

Introduction to SAR: What is Synthetic Aperture Radar?



Heidi Kristenson, GIS Specialist
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Synthetic Aperture Radar (SAR) Data Acquisition

- Microwave range
 - Longer wavelength than infrared, shorter than radio waves
- Active vs. Passive System
- Side-looking Geometry

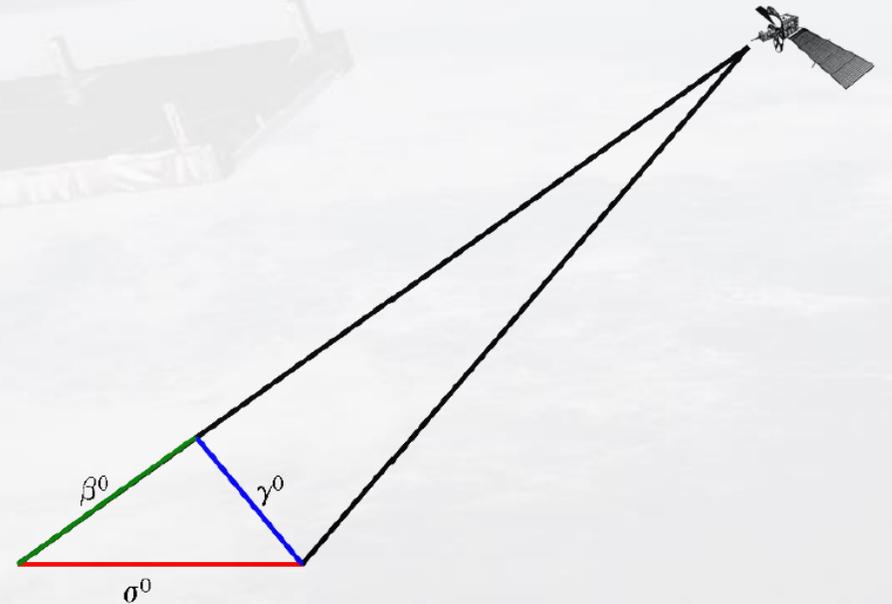
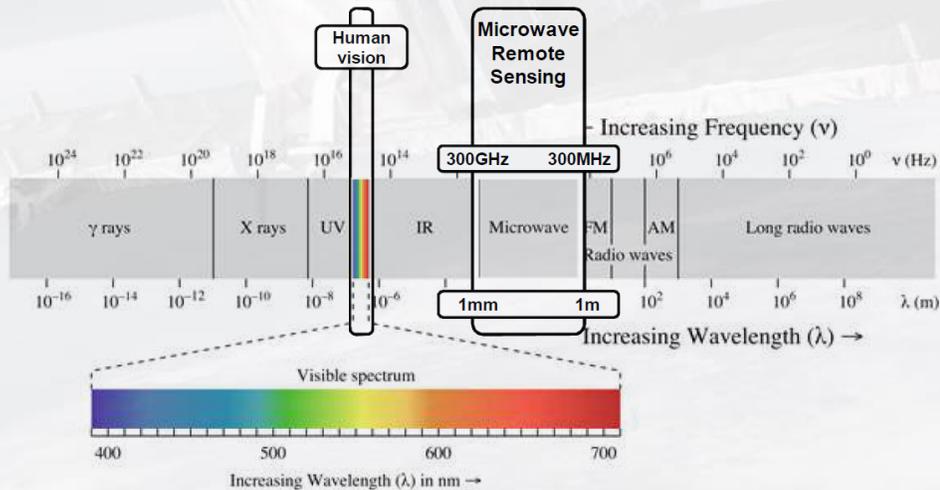
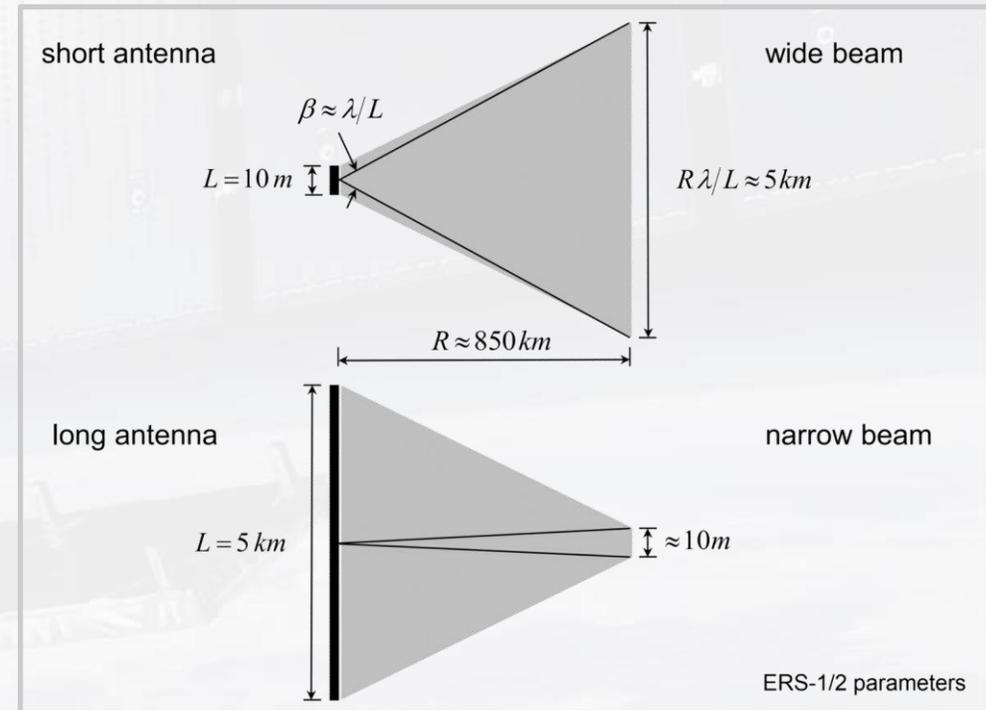
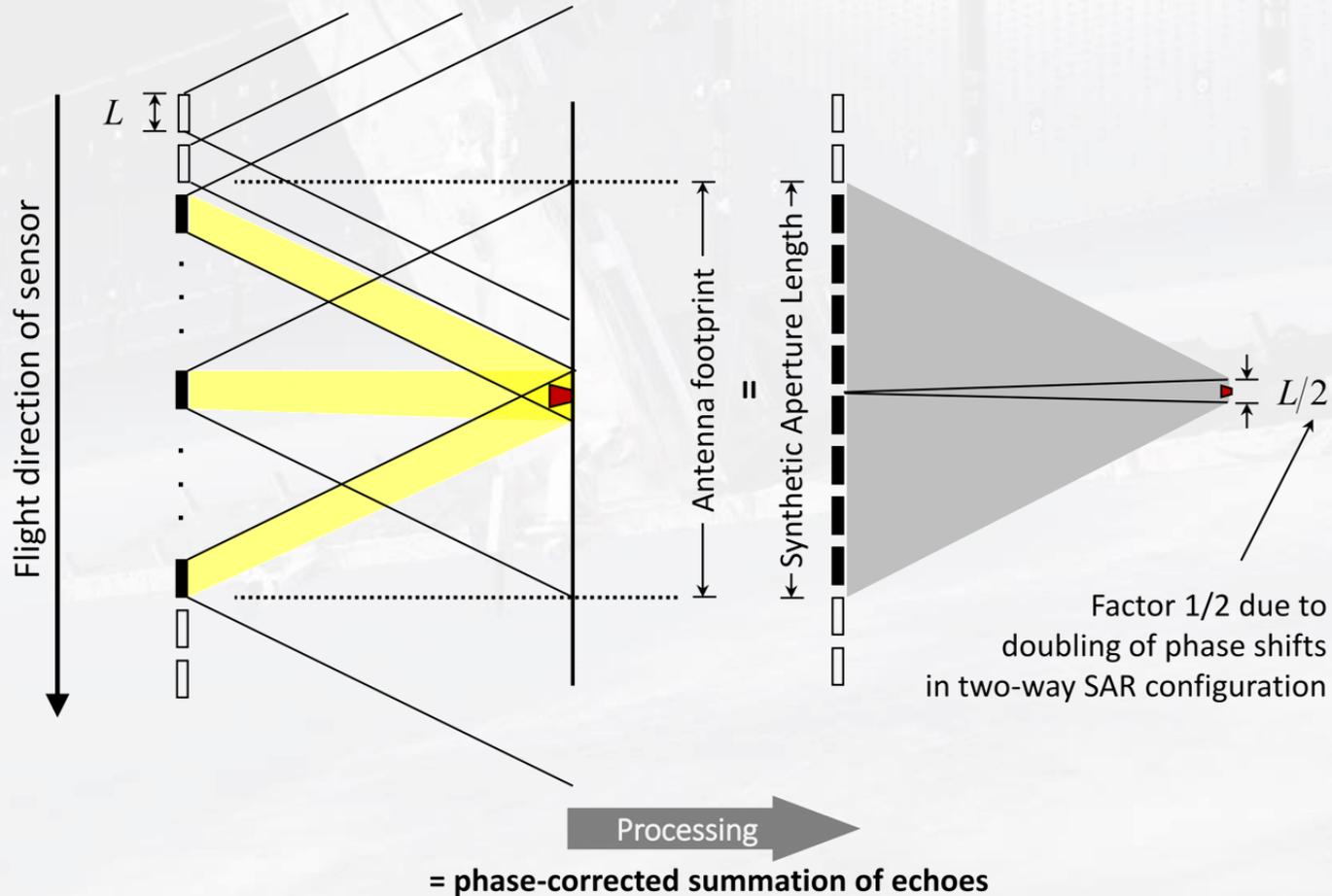


Image: Sentinel-1 Poster, ESA

What is Synthetic about SAR?

- To get reasonable resolution, the antenna would need to be longer than would be physically possible in orbit



- SAR uses the movement of the sensor and data post-processing to synthesize the resolution of a much larger antenna

Diagrams: Franz Meyer Image: Sentinel-1 Poster, ESA

Why Use SAR?

- Can penetrate cloud cover
 - Able to collect imagery in bad weather and in areas prone to frequent cloud-cover
- Not sensitive to light availability
 - Can collect data 24 hours a day
- Global coverage
- Frequent and regular imaging
 - Newer constellations have very frequent return rates and stable orbits
- Different polarizations → detection of different target properties
- Sensitive to very small changes in elevation on the Earth's surface

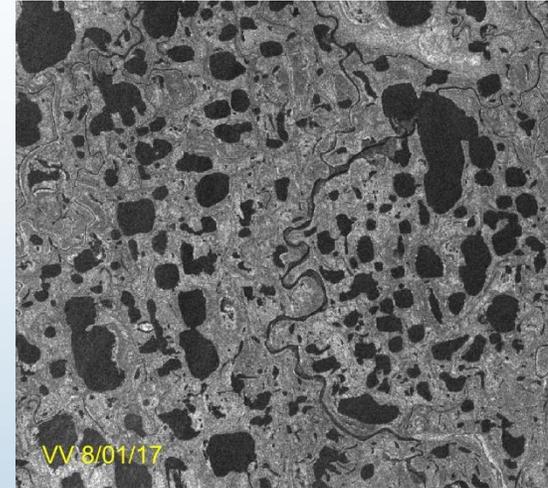
Image: Sentinel-1 heading for orbit, ESA/ATG medialab

AMPLITUDE

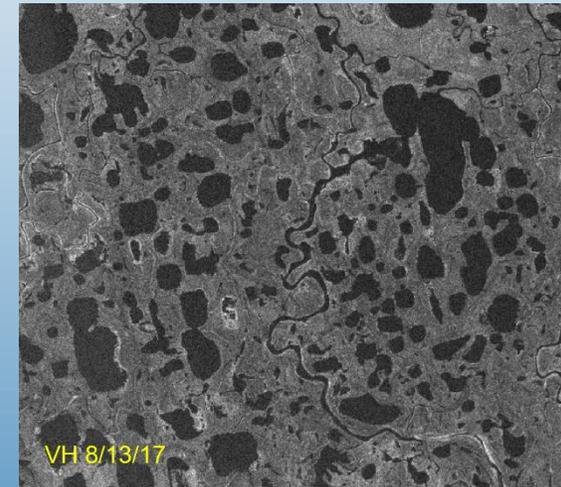
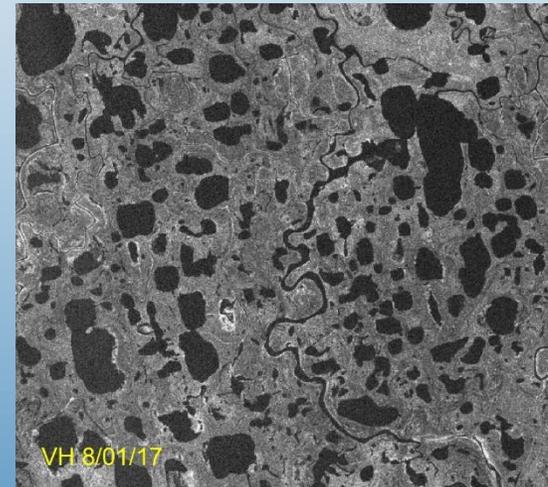
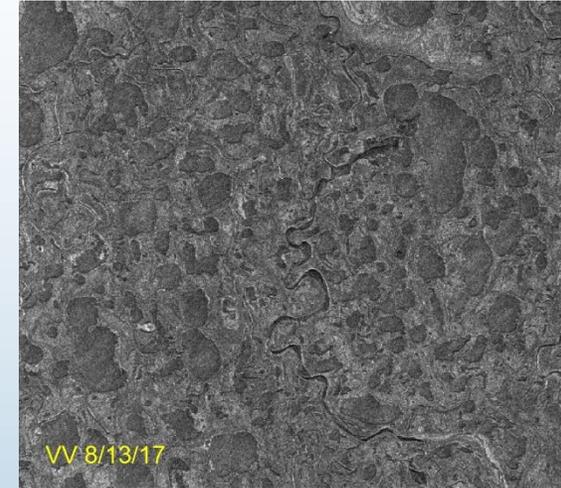
*Amount of signal returned to the sensor
(Radar Backscatter)*

- Polarization
 - VV polarization: surface roughness
 - VH polarization: vegetation
- Dielectric Constant
 - Targets with higher dielectric properties reflect more signal

CALM



WINDY



Images: ASF DAAC 2019 using GAMMA software. Contains modified Copernicus Sentinel data 2017, processed by ESA.

AMPLITUDE

*Amount of signal returned to the sensor
(Radar Backscatter)*

- Polarization
 - VV polarization: surface roughness
 - VH polarization: vegetation
- Dielectric Constant
 - Targets with higher dielectric properties reflect more signal
- Wavelength
 - Signal wavelength determines penetration ability

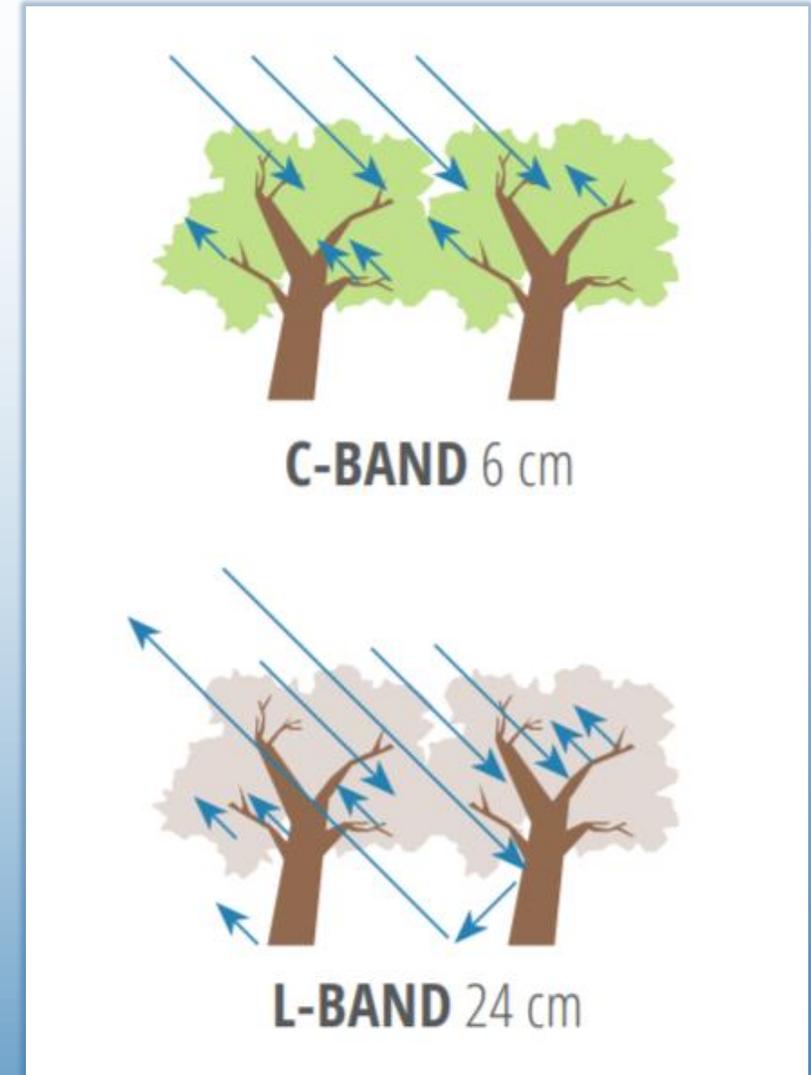
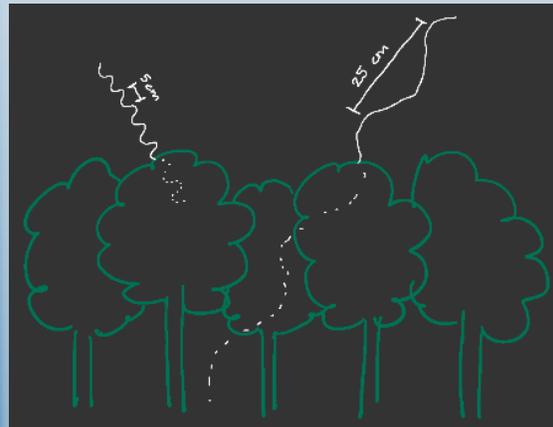
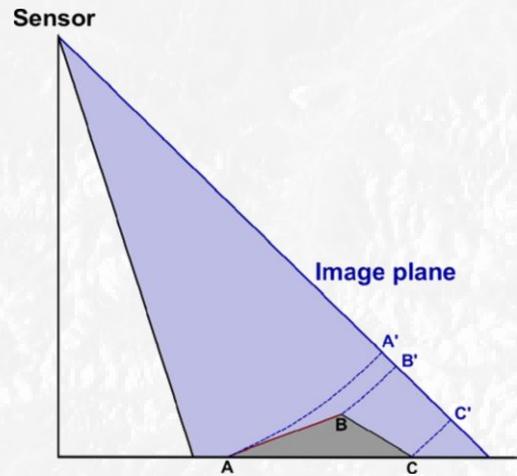


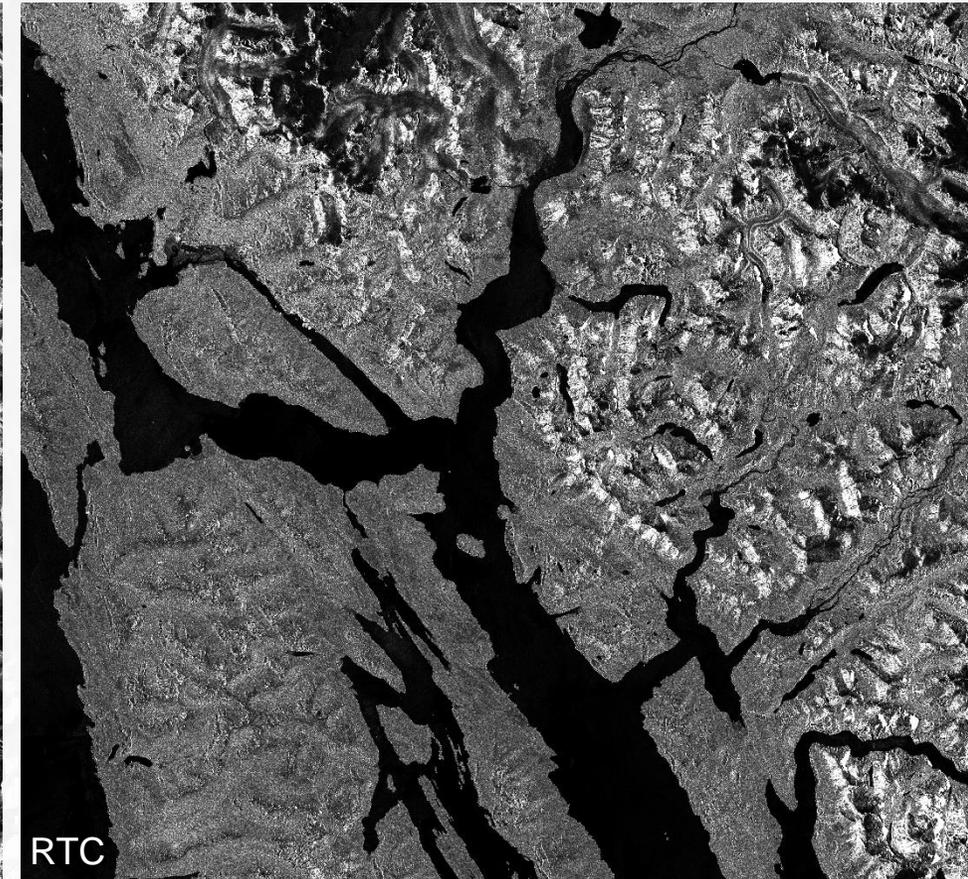
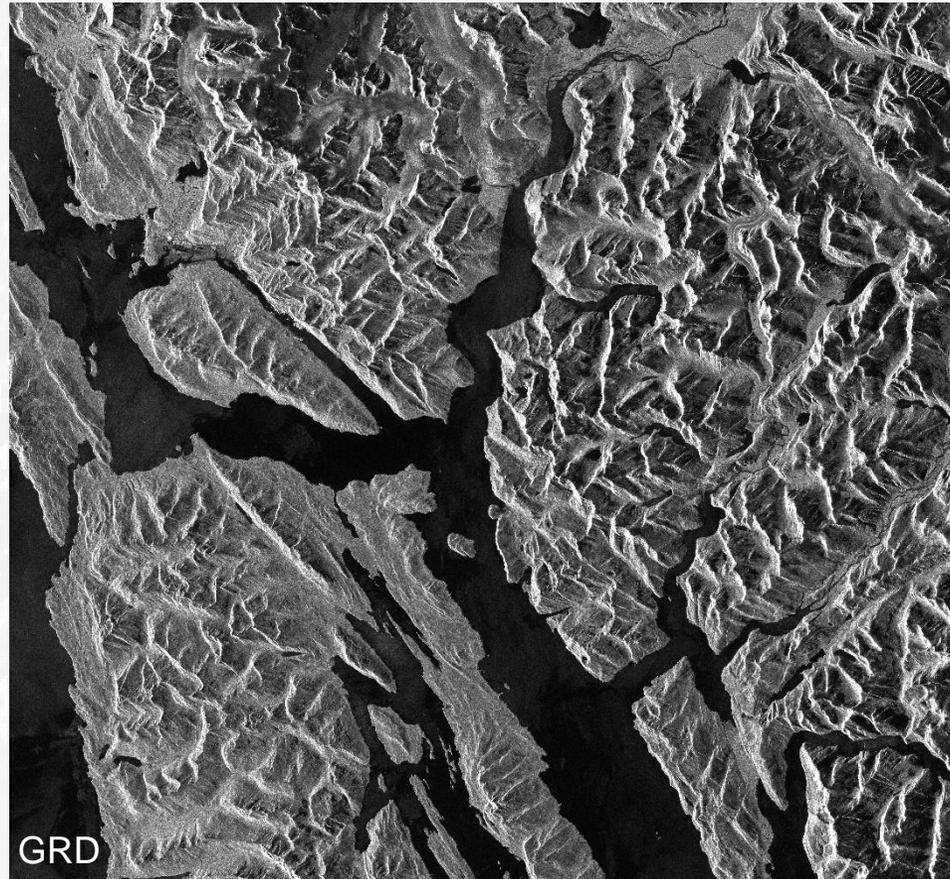
Figure from *The SAR Handbook* DOI: 10.25966/nr2c-s697

Radiometric Terrain Correction

- Matches features in SAR image to actual landscape features
- Adjusts radiometric returns to represent the appropriate surface area

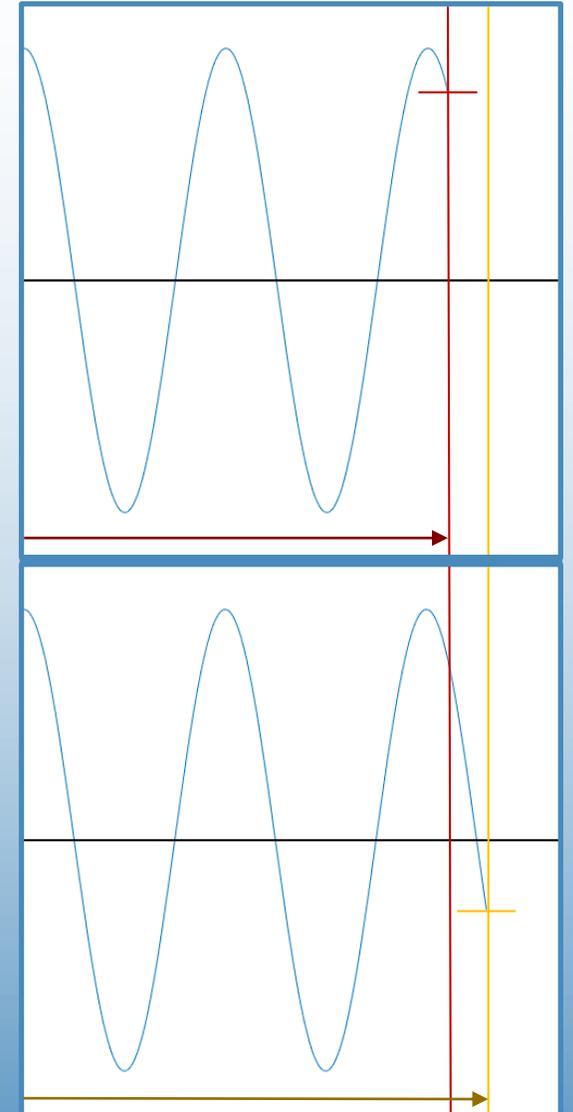


The signal backscattered from the mountaintop (B) is received shortly after the signal from the bottom, even though the bottom (A) is much closer to the sensor on the ground, making the mountains look like they're leaning left, with bright tops.

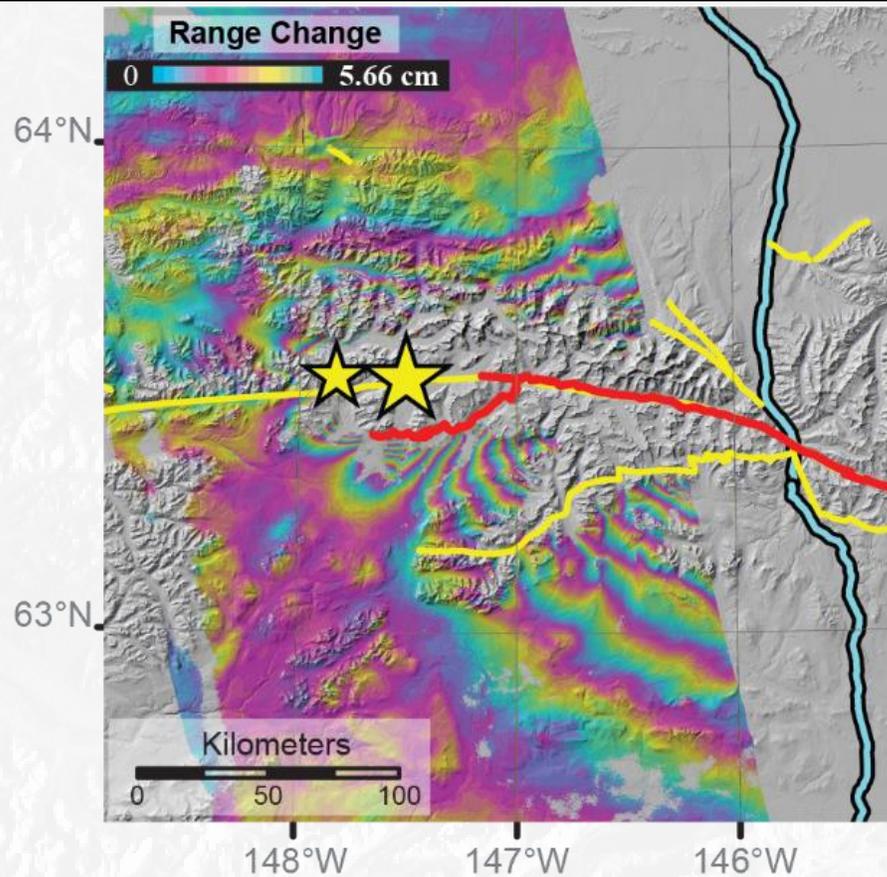


PHASE

- The location of the wave along its cycle when it returns to the sensor is related to the distance traveled
- Measuring phase differences between repeat passes is a powerful tool for detecting small changes in the surface
- Interferometry makes use of this comparative information



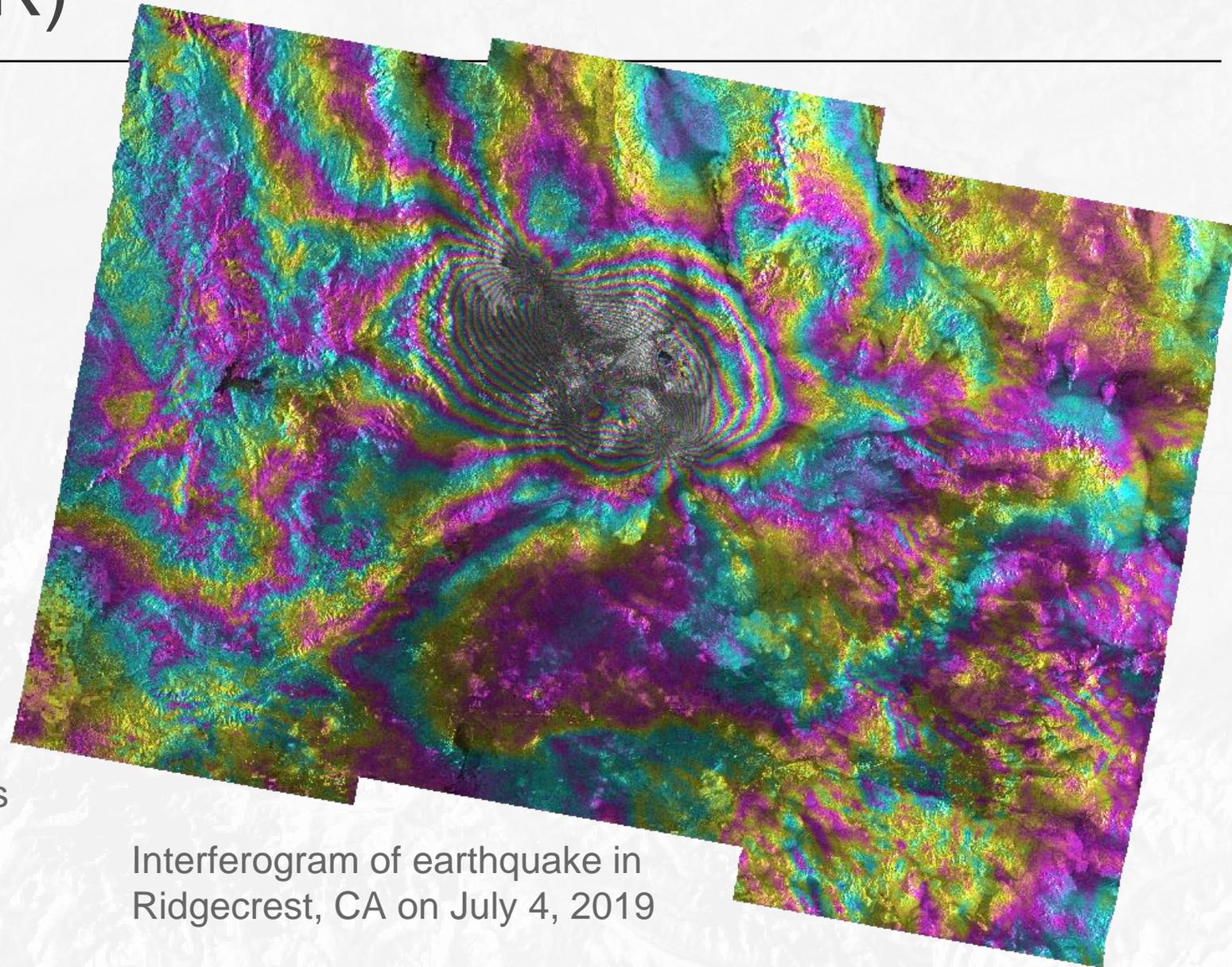
Interferometry (InSAR)



Interferogram for the analysis of effects of earthquakes along the Denali fault

Large star: 7.9 main shock epicenter, November 2002

Small star: 6.7 foreshock epicenter, October 2002



Interferogram of earthquake in Ridgecrest, CA on July 4, 2019

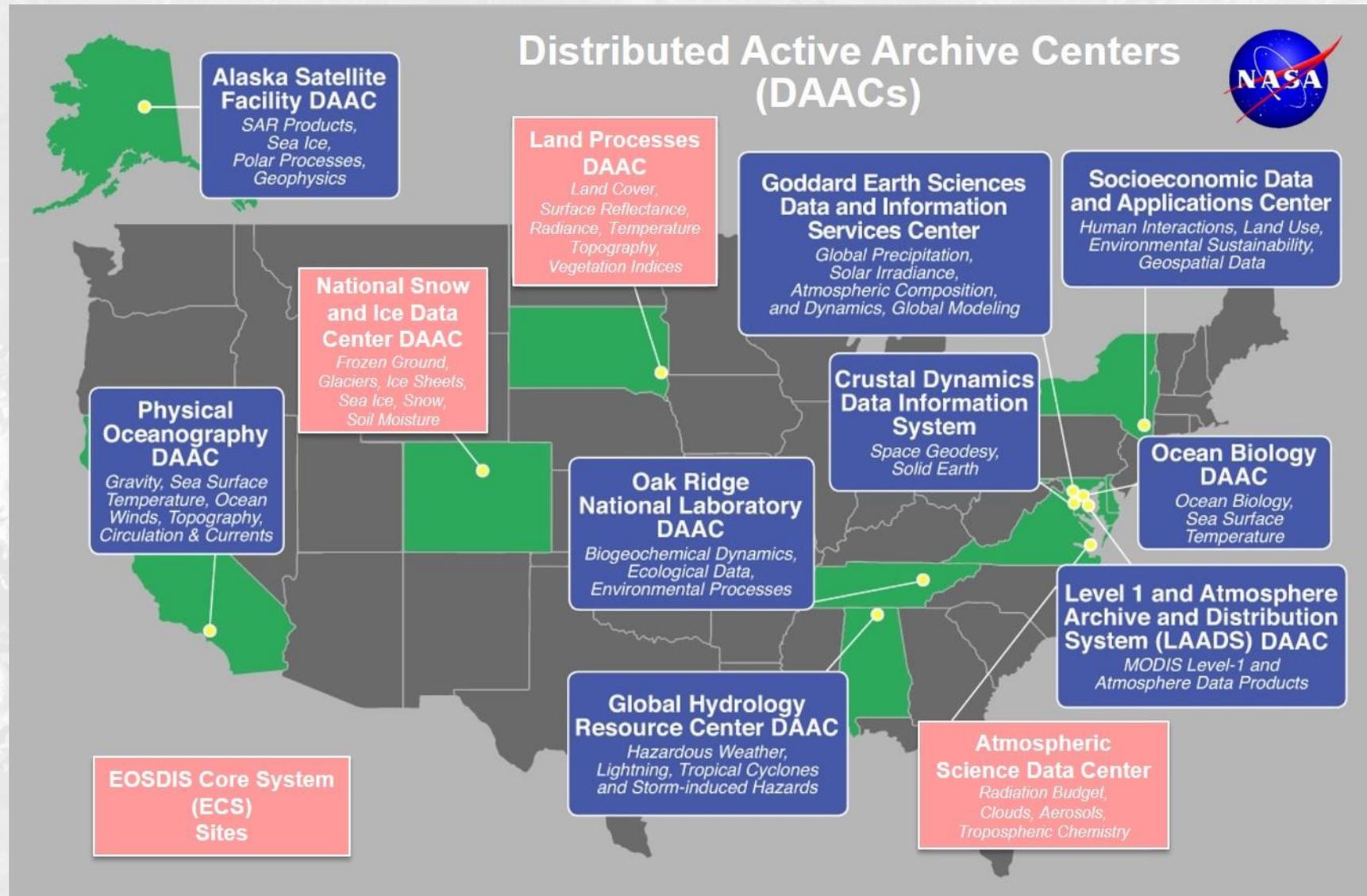
SAR Datasets Available from ASF



Heidi Kristenson, GIS Specialist
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About ASF DAAC

- 1 of 12 DAACs providing data and support services for EOSDIS (Earth Observing System Data and Information System)
- Maintains NASA archive of SAR data
 - Data from NASA, ESA, JAXA, CSA
- Serving datasets that are easy to access and free to use



Data Access: ASF Data Search - Vertex

Requirements for Downloading Data:

- Earthdata Login credentials (EOSDIS User Registration)
- Accept the ASF End User License Agreement (EULA) on Vertex

<https://urs.earthdata.nasa.gov/users/new>

<https://search.asf.alaska.edu/>

The screenshot displays the ASF Data Search Vertex web interface. At the top, there is a navigation bar with the NASA Earthdata logo, a dropdown menu for 'Other DAACs', a 'Feedback' link, and a help icon. Below this is a search bar with a 'SEARCH' button. To the left of the search bar, there are dropdown menus for 'Search Type' (set to 'Geographic') and 'Dataset' (set to 'Sentinel-1'). A 'Filters' button is also present. To the right of the search bar, there is a 'Downloads' icon with a '0' notification, a 'Sign in' button, and a hamburger menu icon. Below the search bar, there is a 'What's New' link. The main area of the interface is a map of the United States of America. Above the map is a toolbar with various icons for map interaction, including 'Map Projection', 'Zoom' (+ and - buttons), 'View' (terrain, street, and satellite views), 'Area of Interest' (rectangle, polygon, and circle tools), and 'Selection Shape' (point, line, and area tools). The current coordinates are displayed as 'lat 60.1302° lon -175.4529°'. The NASA logo is visible in the bottom right corner of the map area. At the bottom of the interface, there is a copyright notice: '© MapTiler | © OpenStreetMap contributors' and '© 2020 ASF | Contact | Non-Discrimination'.

Recent Updates

- ✓ Baseline & SBAS Integration/Updates
- ✓ View Components of Zip Archives and Download Individually
- ✓ More AOI support Shapefile, KML, JSON, WKT
- ✓ Saved Searches
- ✓ Share Searches

The screenshot displays the ASF Data Search Vertex web application. At the top, the search bar is set to 'Geographic' search type, 'Sentinel-1' dataset, and a WKT polygon for the Area of Interest. The search results show 42 files. A detailed view of a file is shown on the right, including metadata such as Start Time, Beam Mode, Path, Frame, Flight Direction, Polarization, and Absolute Orbit. The interface also includes a 'What's New' button and a 'Feedback' link.

Baseline Tool – Updated & Integrated

- Helps identify granules suitable for interferometry
- Now integrated directly into Vertex, with additional features/functionality

Search Type: **Baseline** (1) Master Scene
S1B_IW_SLC__1SDV_20200530T234422_20200530T234454_021817_02969D_FE91
Temporal: -2058 to 0 Perpendicular: -103 to 149

Search Type: Baseline Master Scene
S1B_IW_SLC__1SDV_20200530T234422_20200530T234454_021817_02969D_FE91
Temporal: -2058 to 0 Perpendicular: -103 to 149

1000 Scenes (1000 of 7,552 Files)

Scene ID	Date	0/1
S1A_IW_SLC__1SDV_2020... EB7B	October 05 2020 14:16:15	0/1
S1A_IW_SLC__1SDV_2020... CCA3	October 05 2020 14:15:50	0/1
S1A_IW_SLC__1SDV_2020... 6146	October 05 2020 14:15:25	0/1
S1A_IW_SLC__1SDV_2020... C369	October 05 2020 14:15:00	0/1
S1B_IW_SLC__1SDV_2020... D82F	October 03 2020 13:43:20	0/1

Scene Detail: S1A_IW_SLC__1SDV_20201005T141615_20201005T141642_03466_2_04097A_EB7B
Sentinel-1 - C-Band
Start Time: 10/05/20, 14:16:15
Stop Time: 10/05/20, 14:16:42
Beam Mode: IW
Path: 115
Frame: 467
Flight Direction: DESCENDING
Polarization: VV+VH
Absolute Orbit: 34662
Data courtesy of ESA
Citation
Baseline Tool SBAS Tool More Like This (2)

121 Scenes meters days

Scene ID	Perpendicular (m)	Temporal (days)
S1A_IW_SLC__1SSV_2014... 9487	-3m	-2034d
S1B_IW_SLC__1SDV_2018... CC58	-3m	-625d
S1B_IW_SLC__1SDV_2020... FE91	0m	0d
S1B_IW_SLC__1SDV_2020... 7D81	0m	-13d
S1B_IW_SLC__1SDV_2020... 0313	0m	-121d
S1B_IW_SLC__1SDV_2019... 09A8	0m	-204d
S1B_IW_SLC__1SDV_2019... FF68	0m	-252d

Scene Detail: S1B_IW_SLC__1SDV_20200131T234420_20200131T234451_020067_025F_AA_0313
Sentinel-1 - C-Band
Perpendicular: 0
Temporal: -121
Start Time: 01/31/20, 23:44:20
Beam Mode: IW
Path: 91
Frame: 1172
Flight Direction: ASCENDING
Polarization: VV+VH
Absolute Orbit: 20067
Data courtesy of ESA
Set as Master Citation

Perpendicular (m) vs. Temporal (days) plot showing Master (black), Selected (red), Downloads (blue), and Critical Baseline (grey) points.

Access Options (shown above)

1. Select Baseline for the Search Type and manually enter the filename of the reference scene
2. Search for a scene in Vertex and click the Baseline Tool button in the search results to launch Baseline with that scene set as the reference

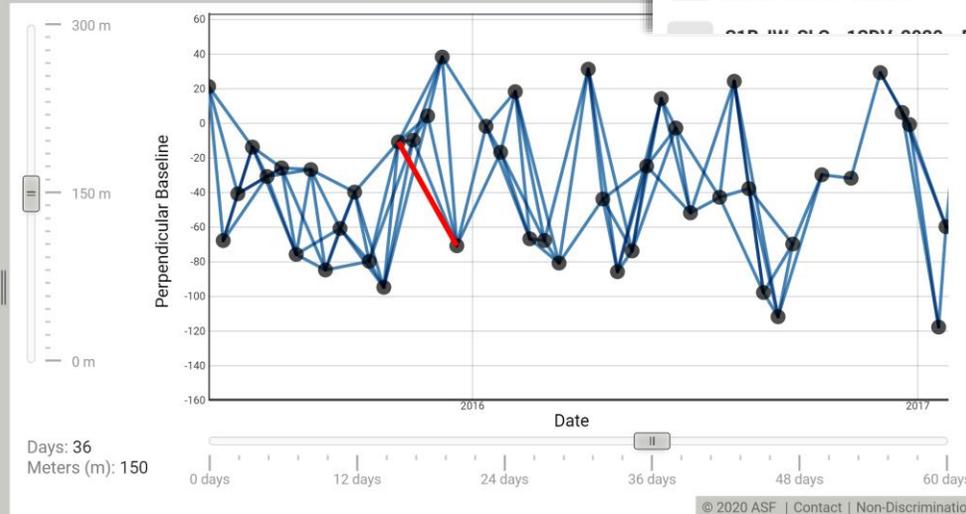
SBAS – Short Baseline Pair Identification

- Identifies suitable granule pairs for InSAR time-series analysis
- Now integrated directly into Vertex, with additional features/functionality

The screenshot shows the ASF Data Search Vertex interface. At the top, there are logos for NASA, EARTHDATA, and ASF Data Search Vertex. A search bar is set to 'Search Type: SBAS' and 'Reference Scene: S1A_IW_SLC_1SDV_20201005T141615_20201005T141642_004097A_EB7B'. Below the search bar, there are controls for 'Temporal: 36' and 'Perpendicular: 150'. A map shows the search area. On the right, a list of search results is displayed, with the first result highlighted. A red box highlights the 'SBAS' search type in the search bar. Another red box highlights the 'SBAS Tool' button in the search results panel.

Access Options (shown above)

1. Select SBAS for the Search Type and manually enter the filename of the reference scene
2. Search for a scene in Vertex and click the SBAS Tool button in the search results to launch SBAS with that scene set as the reference



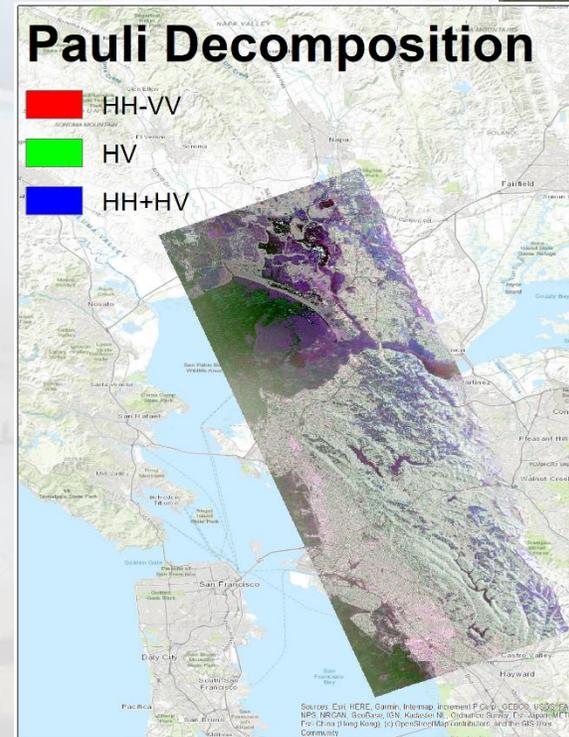
Datasets – Historic

- Seasat – NASA – (L-band)
 - First spaceborne SAR mission, 1978
 - GeoTIFFs available
- AIRSAR – NASA – (C/L/P-band)
 - Airplane, periodically 1990-2004
 - Limited extent, irregular coverage, variety of sensors and frequencies
 - JPGs available (not georeferenced)
- ERS – ESA (European Space Agency) – (C-band)
 - ERS-1 1991-1997, ERS-2 1995-2011, repeat every 35 days
 - We hold a subset of the ERS data, focused on Alaska, Western Canada, Chukotka and Antarctica
 - CEOS data format (no spatial reference)
- JERS – JAXA (Japan Aerospace Exploration Agency) – (L-band)
 - 1992-1998, **most data is restricted; requires a research agreement**
- RADARSAT-1 – CSA (Canadian Space Agency) – (C-band)
 - 1995-2008, **most data is restricted; requires a research agreement**
 - CEOS data format (no spatial reference)
- ALOS PALSAR – JAXA – (L-band)
 - 2006-2011
 - Several products available – including RTC in GeoTIFF format
 - Now unrestricted!

Image: Seasat 1, NASA/JPL-Caltech

NASA Datasets – Ongoing Acquisition

- UAVSAR – JPL (Jet Propulsion Laboratory)
 - Quad-pol L-band, 2008-present
 - Airborne, targeted locations, irregular timing
 - Flights can be requested for your area of interest
 - Pre-processed backscatter and interferometric products
 - PolSAR and Repeat-Pass Interferometry
 - Data is free and openly available



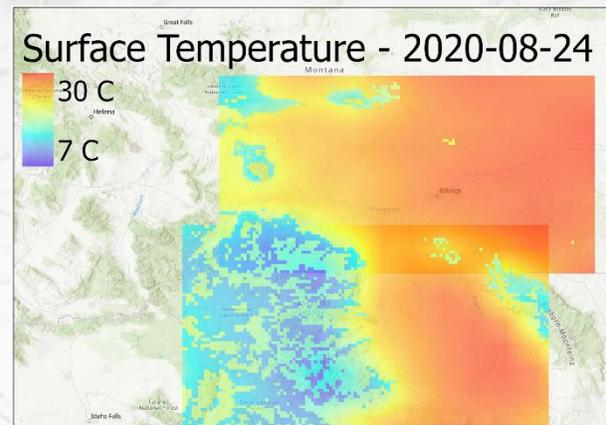
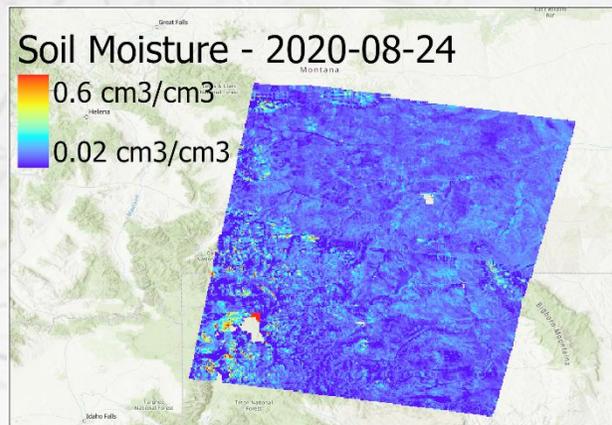
UAVSAR coverage in Alaska

NOTE: UAVSAR data will be used for the GeoGateway tutorial later in this course.

Image: UAVSAR Aircraft, NASA/JPL-Caltech

NASA Datasets – Ongoing Acquisition

- SMAP (Soil Moisture Active Passive) – NASA
 - L-band, 2015-present (currently only passive sensor operational)
 - ASF serves the SAR data acquired when active sensor was operational
 - Measures soil moisture and freeze-thaw state in top 5 cm of soil globally every three days (multi-kilometer resolution)
 - High resolution capabilities lost with loss of active sensor
 - Recent efforts to integrate Sentinel-1 data have generated higher-resolution products
 - Variety of soil moisture products available: <https://smap.jpl.nasa.gov>



1-km products generated using Sentinel-1 SAR (Soil Moisture and Surface Temperature)

Image: SMAP Antenna, NASA/JPL-Caltech

Sentinel-1

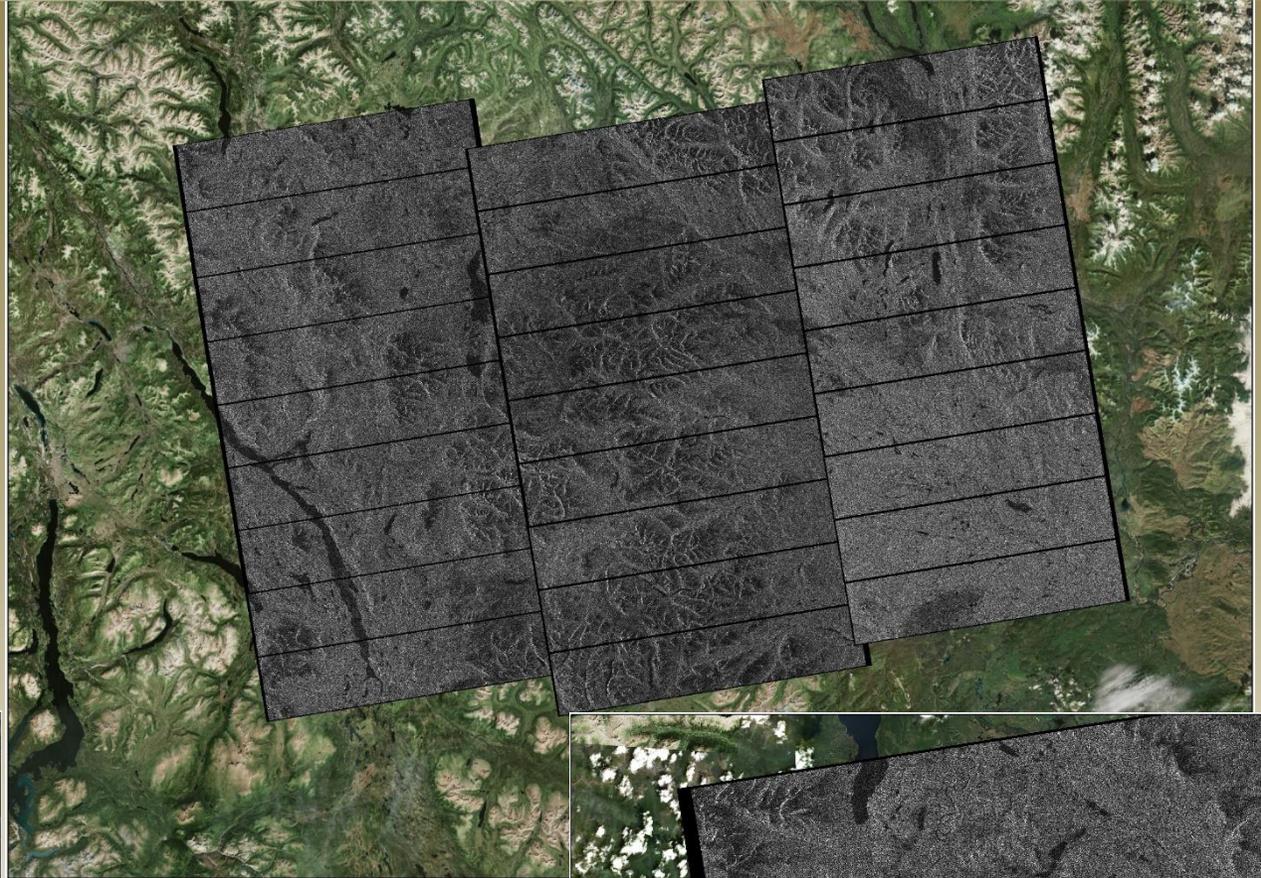
European Space Agency

<https://sentinel.esa.int/web/sentinel/missions/sentinel-1>

- Global coverage with C-band SAR
- 2 satellites
 - Sentinel-1A launched 2014, 1B launched 2016
 - Each with 12-day return cycle, orbiting 180° apart
 - Most places on the earth are currently imaged at least every 6 days
 - Polar regions generally have even more frequent coverage due to polar orbit
- New data available to download within 3 days of acquisition
 - Most often available within 24 hours of acquisition
- Free and easy to download in several formats (RAW, SLC, GRD, OCN)

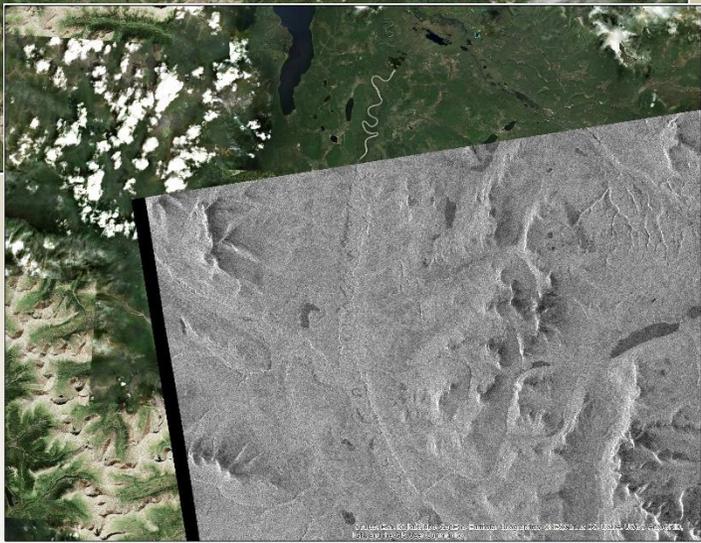


Image: Sentinel-1 Poster, ESA



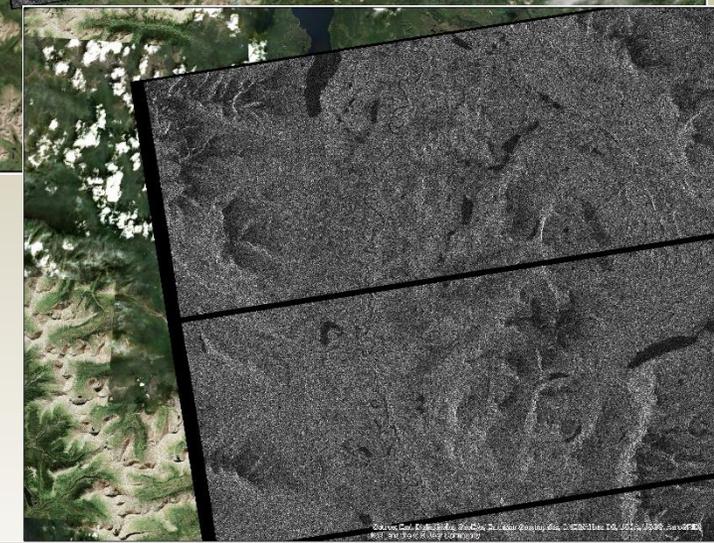
GRD

Ground Range
Detected



SLC

Single Look
Complex

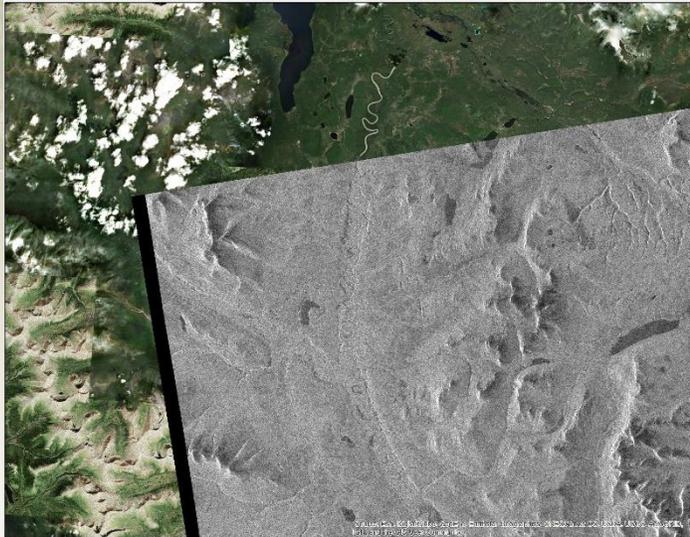


Best for Amplitude applications

- No effort required to view data in a GIS
- Easy to project to desired coordinate system
- Pixels are in ground-detected geometry
- One consolidated image for each polarization
- Square pixels
- Smaller file size

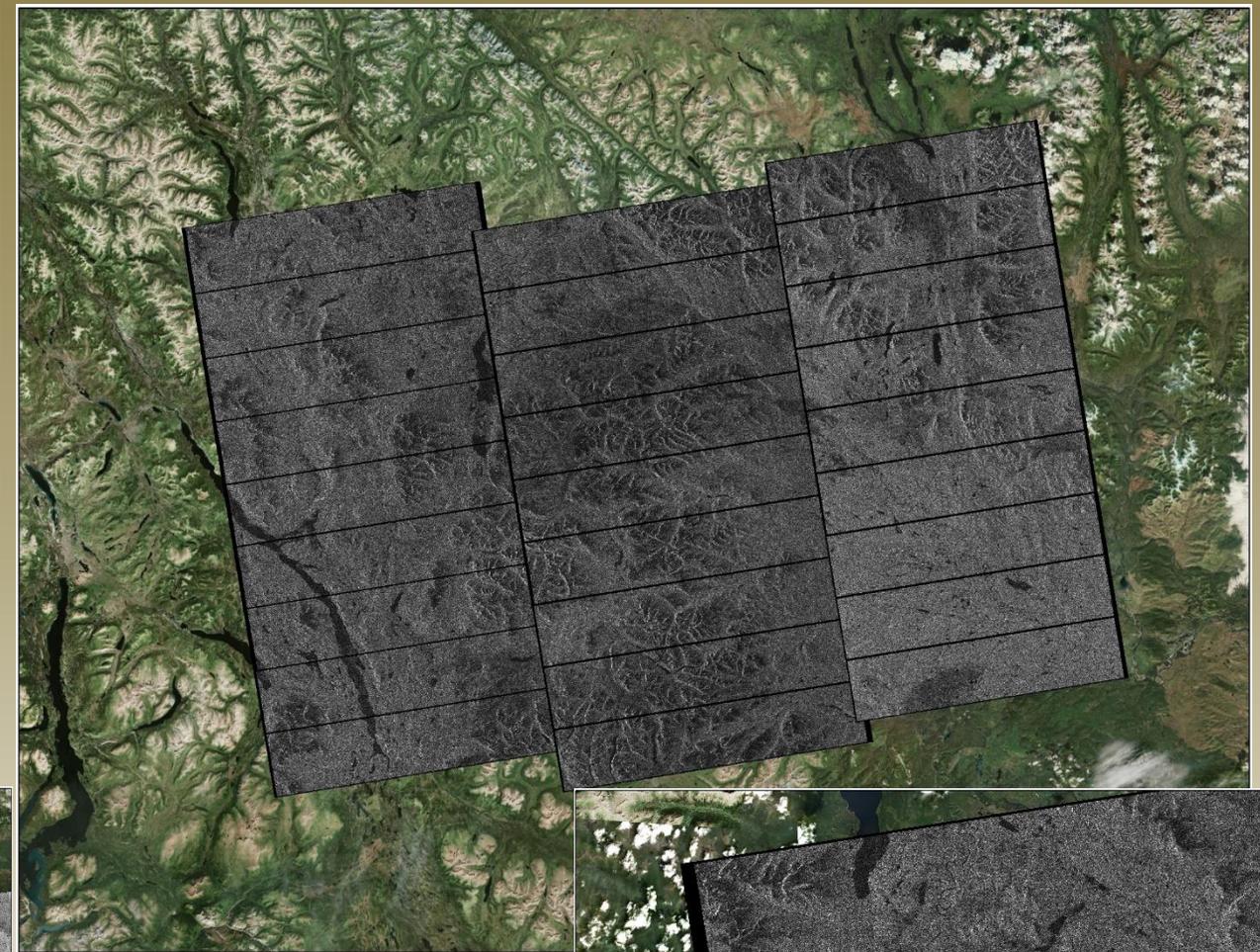
GRD

Ground Range
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SLC

Single Look
Complex

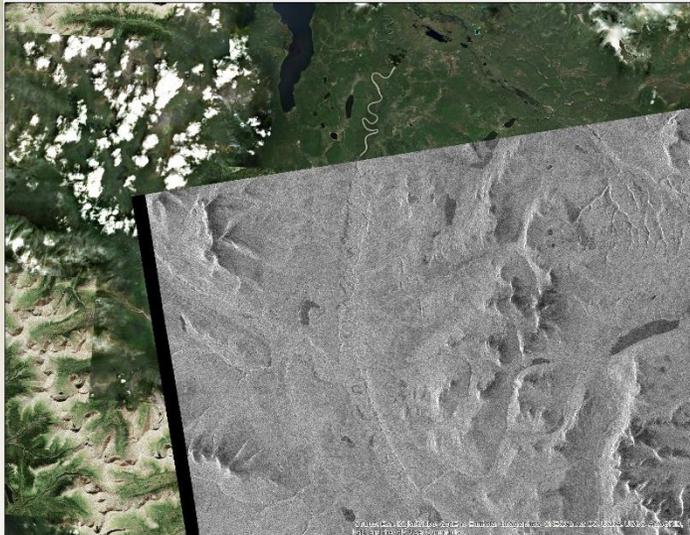


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GRD

Ground Range
Detected

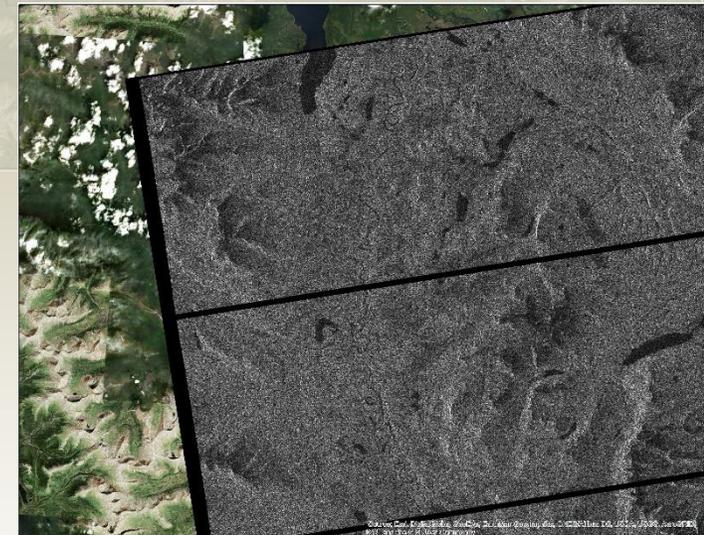


Necessary for Interferometry

- Remains in slant-range geometry
- Phase data is retained
 - ✓ Suitable for detecting changes in surface elevation
 - ✓ Required for generating interferograms
- Several images for each SLC
- Retains each subswath (including overlap) and series of bursts, with a black line grid

SLC

Single Look
Complex



Planning for the Future

NISAR

<https://nisar.jpl.nasa.gov/>

- Launching in 2022
- Joint venture between NASA and ISRO (Indian Space Research Organisation)
- L-band (greater penetration through canopy and soil than C-band)
 - Also an S-band sensor (12 cm wavelength)
- 12-day average repeat cycle
- Analysis-ready (Level-2) products (including InSAR)

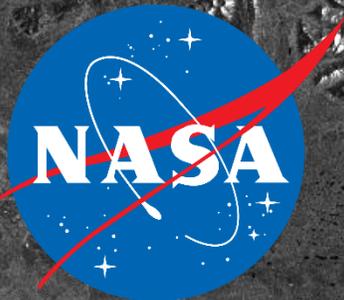


Image: NISAR rendering, NASA/JPL-Caltech

GSA 2020 SAR Short Course: Intro - 23

Heidi Kristenson, Alaska Satellite Facility

Analysis-Ready Datasets Available on Vertex



Heidi Kristenson, GIS Specialist
Alaska Satellite Facility

ALOS PALSAR RTC Products

- Download directly from Vertex
 - Already processed, ready for use
 - Available in 12.5-m or 30-m resolution
 - Projected to UTM Coordinates

<https://search.asf.alaska.edu>

The screenshot displays the ASF Data Search web application. A search for 'ALOS PALSAR' is active, showing 250 of 11,942 files. The interface includes a sidebar with product categories like Sentinel-1, ALOS PALSAR, and AVNIR-2. A 'Filters' panel is open, showing 'Path and Frame Filters', 'Seasonal Filter', and 'Additional Filters'. The 'Additional Filters' section includes 'File Type' (0/6 selected), 'Beam Mode' (0/0 selected), 'Polarization' (0/9 selected), and 'Direction' (0/2 selected). A red box highlights the 'File Type' dropdown, and a red arrow points to a secondary filter menu on the right. This secondary menu contains checkboxes for 'Level 1.5 Image', 'Level 1.1 Complex', 'Level 1.0', 'Hi-Res Terrain Corrected', and 'Low-Res Terrain Corrected', with the latter two also highlighted by a red box.

Sentinel-1 Interferograms (Limited spatial coverage)

- Download directly from Vertex

<https://search.asf.alaska.edu>

- Already processed, ready for use
- Download choices:
 - Full netCDF product
 - Select layers as GeoTIFFs

The image shows a screenshot of the ASF Data Search web application. On the left, a search results dropdown menu is open, listing various satellite datasets. The 'S1 InSAR (BETA) - 2014 to Present' option is highlighted with a red box. The main map area shows a satellite view of the United States and surrounding regions. On the right, a detailed view of a specific S1 InSAR interferogram is displayed. The interferogram shows a colorful pattern of fringes, indicating ground deformation. The scene details on the right include: Start Time: 02/23/20, 13:51:17; Beam Mode: slc; Path: 71; Flight Direction: descending; Polarization: VV; Campaign Name: S1 I-grams (BETA) - Southern CA; Data courtesy of ESA. Below the main interferogram, a timeline of smaller thumbnails shows the sequence of acquisitions from March 12, 2020, to February 23, 2020. A checkbox at the bottom indicates 'Only display scenes with a browse image' is checked.

UAVSAR Georeferenced Products (KMZ format)

UAVSAR Georeferenced Products
(~6 m Pixel Spacing)

PoISAR

Polarimetry (Single-Pass)
(quad-pol backscatter decomposition)
Red: HH | Green: HV | Blue: VV

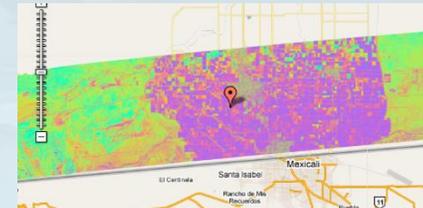


Repeat-Pass Interferometry

Amplitude
(backscatter for each polarization)



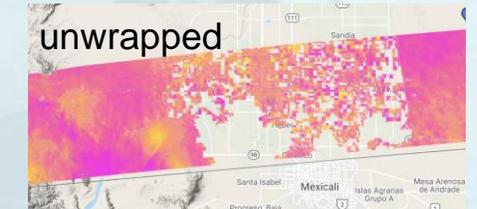
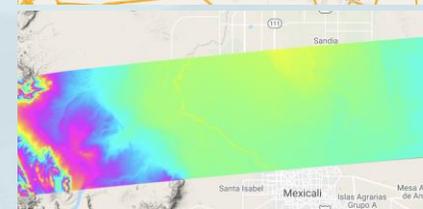
Correlation
(phase coherence between passes)



Interferometry
(landscape change)



Digital Elevation Map
(reference)



NEW! On-Demand SAR Processing in Vertex

1 Sign in with Earthdata

2 Use button to add products to the On Demand Queue

3 Click on On Demand to view the queue

4 Enter a Project Name and adjust processing options (if desired)

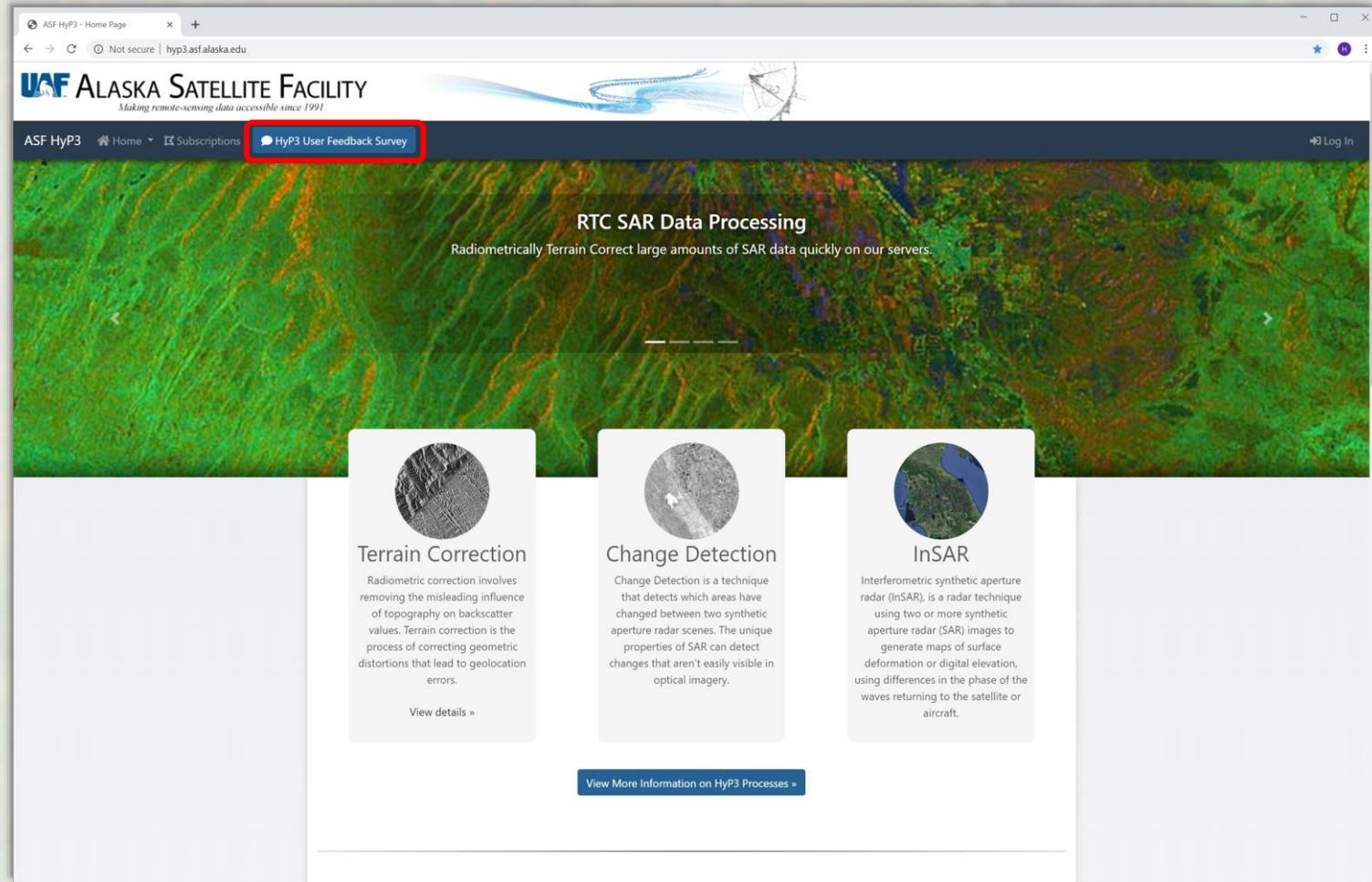
5 Click the Submit Queue button

6 Select On Demand Products Search Type to view products

- Sentinel-1 Analysis-Ready Products
 - Currently supporting RTC products
 - More products to be added...

HyP3 v1 – On-demand SAR Processing

- Cloud-based SAR Processing
- Order/Access products using the GUI or API
- Multiple Product Types
 - Plan to integrate more of the product types into HyP3 v2
- Beta: Users can test in exchange for feedback



<http://hyp3.asf.alaska.edu/>

Data Recipes

<https://asf.alaska.edu/how-to/data-recipes/data-recipe-tutorials/>

- Radiometric Terrain Correction
- InSAR (Interferometry)
- Inundation Mapping
- Environmental Change Detection
- Your requested recipe....

Data Recipe (Tutorials) | ASF

asf.alaska.edu/how-to/data-recipes/data-recipe-tutorials/

EARTHDATA Other DAACs - Feedback

ASF Distributed Active Archive Center

Data Recipe (Tutorials)

All

- ASF MapReady
- ArcGIS
- Cloud Computing
- GAMMA
- GDAL
- GMT5SAR
- InSAR
- QGIS
- Radiometric Terrain Correction
- SNAPHU
- Sentinel-1 Toolbox

Data Recipes — Further Reading
Learn more and find extended references in a variety of topics related to ASF's Data Recipes to expand your SAR knowledge....

How to Create Cloud Storage Using AWS Simple Storage Service (S3)
Learn more about creating cloud storage using the Simple Storage Service (S3) in this Alaska Satellite Facility Data Recipe....

Mapear la Inundación Regional con SAR de banda L por el Espacio
Esta receta de datos de dos partes es para los usuarios quienes quieren mapear la inundación regional con el Radar de Apertura Sintética de banda L....

How to Configure AWS for Running the GMT5SAR InSAR Recipe
Script output images: color phase products for each swath F1, F2, F3....

How to Map Regional Inundation with Spaceborne L-band SAR using ArcGIS
Learn more about mapping regional inundation using spaceborne L-band SAR data and ArcGIS with this Alaska Satellite Facility Data Recipe....

How to Move files in and out of an AWS EC2 Instance – Windows
Learn more about moving files in and out of an AWS Elastic Compute Cloud instance on Windows with this Alaska Satellite Facility Data Recipe....

How to Phase Unwrap an Interferogram
Learn more about phase unwrapping interferograms using the European Space Agency's Sentinel-1 Toolbox with this Alaska Satellite Facility Data Recipe....

How to Create and Unwrap an Interferogram with GMT5SAR Script in the Cloud — Windows
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Image: Hurricane Florence Color Decomposition, ASF DAAC 2018.
Contains modified Copernicus Sentinel data 2018, processed by ESA
Basemap: National Geographic