit interval C-band radar	Snow Line, Terminus positions, Ice berg monitoring	Pros: Temporal extent, acquisition regardless of atmospheric conditions, wavelength allows penetration through snow cover allowing for glacier measurements year round, inexpensive Cons:
IceSat/GLAS	2003- present	70 meter footprint	Topography, Ablation, Sea ice thicknessPros: Sensor designed specifically for ice sheet monitoring.	Pros: Sensor designed specifically for ice sheet monitoring. Precise Cons: Limited coverage

MODIS

- Applications
  - Terminus position mapping
  - Snow equilibrium line mapping
  - Albedo
  - Water quality
  - Regional land cover
- Multispectral
- Frequent revisit interval (daily Aqua and Terra)
- Data are free
- Derived products
  - Multi-day composites are ideal for Bering weather conditions
  - Over 40 products, including albedo

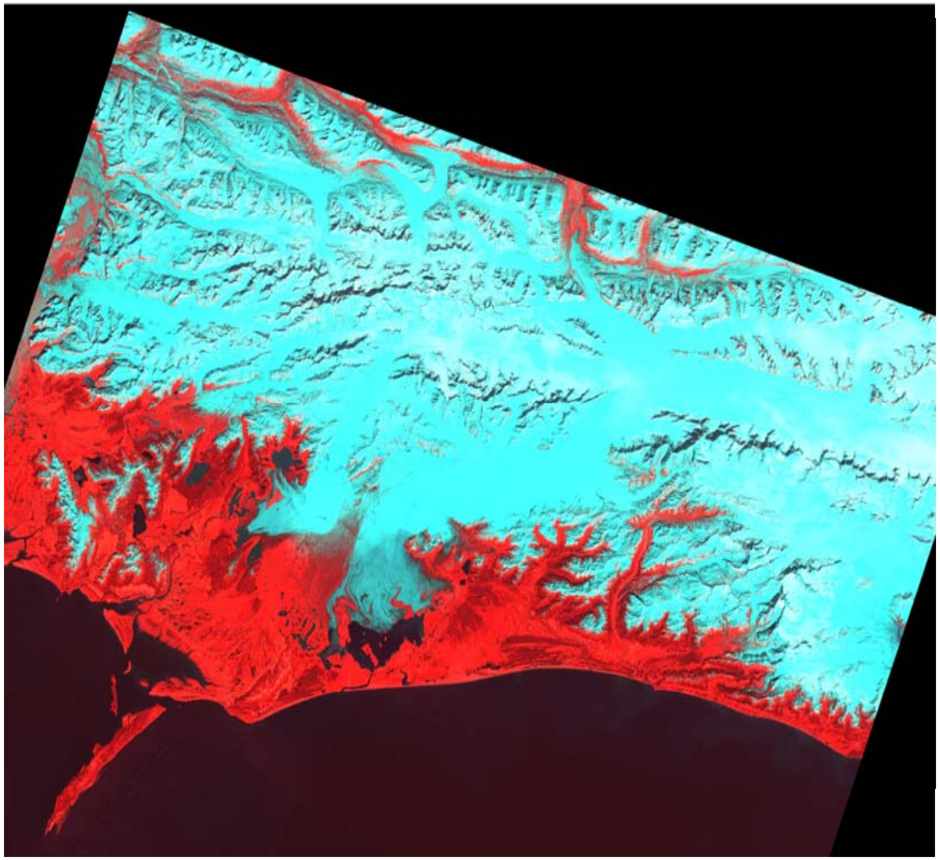


ASTER

- Applications:
  - DEM
  - Terminus position mapping
  - Snow equilibrium line mapping
  - Land cover mapping
- Image acquisition has to be tasked
- 16-day repeat interval
- High cloud cover at the Bering Glacier make clear images rare
- Landsat replacement?

Landsat

- Applications:
  - Terminus position mapping
  - Snow equilibrium line mapping
  - Land cover mapping
- Multispectral
- Well documented in published literature
- 16-day repeat interval
- High cloud cover at the Bering Glacier make clear images rare
- Nearing end of sensor life

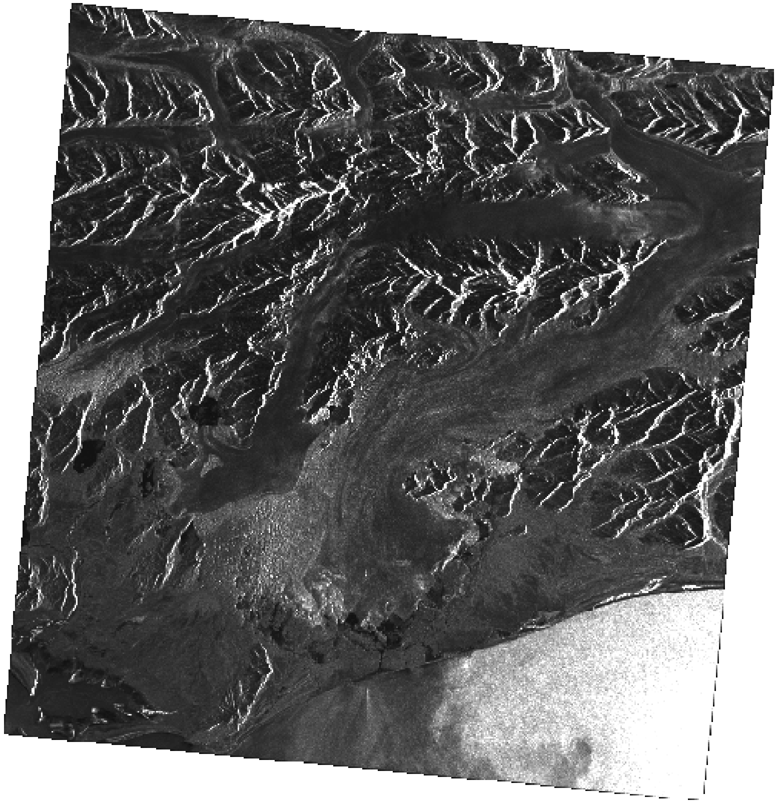


QuickBird/Ikonos/OrbView

- Applications:
  - Ice berg monitoring
  - Potential seal monitoring
  - Water quality (turbidity)
- High resolution
- Frequent revisit interval (1-3 days)
- Costly
- Image acquisition has to be tasked

Bering Glacier Field Camp

Synthetic Aperture Radar (SAR)

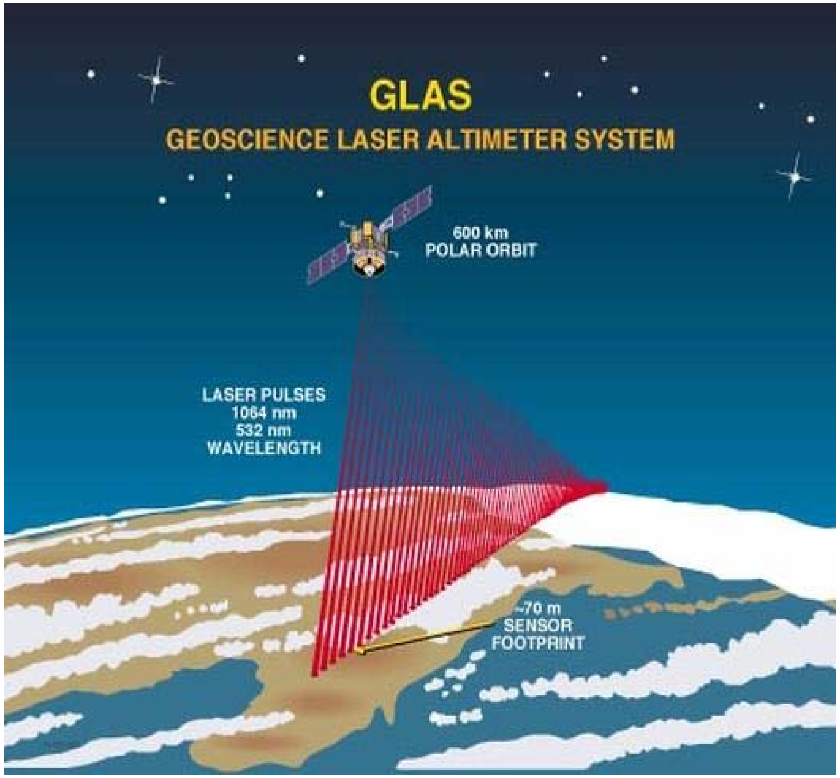


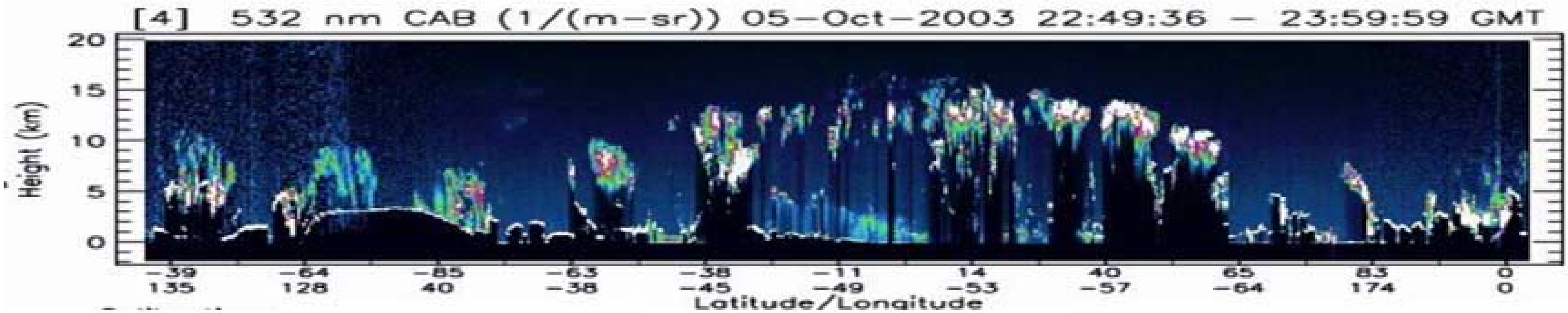
Bering Glacier SAR 2002

- Applications:
  - Terminus position mapping
  - Snow equilibrium line mapping
  - Ice berg and glacier calving monitoring/mapping
- Imagery collection is independent of cloud and weather conditions
- Bering Glacier imagery is collected several times a month

ICESat/GLAS

- Applications:
  - Highly accurate topography
  - Ablation
  - Sea ice thickness
- Geoscience Laser Altimeter System (GLAS) – next generation space lidar

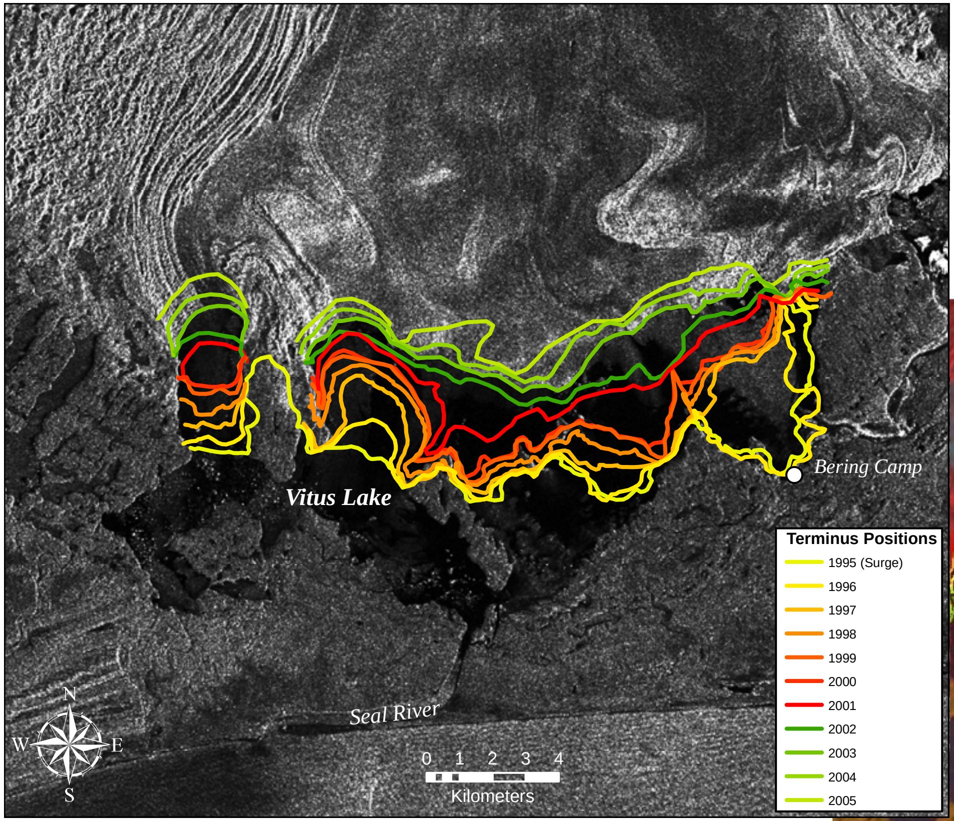




Bering Glacier Remote Sensing Applications

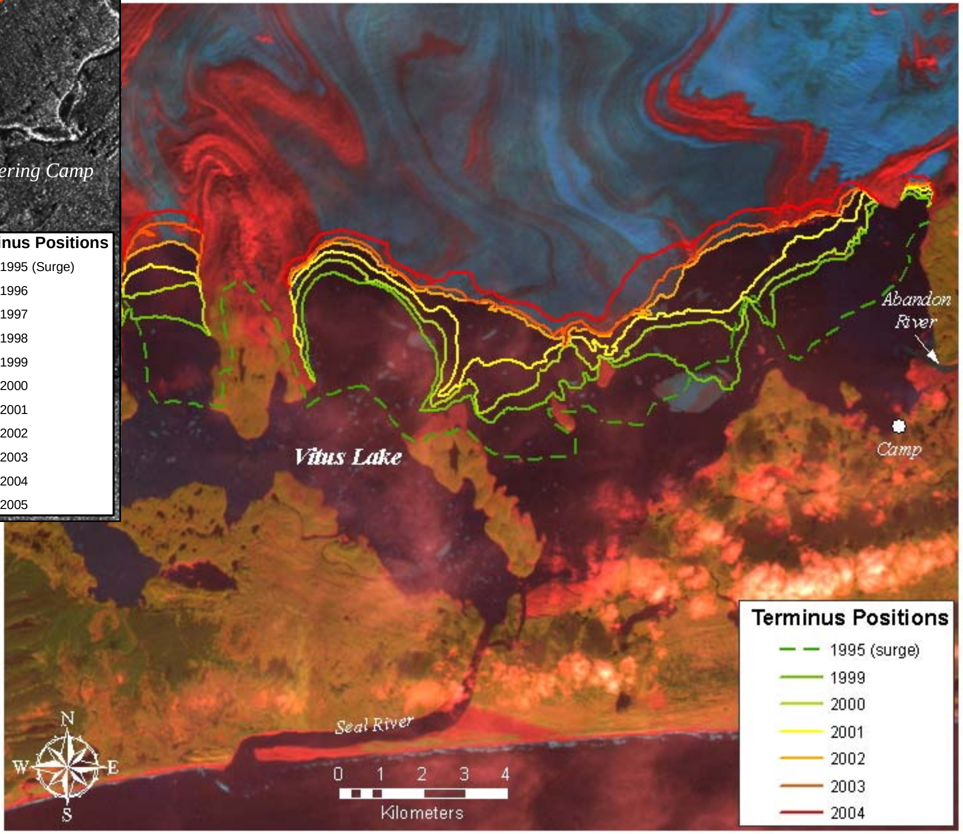
- Glacier terminus locations
- Snow line delineation
- Topography DEMs (change in mass calculation)
- Iceberg surveys
- Seal monitoring
- Glacier calving rates
- Vitus and Berg Lake area analysis (volume with bathymetry)
- Vitus Lake frontal boundaries
- Water quality
- Land cover classification
- Glacier velocity
- Glacier surface features (crevasses, moraines, etc.)

Terminus Mapping



SAR Derived

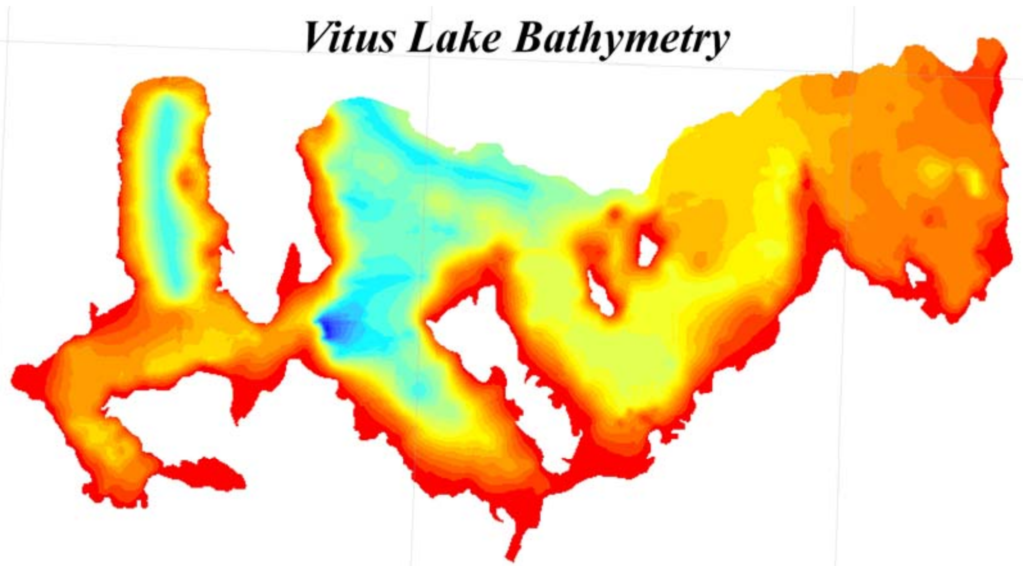
Landsat Derived



Lake Volume Change Analysis

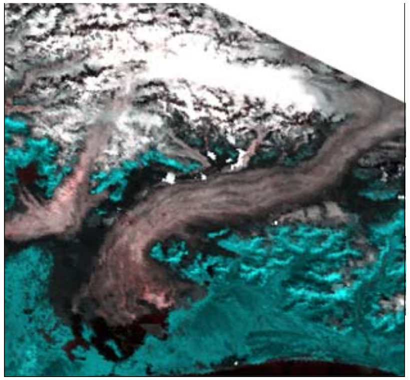
Year	Volume			Area		
	km^3	Percent Change		km^2	Percent Change	
		Annual	*Cumulative*		*Annual*	*Cumulative*
1995	2.6	-	-	58.4	-	-
1999	4.4	67.0	67.0	80.6	38.0	38.0
2000	4.9	12.2	87.3	89.0	10.4	52.4
2001	5.4	10.4	106.8	96.2	8.1	64.7
2002	6.2	14.9	137.5	105.8	9.9	81.1
2003	6.4	4.0	147.0	108.8	2.9	86.3
2004	6.9	6.5	163.1	114.0	4.8	95.3

- Derived using Landsat data and bathymetric measurements
- GIS analysis



Snow Equilibrium Line Mapping

- Difficult to map snow equilibrium using any one sensor data
- A data fusion product (ex. SAR/MODIS) facilitates discernment of snow line



MODIS

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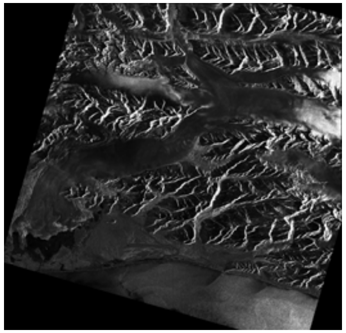

SAR

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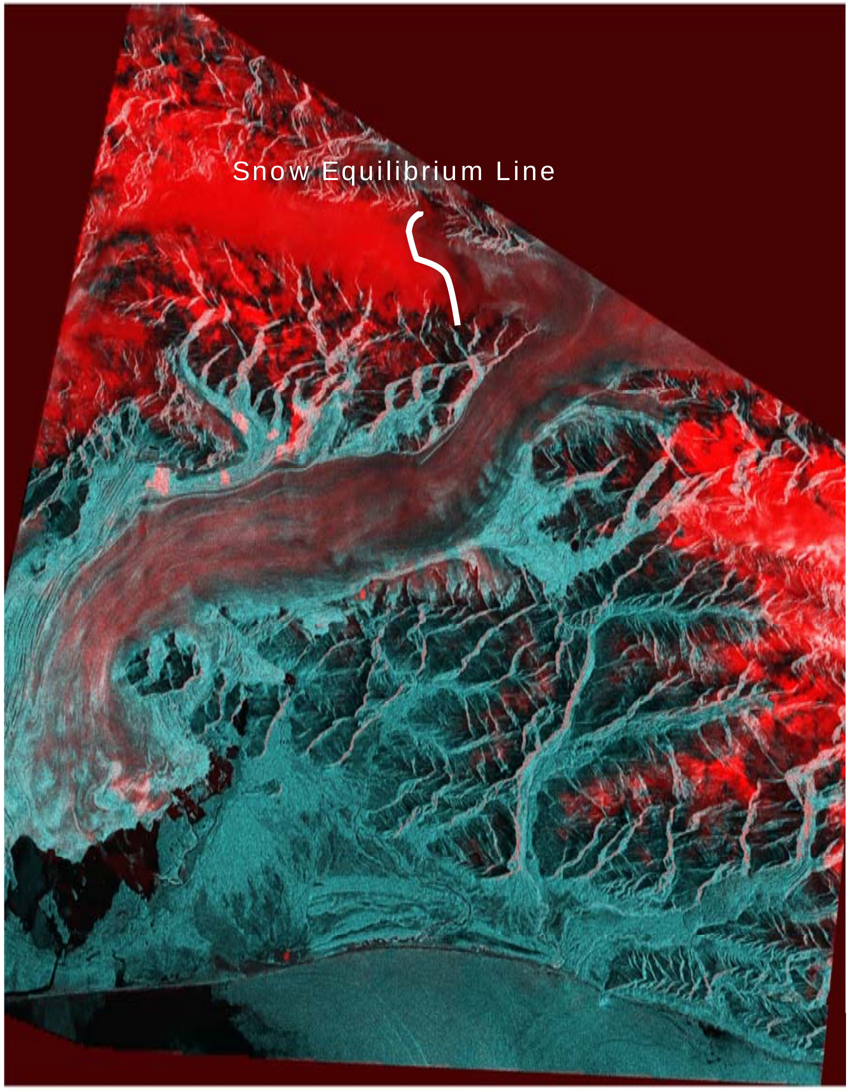
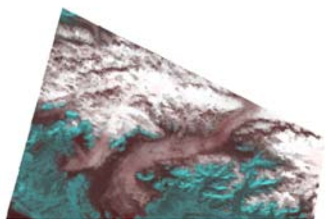
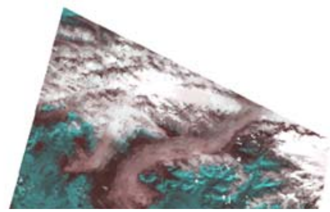


Time Series Environmental Monitoring

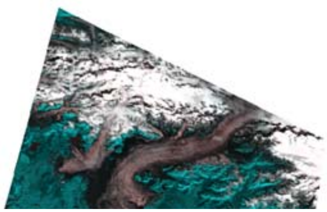
MODIS Annual Comparison (2000-2005)



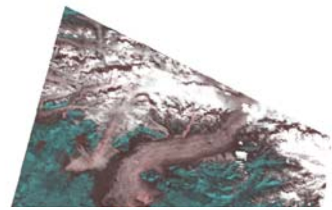
August 21-28 2000



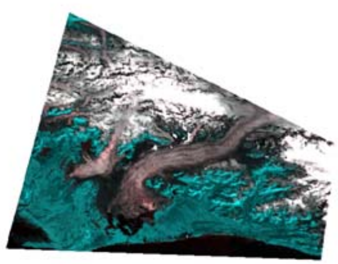
August 21-28 2001



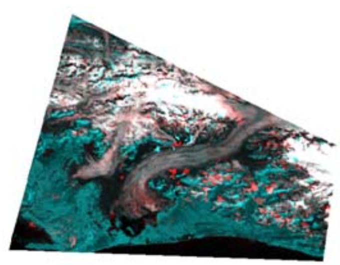
August 21-28 2002



August 21-28 2003

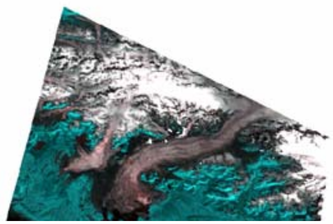


August 21-28 2004

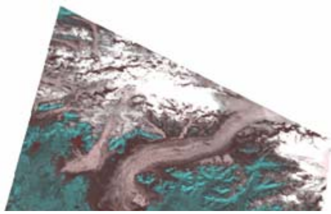


August 21-28 2005

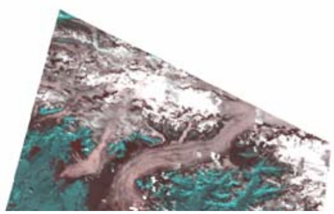
MODIS Inter-Annual Comparison (2004)



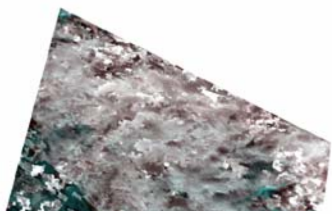
August 21-28



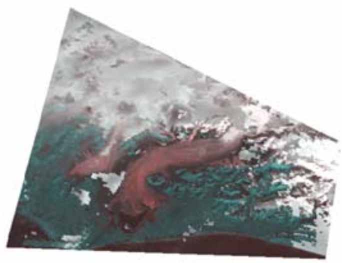
August 29 - September 5



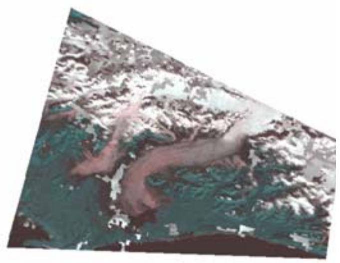
September 6 -13



September 14 -21



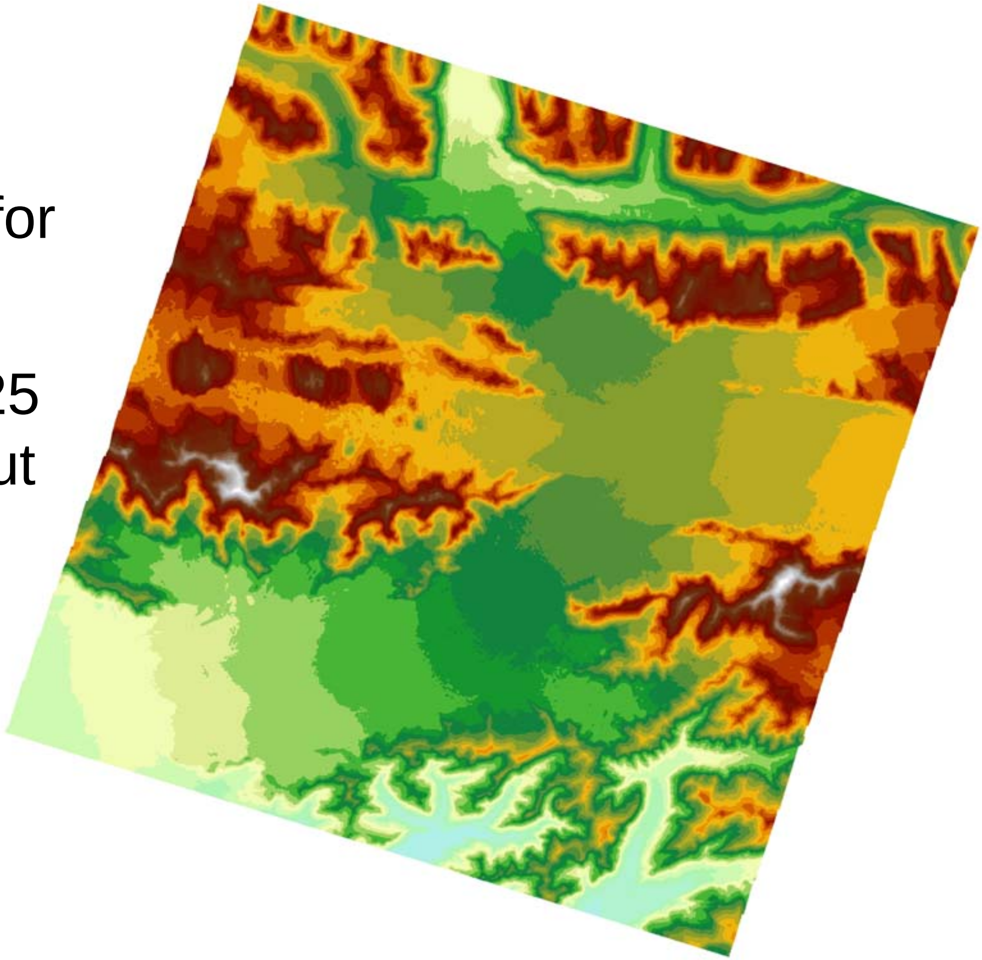
September 22 -29



September 30 - October 7

DEM (Digital Elevation Model)

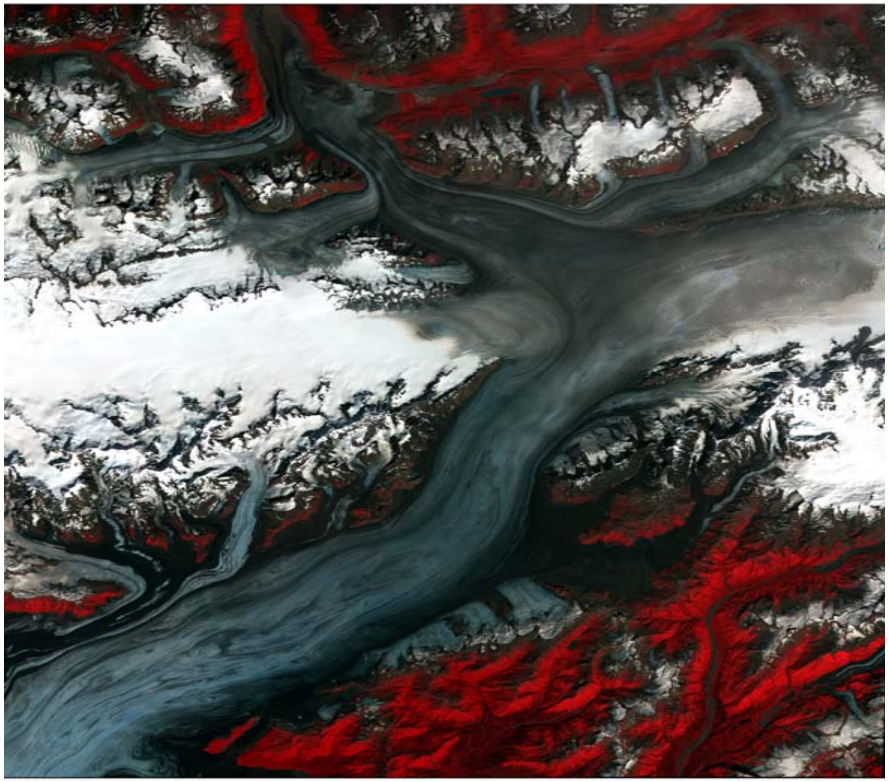
- ASTER forward and backward looking bands provide data necessary for DEM creation
- Accurate to better than 25 meters RMSE xyz without ground control points



ASTER Bering Glacier DEM
(created using SILCAST)

DEM

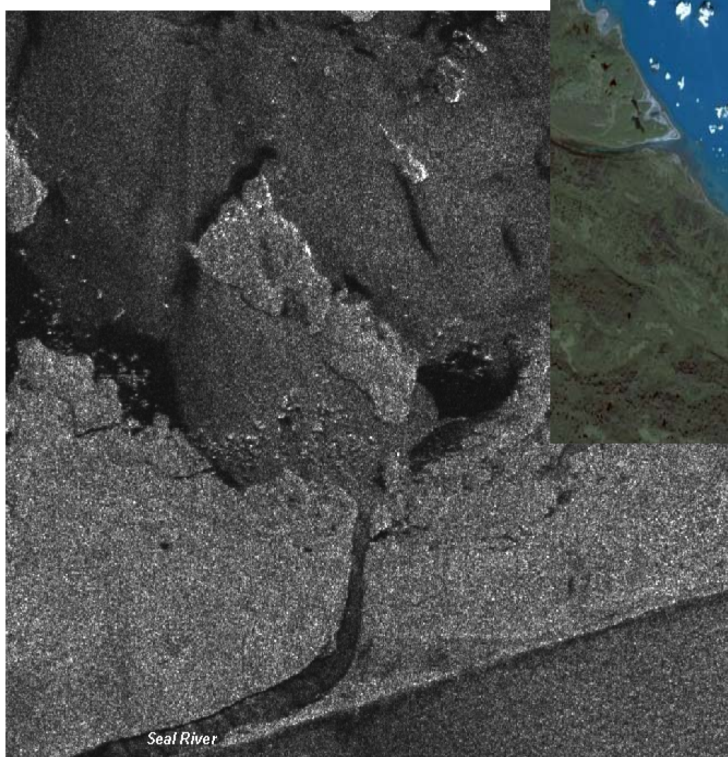
- Bering DEM created from ASTER data
- Red markers indicate location of Glacier Ablation Sensors



Iceberg Detection

- Determine iceberg densities and relative size as a function of time

QuickBird



SAR

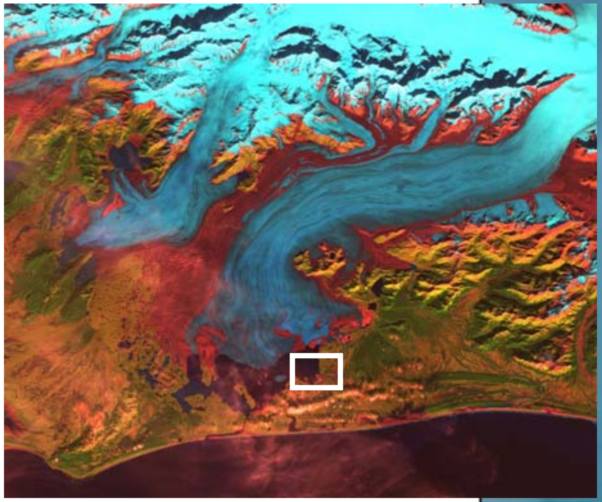
Seal Monitoring

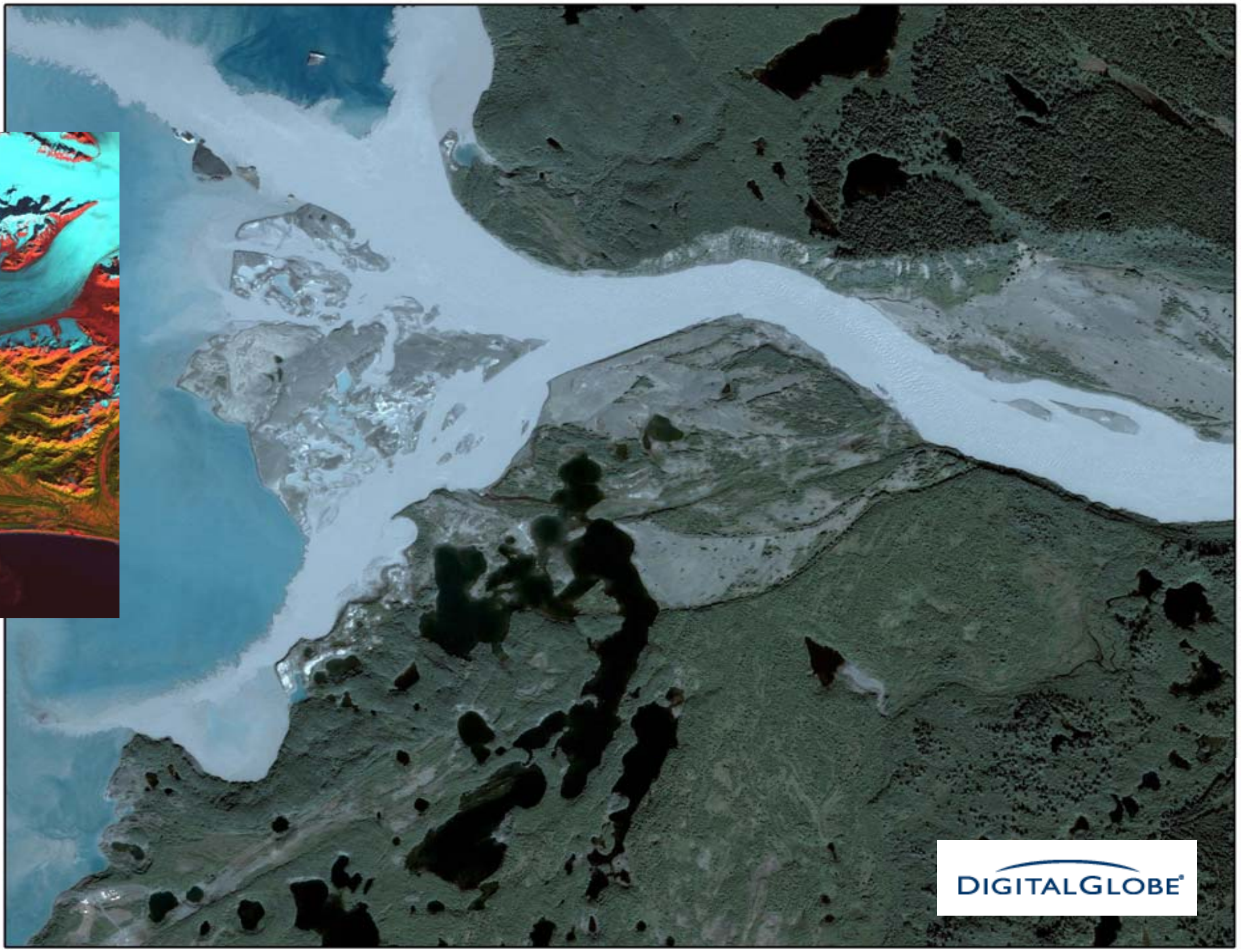
QuickBird

Aerial helicopter view

Water Quality

- Sediment loading and turbidity measurements





ALTARUM

Bering Remote Sensing Studies Next Steps

USGS science for a changing world

- Complete snow equilibrium line analysis
- Generate DEMs of Bering Glacier System using SAR, ASTER, and ICESAT data
- Generate an updated land cover map for the Bering Glacier region using e-Cognition
- Acquire ICESAT, ASTER, MODIS, and additional SAR data sets
- Quantify iceberg density using a combination of EO and SAR sensors
- Explore the use of MODIS for water quality assessment of Vitus Lake

Conclusions

- Remote sensing technologies, when combined with in situ field measurements and geographic information systems (GIS), has proven to be a powerful tool for environmental monitoring at the Bering Glacier
- Sensors have their strengths and weaknesses, and no one sensor can be used for every aspect of monitoring due to:
  - Spatial resolution
  - Spectral resolution
  - Temporal resolution
  - Atmospheric conditions
- Combining data derived from different sensors and with field data can be a powerful tool for environmental monitoring at the Bering Glacier
  - SAR/ MODIS data fusion

References

- Konig, Max, Jan-Gunnar Winther, Elisabth Isaksson. Measuring snow and glacier properties from satellite. American Geophysical Union, Review of Geophysics. 39:1, Pp 1-27.
- Winther, Jan-Gunnar, Robert Bindschadler, Max Konig, Dieter Scherer. Remote Sensing of Glaciers and Ice Sheets. Remote Sensing in Northern Hydrology: Measuring Environmental Change, Geophysical Monograph Series, American Geophysical Union. Pp 39-62.
- Josberger, E.G., Shuchman, R.A., Meadows, G.A., Savage, S. and Payne, J., Hydrography and Circulation of Ice-Marginal Lakes at Bering Glacier, Alaska. in press, Arctic, Antarctic and Alpine Research.

Need More ?

The Bering Glacier Integrated Science Program provides opportunity for scientists from around the world to expand knowledge in a setting that brings together life and physical science disciplines to understand the dynamic processes of this unique environment.

For More Information

www.beringglacier.org