

Unlocking global archives of historical satellite imagery to enable long-term quantitative change detection

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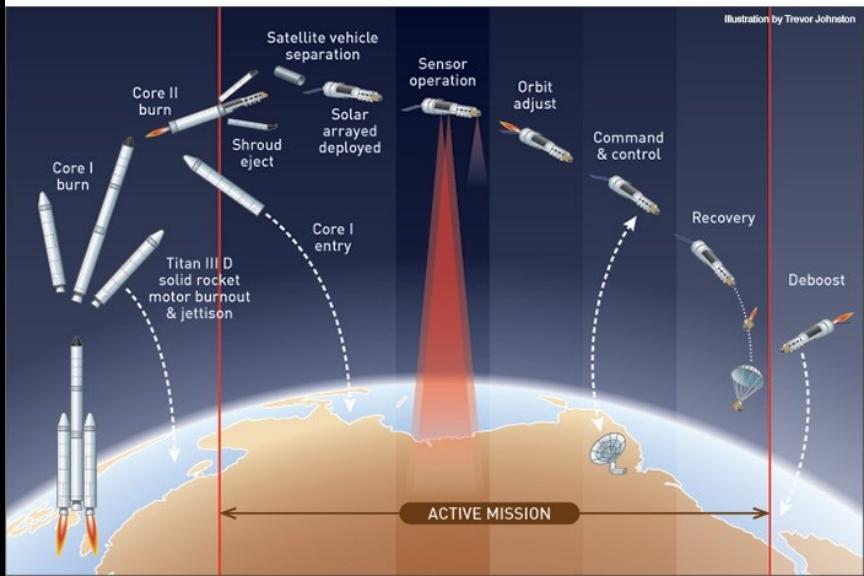
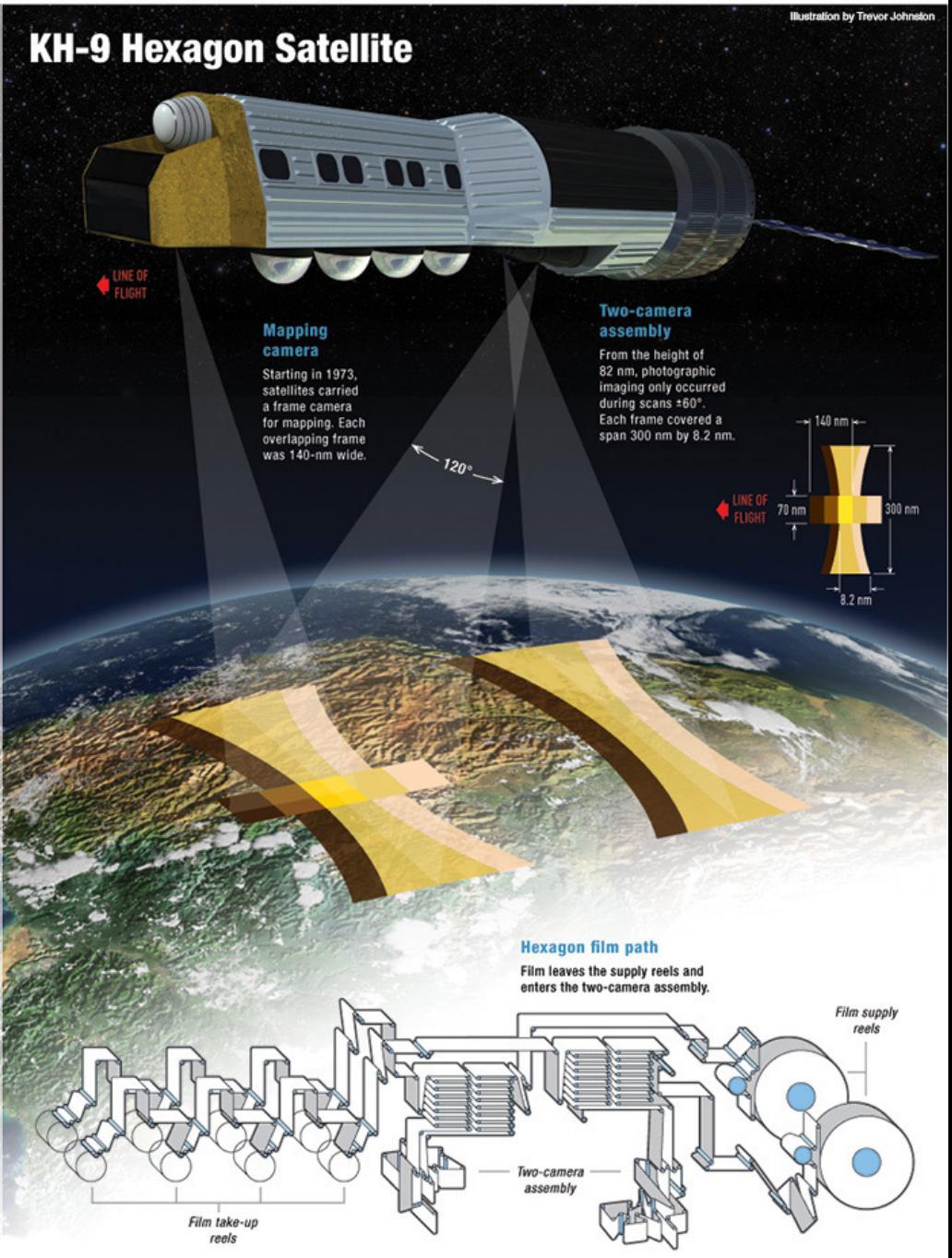
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Declassified Stereo Imagery

- Top secret U.S. satellite reconnaissance missions
 - 1960s to 1980s
 - Launches every ~3-6 months, mission duration ~weeks to ~6 months
 - Global coverage - most images collected over cold-war era adversaries (USSR, China)
- Recovered film (6-9" wide, up to 40 miles of film on board)
- Best image quality and coverage
 - Corona KH-4A/4B (1963-1972)
 - Panoramic stereo (~1-2 m)
 - Hexagon KH-9 (1971-1984)
 - Panoramic stereo, optical bar cameras (~0.3-0.4 m)
 - Terrain mapping camera (~5-10 m)
- Image availability:
 - 3 releases: 1996, 2003, 2011
 - USGS EROS has a copy of most film rolls, only U.S., Alaska, and polar regions for Hexagon (scans \$30/frame)
 - National Archives (NARA) has originals with best quality, global coverage (contractor scans at ~\$150/frame, or BYOS)

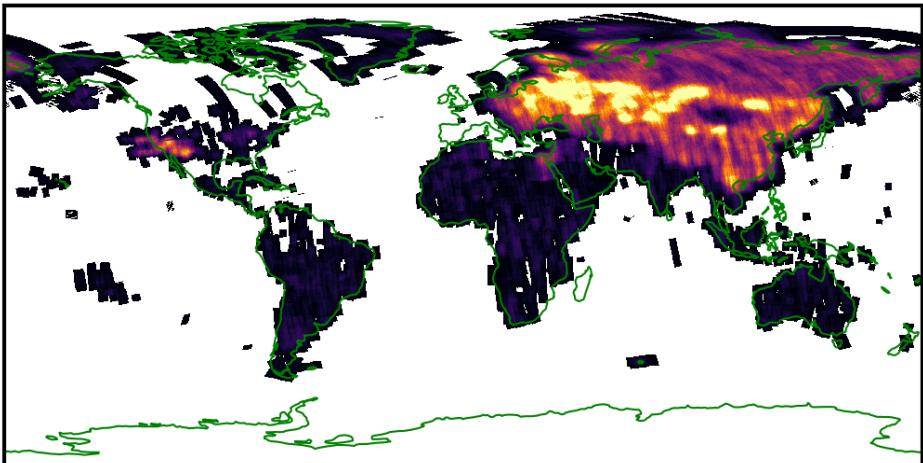
KH-9 Hexagon Satellite



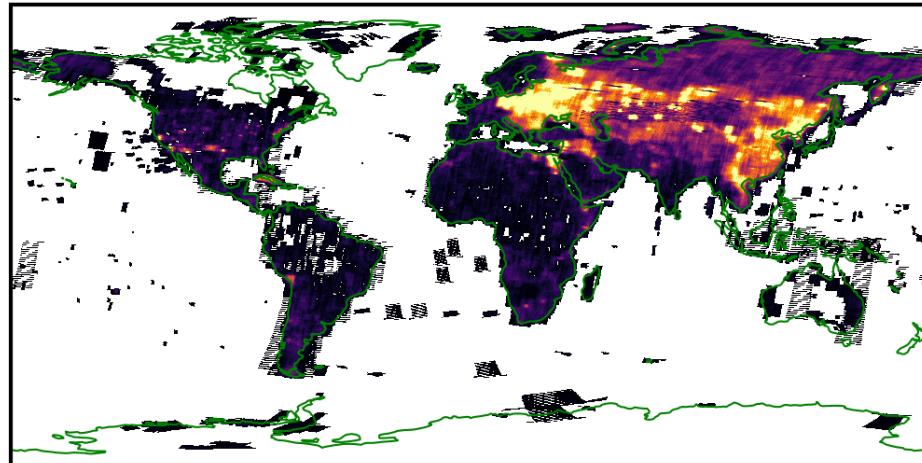
NRO / US Air Force

Declassified stereo coverage (USGS EROS and NARA archives)

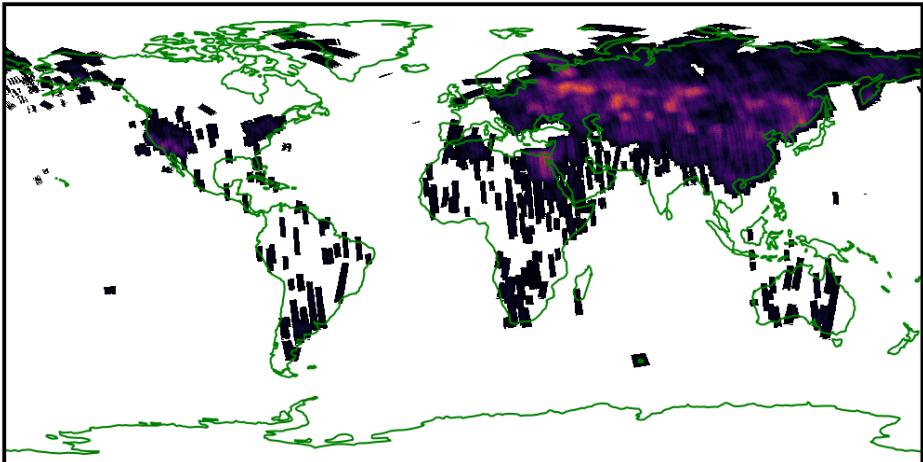
1963-1969_KH4A_CORONA_I_1001-1052



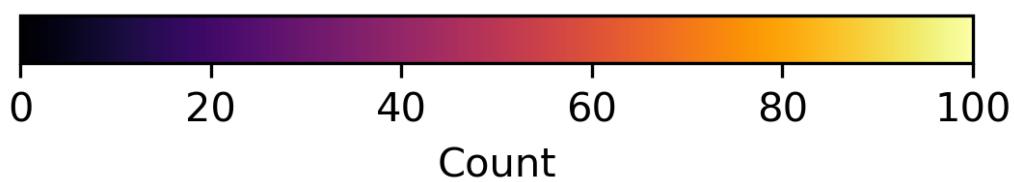
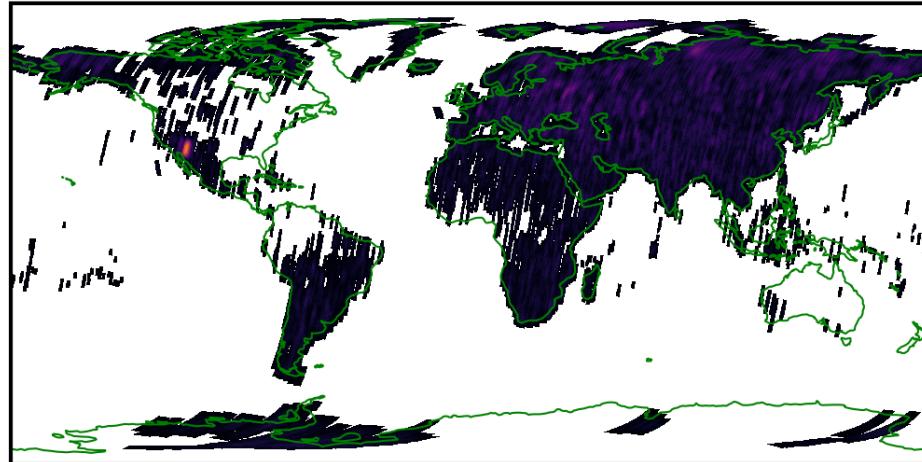
1971-1984_KH9_HEXAGON_III_A_F_1201-1219_NARA



1967-1972_KH4B_CORONA_I_1101-1117



1973-1980_KH9_HEXAGON_II_T_1205-1216

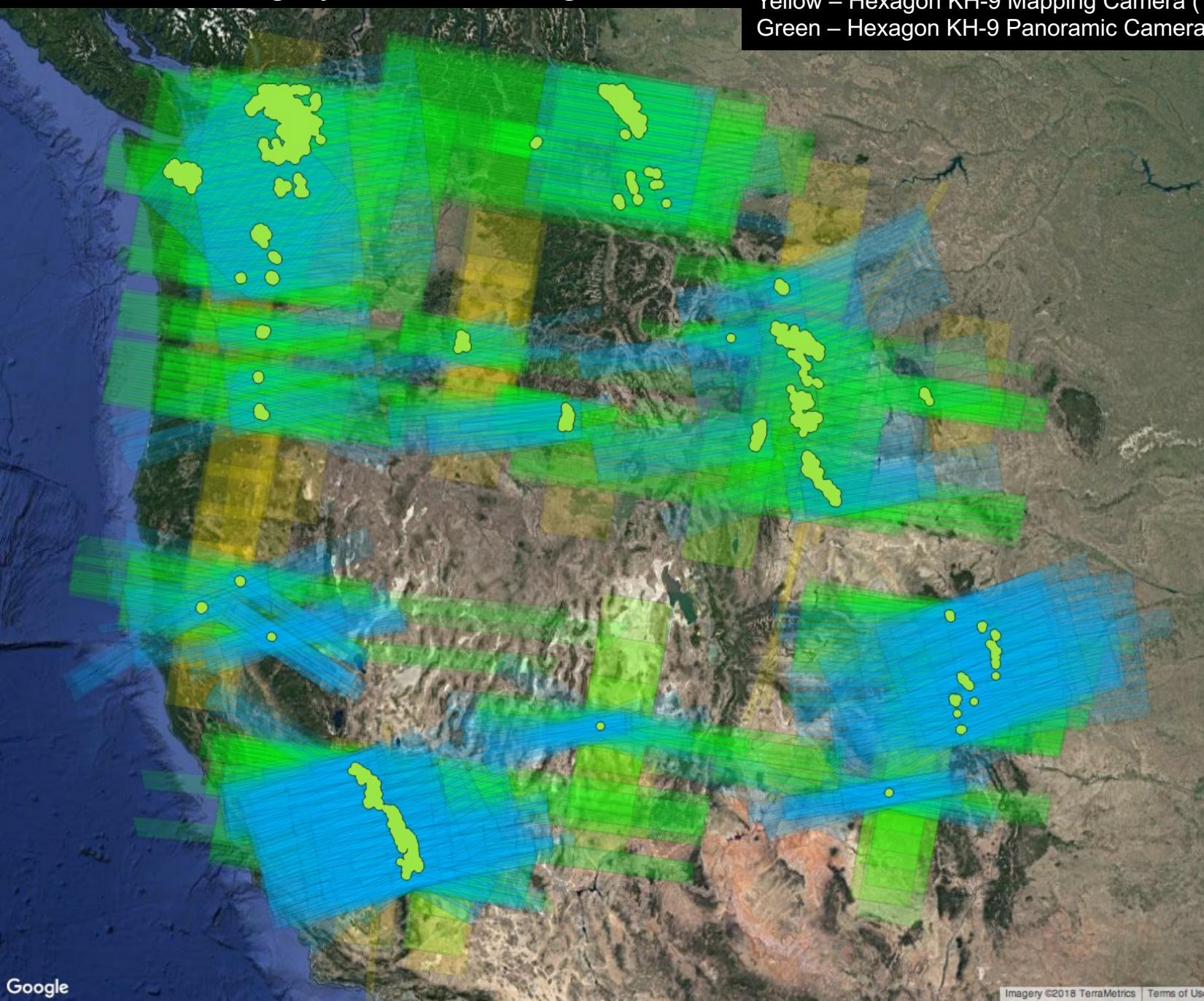


Declassified imagery over CONUS glaciers

Blue – Corona KH-4A/B (1960s)

Yellow – Hexagon KH-9 Mapping Camera (1970s)

Green – Hexagon KH-9 Panoramic Cameras (1970s-1980s)



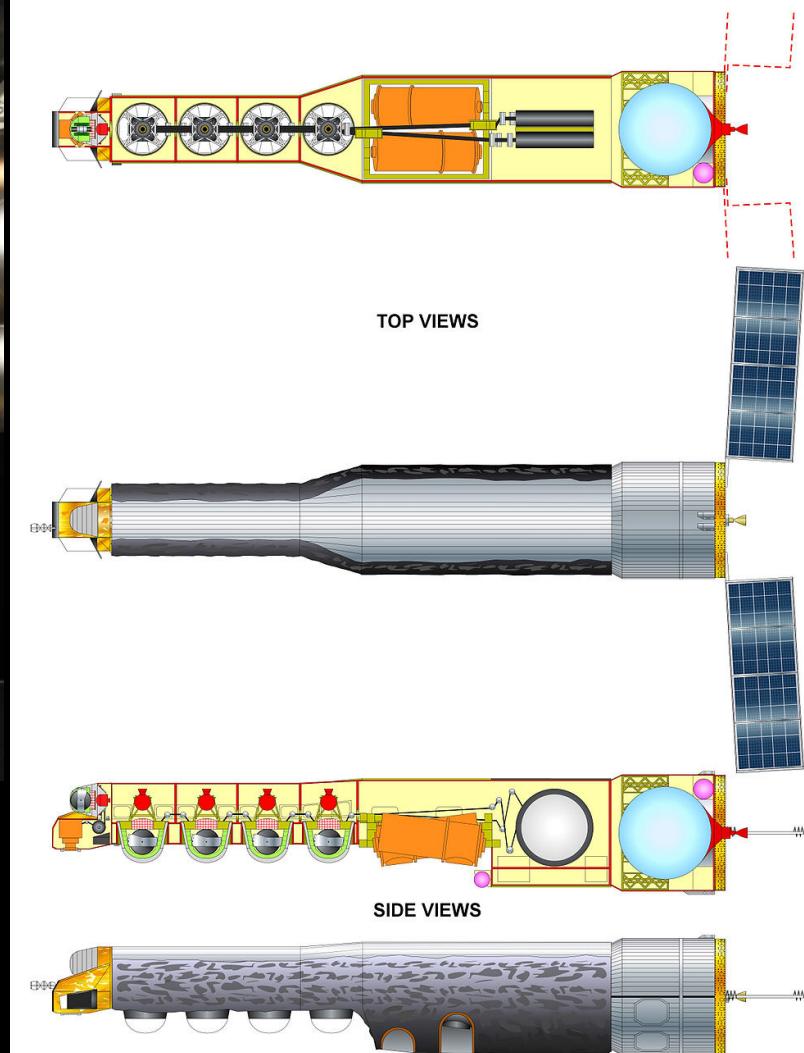
Data processing options

- Most users just look at images
- One-off processing for publications
 - Manual GCP picking
 - Some DEM generation using commercial photogrammetry packages (SOCET SET, LPS eATE)
- Automated approaches for Hexagon Terrain Mapping Camera
 - HEXIMAP
 - JPL
- Preliminary support now in NASA Ames Stereo Pipeline (ASP)
 - Uses available corner coordinates from USGS/NARA (provided by NGA)
 - Uses accurate reference DEM (e.g., SRTM, TanDEM-X) to refine camera models
 - Standard stereo processing core

Hexagon Panoramic Cameras



<https://youtu.be/LQq9KcEw7nk?t=262>



Hexagon Panoramic Cameras

- Rotating “Optical Bar Cameras” (OBC)
- Focal length: 1.524 m (f/3)
- GSD of ~0.3-0.4 m! (~0.7 m @7 micron scan)
- +10° forward, -10° aft-facing stereo cameras
- 6.5” wide film, 6” exposed
- Up to 125” long (120°), sometimes 30 or 60°
- ~30 km along-track, ~360 km across track
- <http://ambivalentengineer.blogspot.com/2013/04/optical-bar-cameras.html>

D3C1217-200742F002

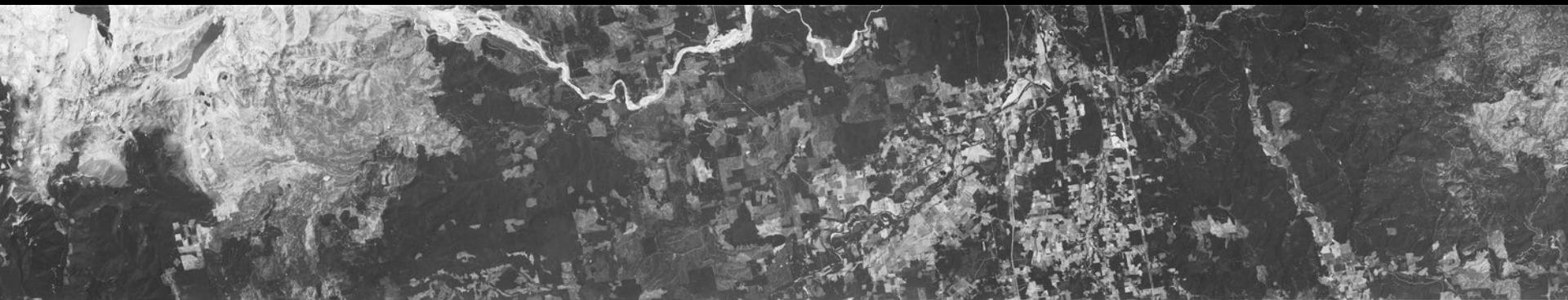
July 22, 1982

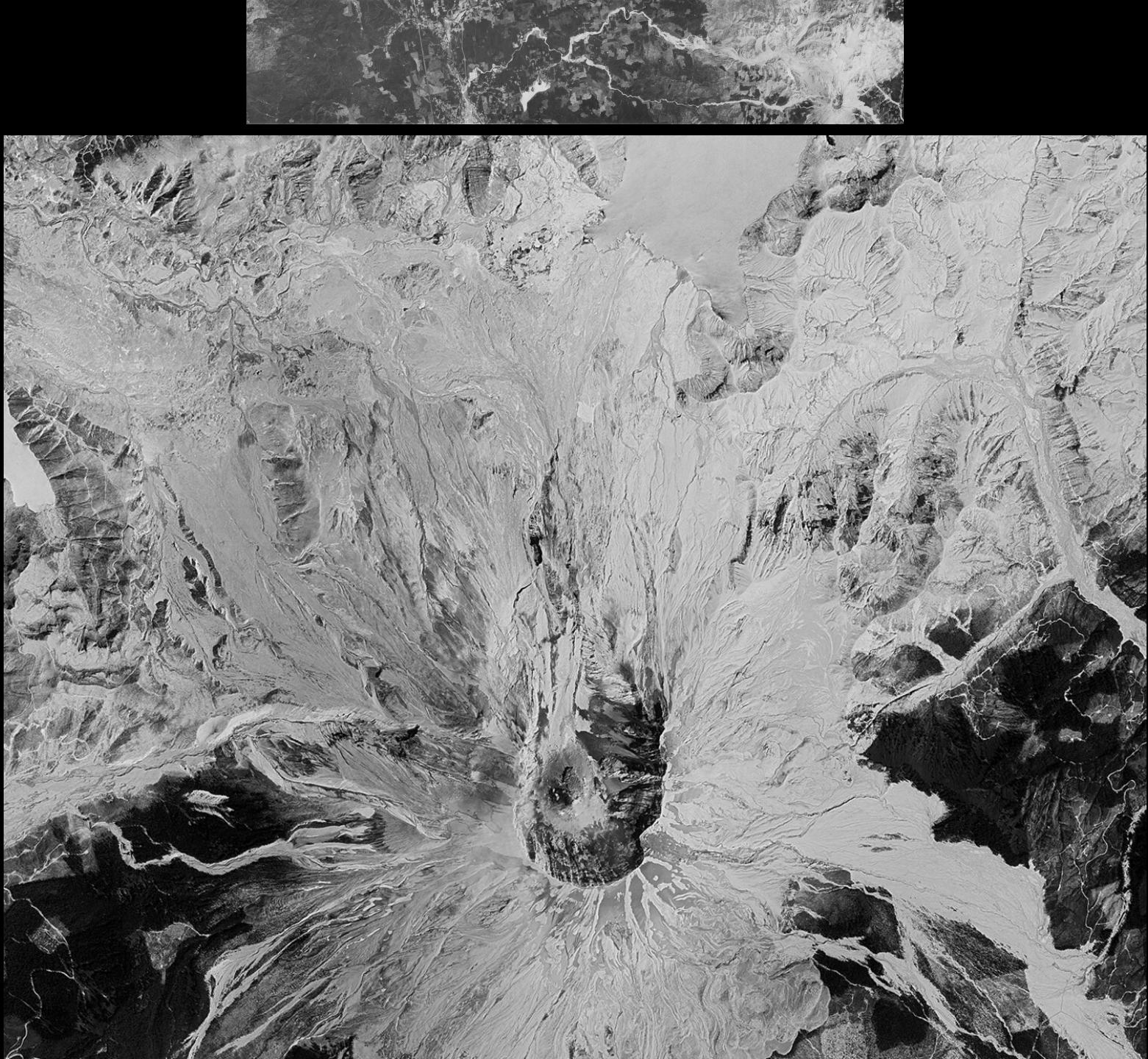
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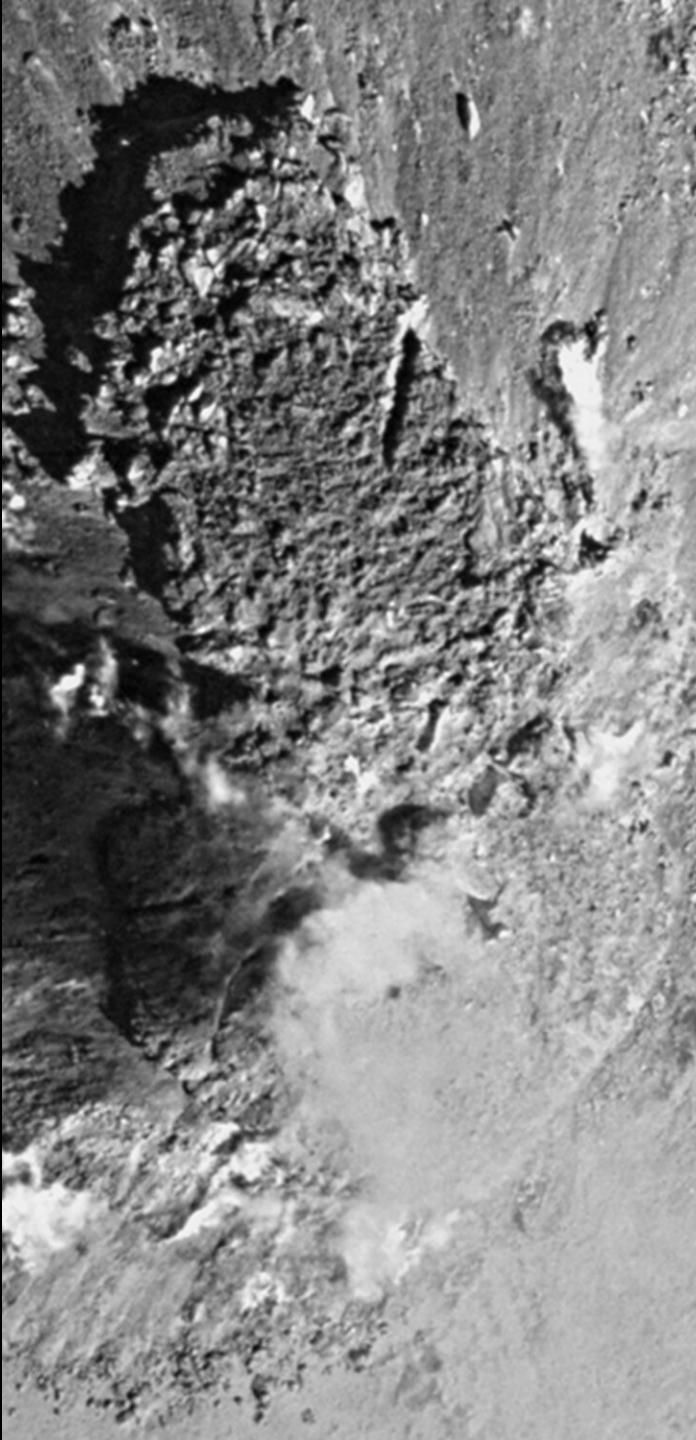


D3C1217-200742A003

Note aft 180° orientation









Can resolve cars (windshields?), dashed lines on road

Hexagon KH-9 Panoramic Stereo, ~0.3 m

Mt. St. Helen's, WA – July 22, 1982 (2.2 years after 1980 eruption)

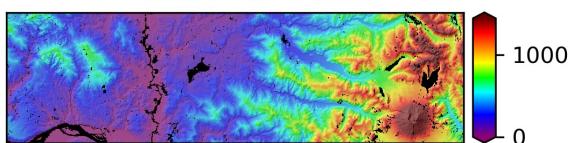
D3C1217-200742F003 (Forward)



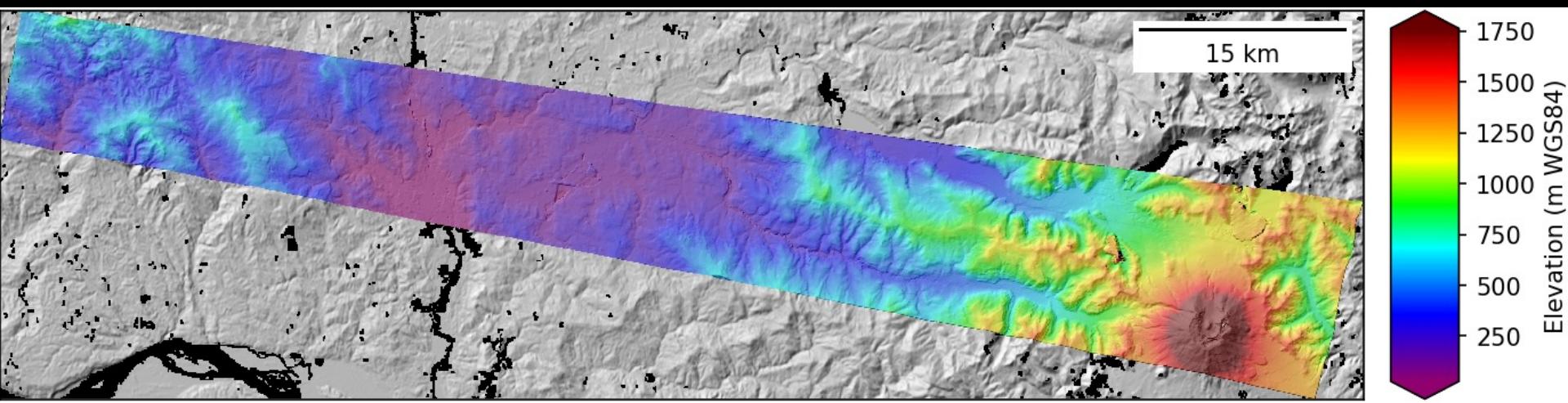
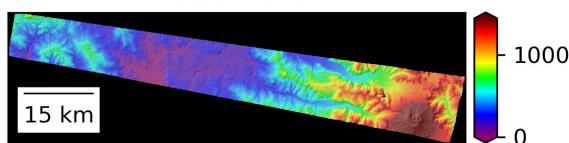
D3C1217-200742A004 (Aft, flipped)



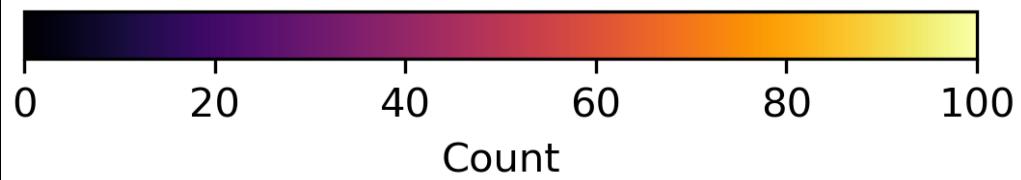
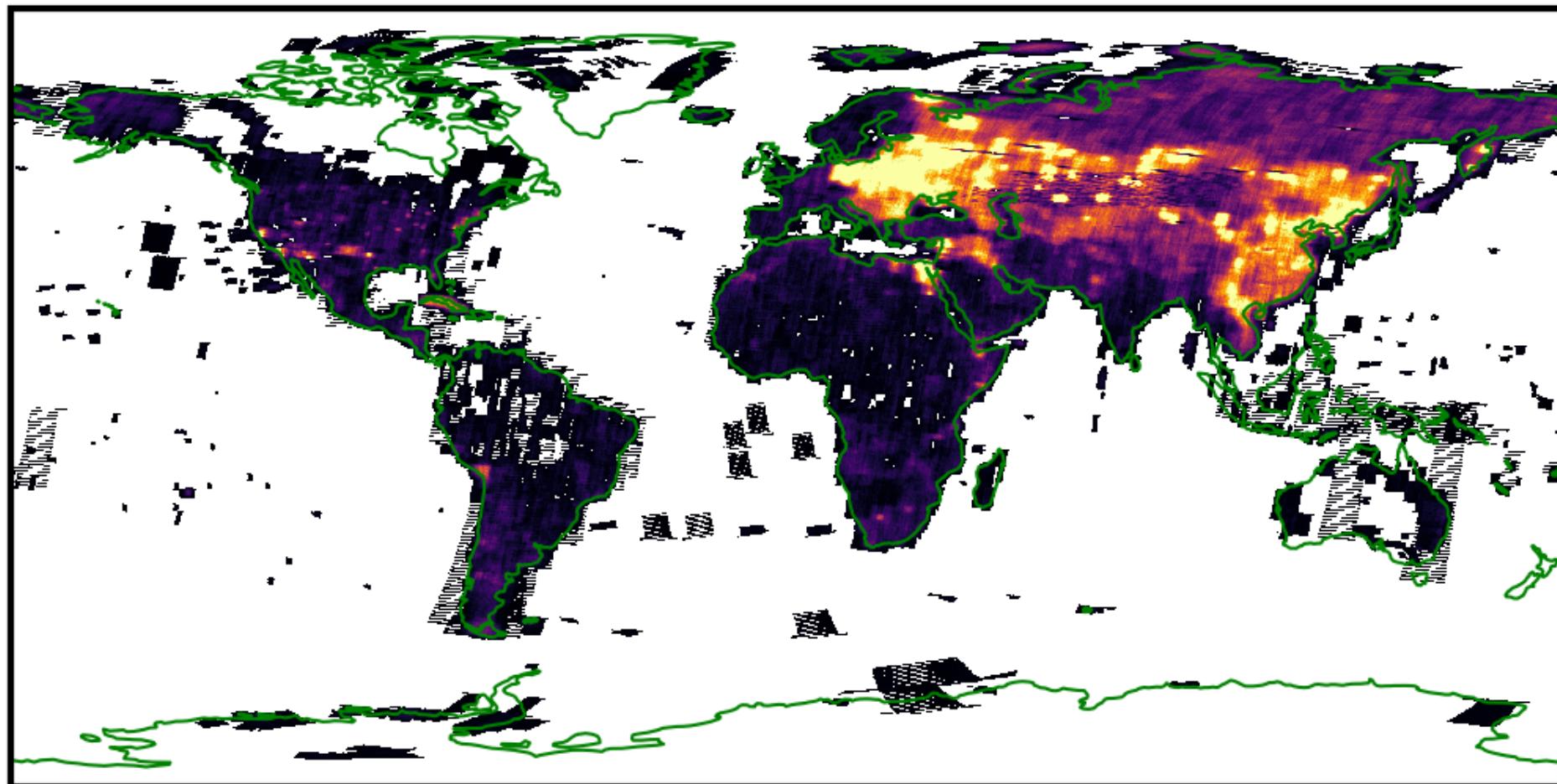
Reference DEM



Source DEM



1971-1984_KH9_HEXAGON_III_A_F_1201-1219_NARA



Corona KH-4B Panoramic Stereo, ~2 m

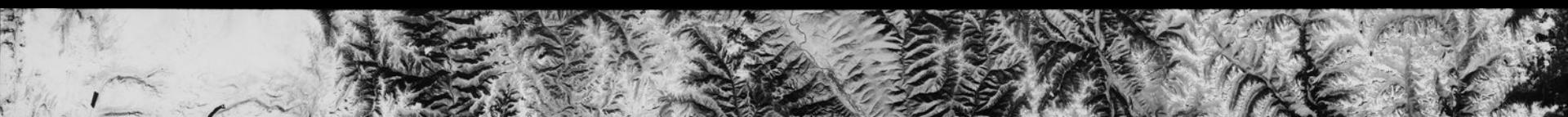
High-mountain Asia - November 19, 1968



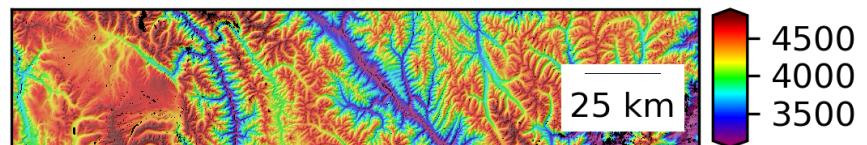
DS1105-2248DF076 (Forward)



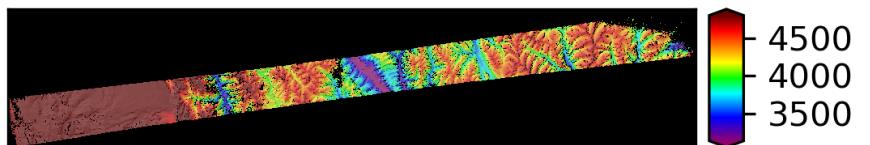
DS1105-2248DA082 (Aft, flipped)



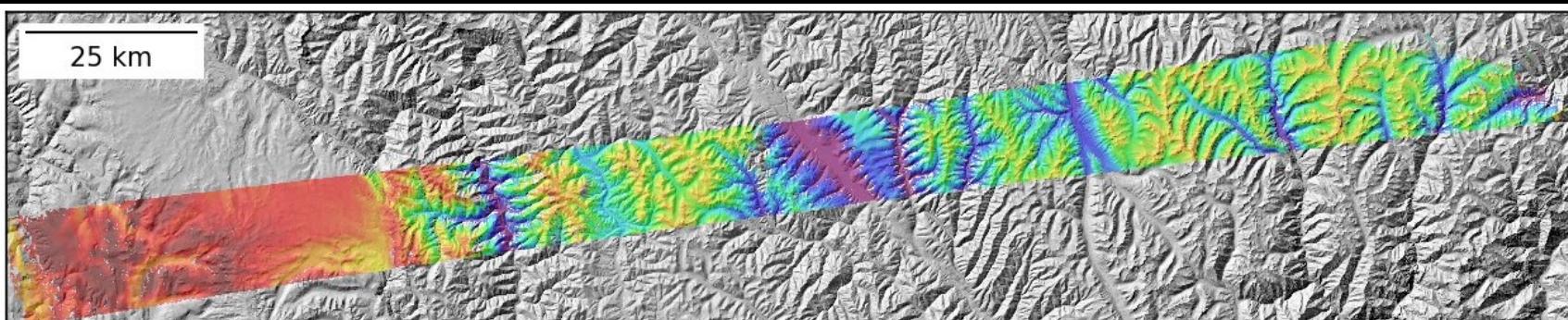
Reference DEM



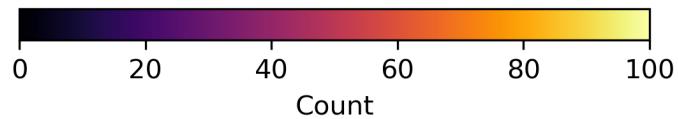
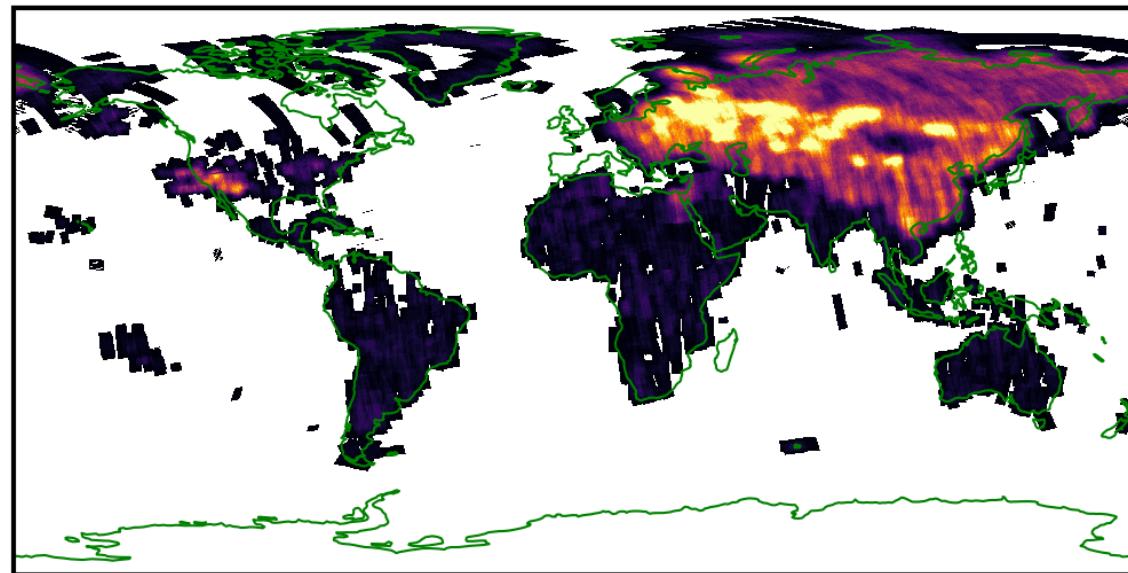
Source DEM



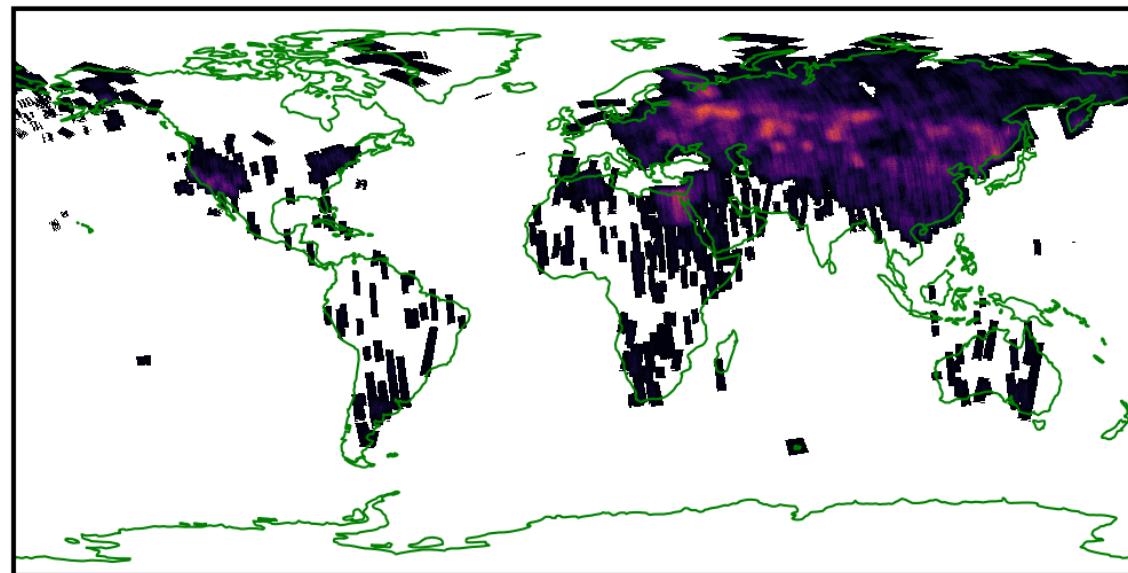
25 km



1963-1969_KH4A_CORONA_I_1001-1052



1967-1972_KH4B_CORONA_I_1101-1117



Hexagon KH-9 Terrain Mapping Camera, ~5-10 m

DZB1206-500062L002001-5001

Western Washington state, July 26, 1973

USGS Scans

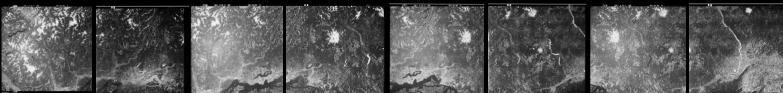
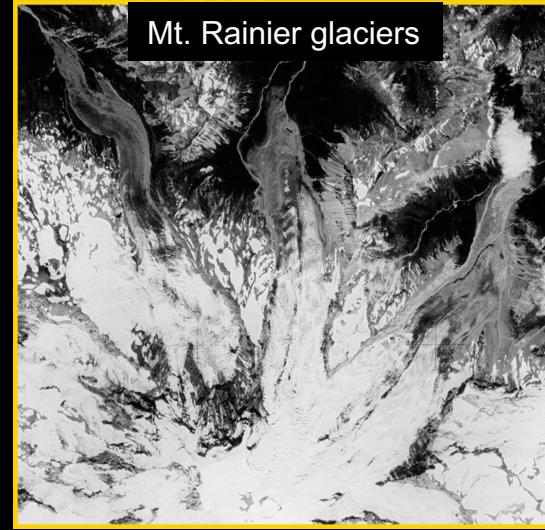
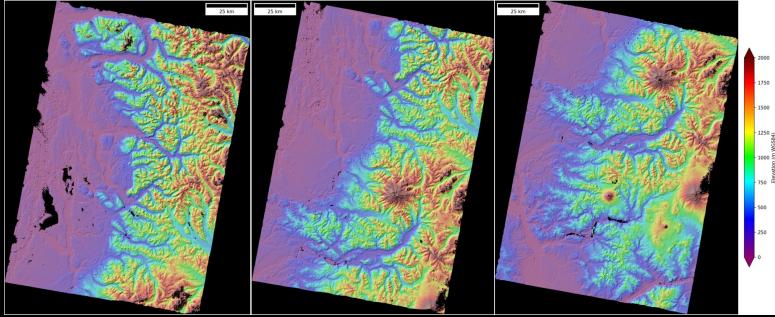


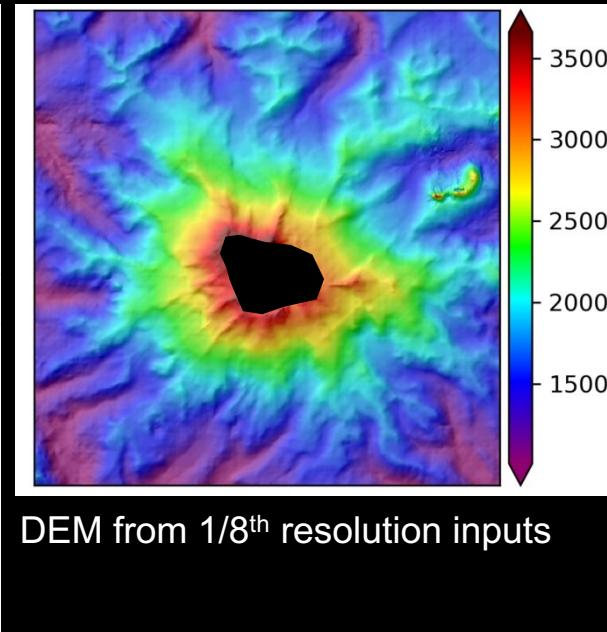
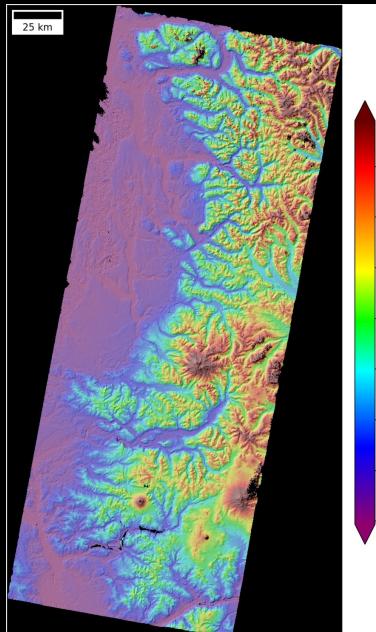
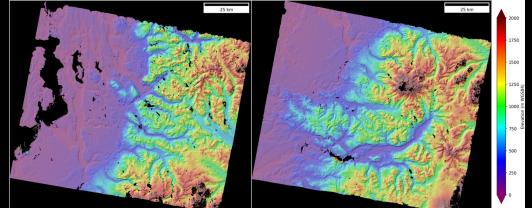
Image pre-processing output



Adjacent frames (~70% overlap)

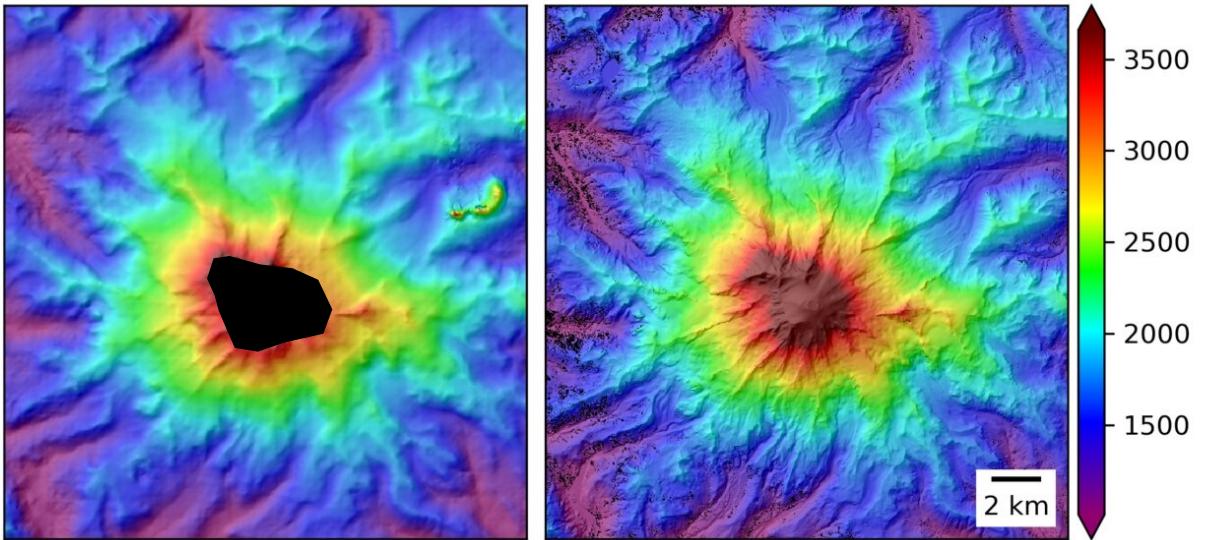


Subadjacent frames (~40% overlap), Larger convergence angle



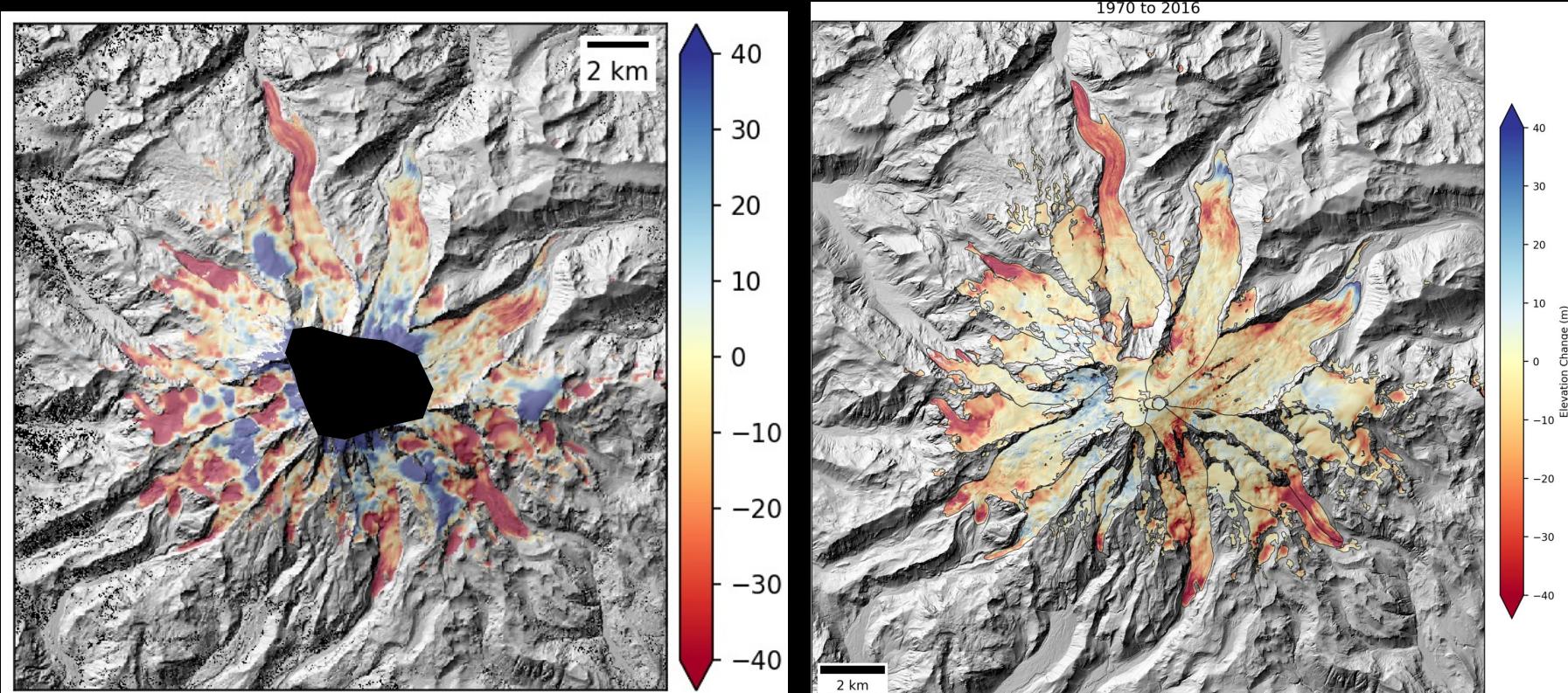
1973

2016

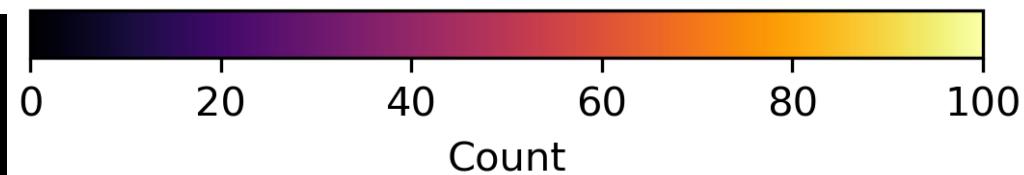
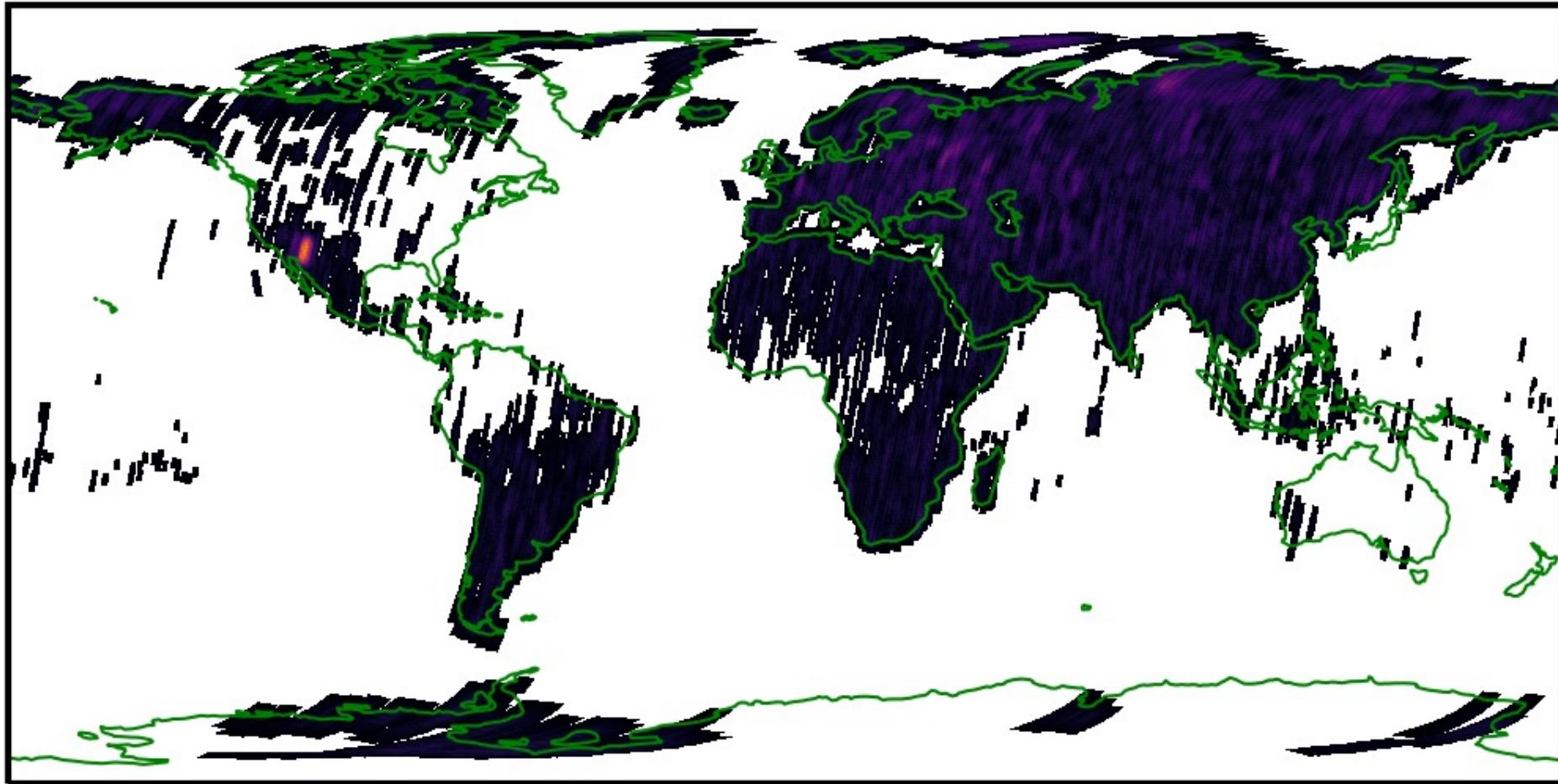


12.5% of native image res
"Old" workflow

Need to rerun with full-res
input images and latest
workflow



1973-1980_KH9_HEXAGON_II_T_1205-1216



ASP Optical Bar Model

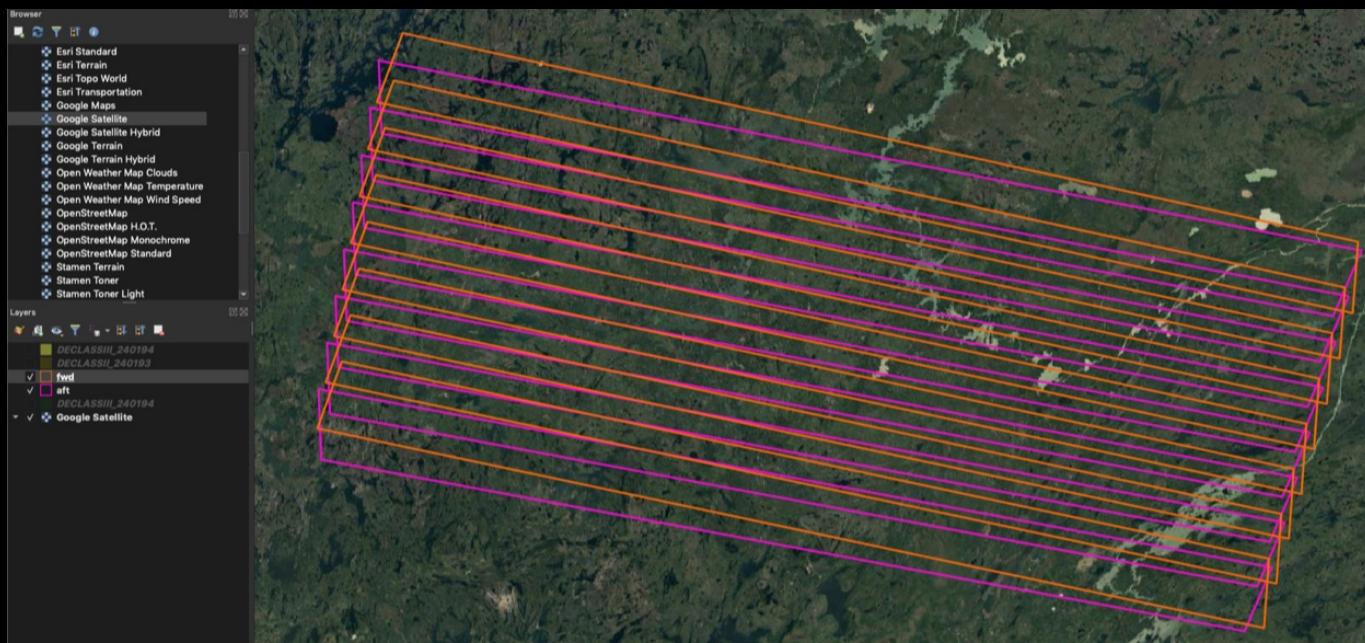
VERSION_4
OPTICAL_BAR
image_size = 14348 2728
image_center = 7174 1364
pitch = 5.599999999999999e-05
f = 1.5
scan_time = 0.6999999999999996
forward_tilt = 0.1745329999999999
iC = -2526122.8583297855 -3790769.7562466105 4693664.9844561201
iR = 0.59421994666808442 -0.44832474123881372 0.66776311771086116 -
0.80429997581583013 -0.33333836224104341 0.49192182830315001
0.0020503376389777173 -0.82939162200471339 -0.55866388236931575
speed = 8000
mean_earth_radius = 6371000
mean_surface_elevation = 0
motion_compensation_factor = 1
scan_dir = left

Challenges

- Processing
 - Each camera on each mission requires calibration
 - Individual frames have unique distortion due film warping, scanning
 - Some calibration reports available at NARA
 - Optimize across all inputs for a single camera
- Scanning
 - USGS quality issues
 - NARA only allows user to “check out” 12 film rolls, can only scan 1 roll at a time
 - ~3-day lag to pull from cold storage
 - Professional scanners are \$10-100K
 - Need higher-level coordination (USGS, Google?)
- Computing
 - Scaling and storage should not be a problem with AWS/GCP
 - Automated quality control
- Classification
 - Many documents are still classified
 - It’s highly likely that many of these problems were solved by NGA/NRO decades ago

Future work

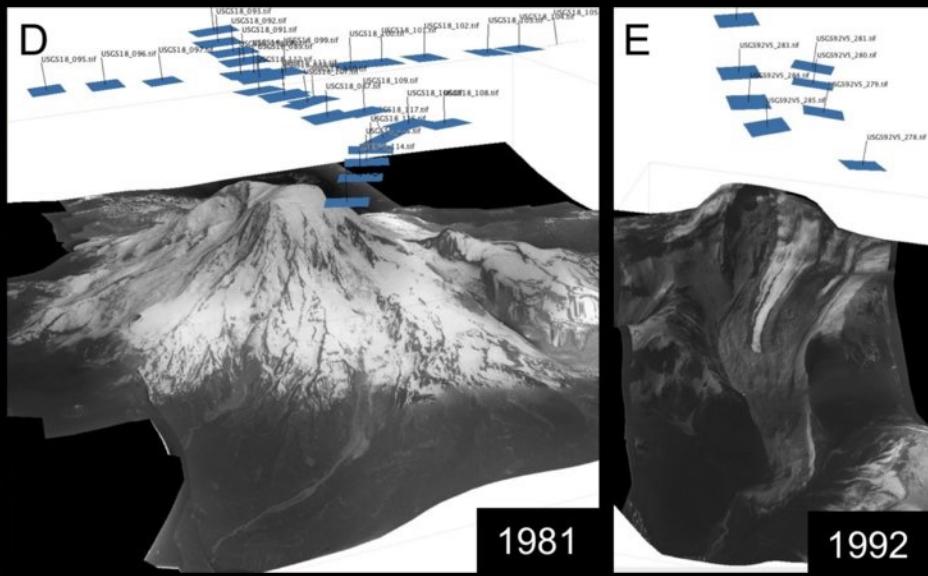
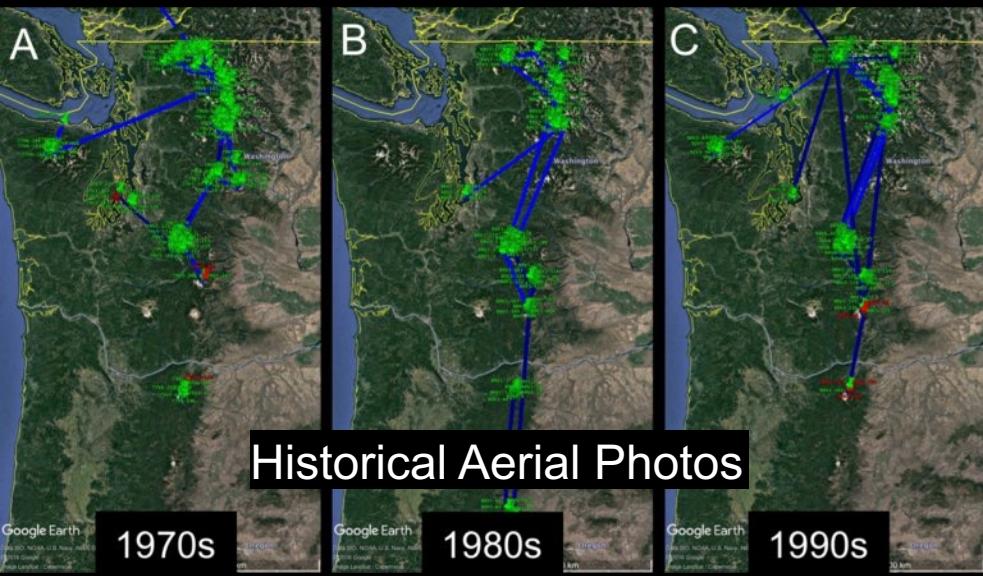
- Implement “rig” constraint for fixed relative offset and orientation between the forward and aft-facing cameras
- Integrate multiple overlapping strips from each camera to refine rotation rates and camera models



Applications

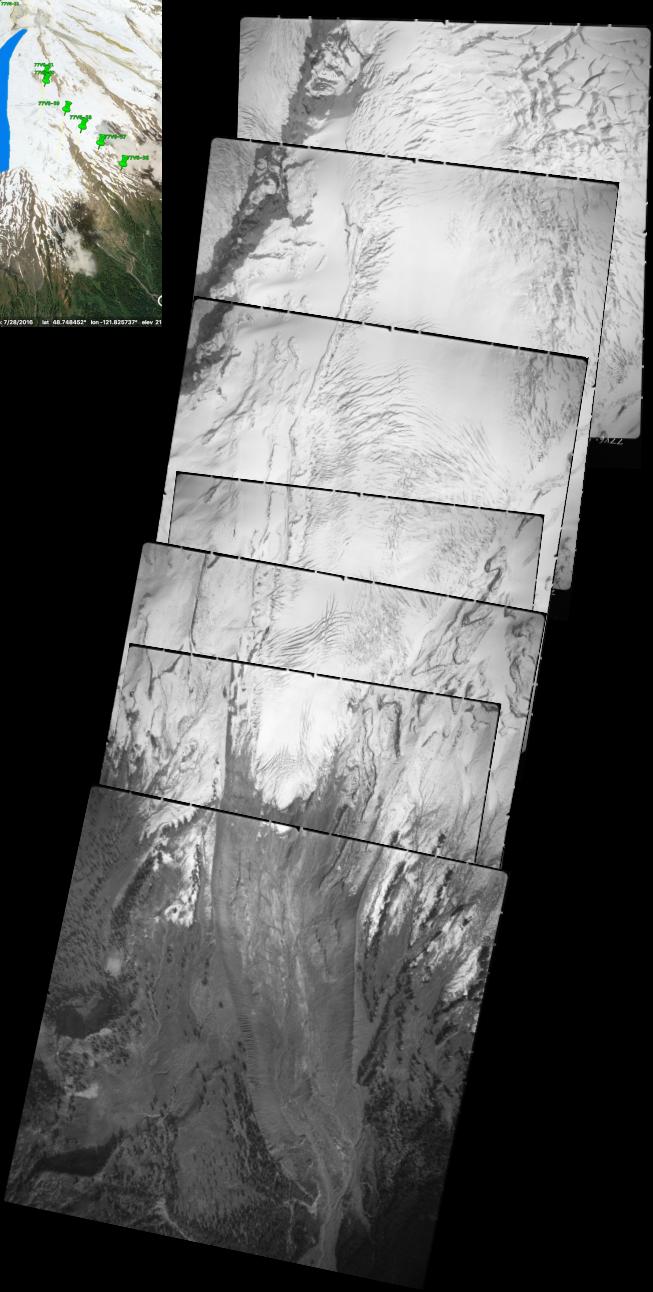
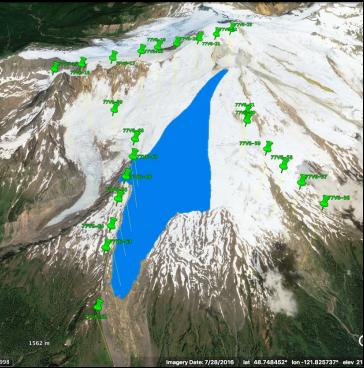
- Annual to decadal elevation change
- Research disciplines:
 - Glaciology
 - Natural hazards (landslides, floods)
 - Archaeology
 - Forestry
 - Coastal erosion
 - Volcanic deformation
 - Earthquake displacements
- Can start by reviewing record of all major geologic events

UW/USGS Digital Glacier Time Machine



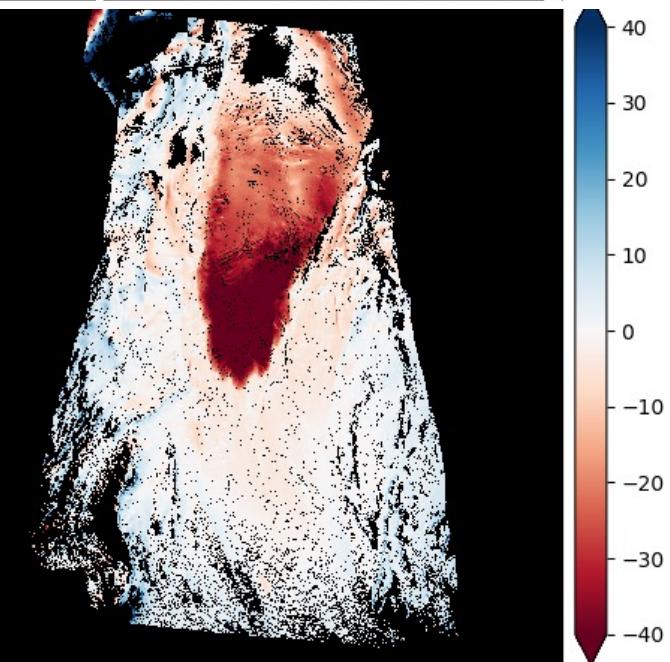
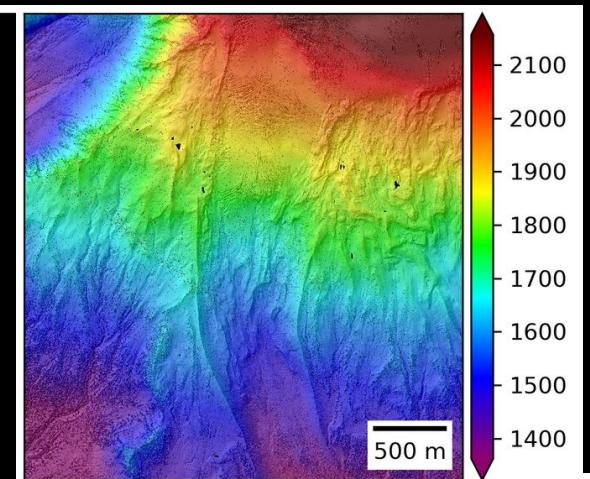
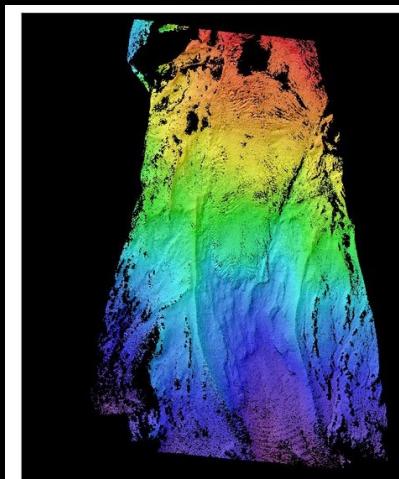
Declassified Spy Satellite Imagery (1960s-1980s)





1977 NAGAP DEM

2015 Baker lidar



F. Knuth