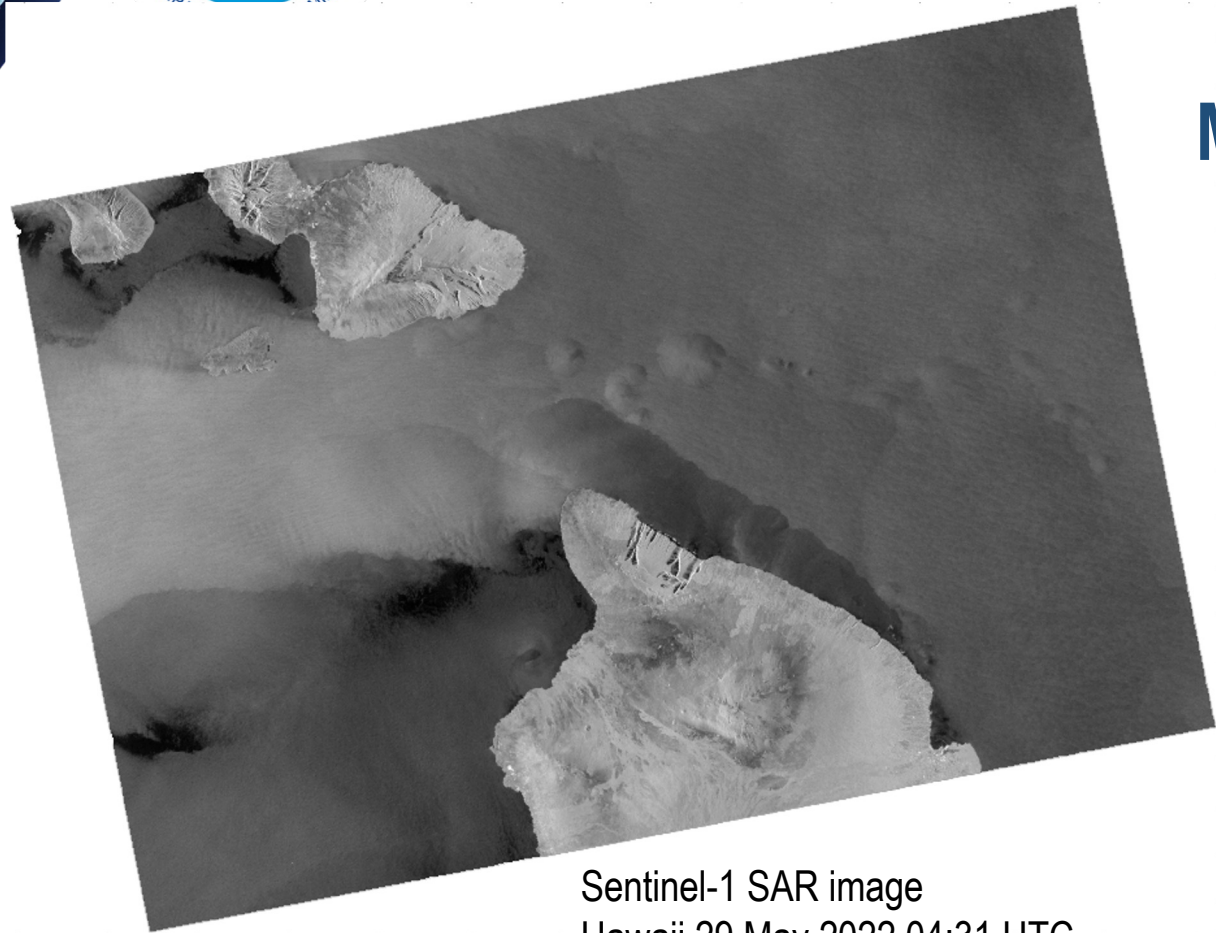


An Overview of Synthetic Aperture Radar

Module 1: Synthetic Aperture Radar Series

NOAA Coastwatch Satellite Courses



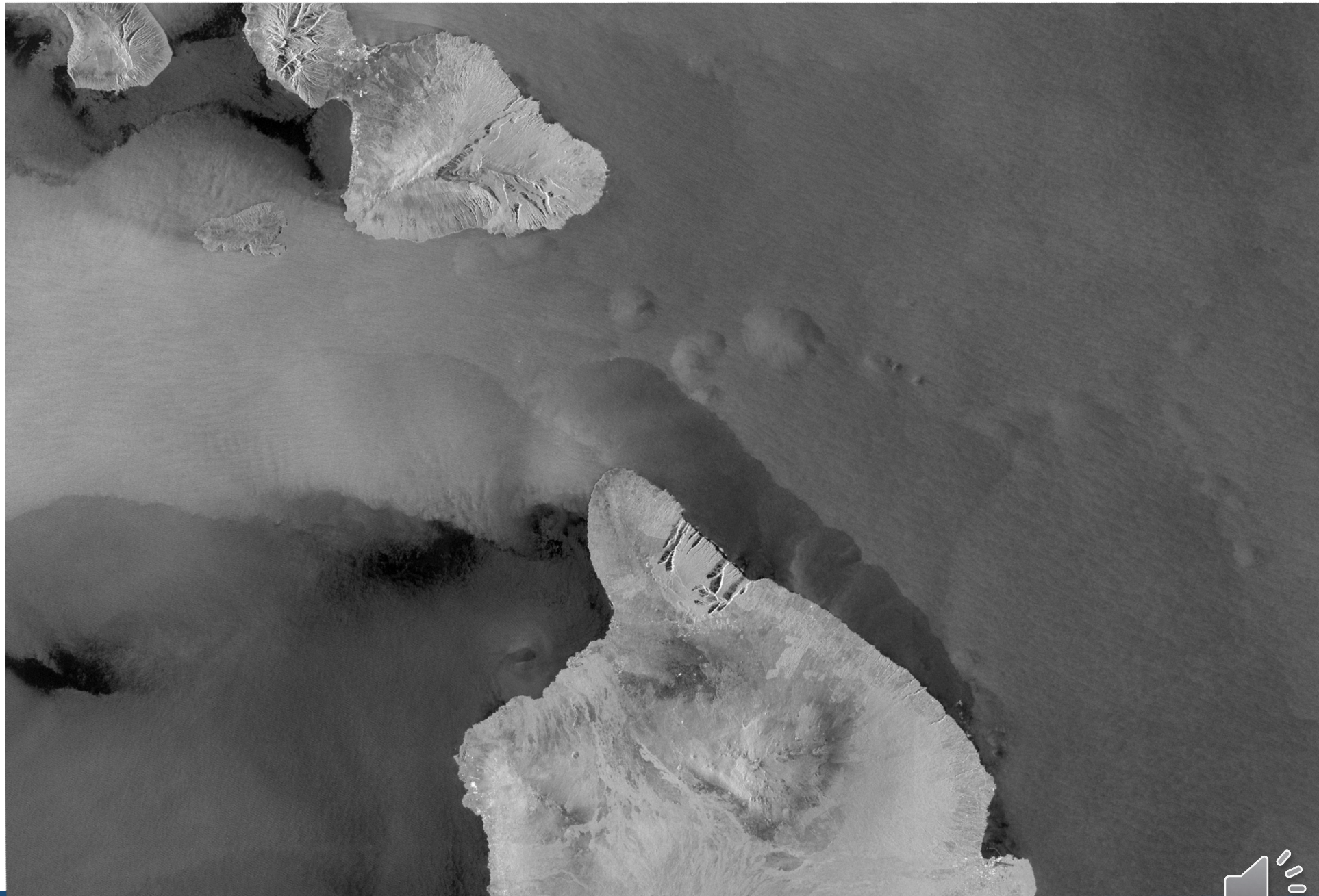
Sentinel-1 SAR image
Hawaii 29 May 2022 04:31 UTC

Last Updated: 1/4/2023

coastwatch.info@noaa.gov



**Sentinel-1
C-Band VV
image over
Hawaii
29 May 2022
04:31 UTC**



The CoastWatch Synthetic Aperture Radar instructional series

The CoastWatch Synthetic Aperture Radar (SAR) instructional series consists of three (3) training modules:

Module 1: An overview of SAR (this module)

Module 2: Descriptions of available SAR products and where to find them

Module 3: Examples of how various phenomena appear in SAR imagery



Module 1: An overview of Synthetic Aperture Radar (SAR)

Outline

Why should I care about SAR

- What can SAR measure?
- The pros and cons of using SAR

Background

- Radar and how it works
- How is SAR different from standard radar?

SAR specifications

- SAR Frequency Bands
- SAR Polarization

Overview of SAR satellite missions and products



What can be detected by SAR?

OCEANIC

Surface Waves

- Significant Wave Height
- Wave Spectra

Surfactants (Biogenic Slicks, Oil Seeps)

Sea Ice

Internal Waves

Currents and Fronts

Eddies

Upwelling

Underwater Topography

ATMOSPHERIC

Surface Wind

Convection Cells / Rolls

Storm Systems

Vortex Streets

Gravity Waves

Rain Cells / Thunderstorms

ANTHROPOGENIC

Hard Targets (Ships/Oil Platforms)

Ship Wakes

Pollution (Oil Spills)

COASTAL / LAND

Flooding and Inundation

Shorelines

Land Use

Land Deformation (interferometry)

Burn Scar Identification

...there are many other applications



The pros and cons of SAR measurements

SAR Advantages

- Data collection is independent of lighting and cloud conditions
- Wide area coverage (100–450 km swath)
- High resolution coverage (30-100 m)
- Fine resolution is available (1m-3m)
- Many different products can be derived

SAR Disadvantages

- Expertise is required to interpret the data
- Specialized software to read and calibrate
- Scheduled data acquisitions limit global coverage

Traditional barriers

- Cost - free access is now available
- Difficulty in reading and interpreted data
- Irregular temporal revisit times



What's RADAR?

The acronym RADAR stands for RAdio Detection And Ranging

- Any system that *actively* sends electromagnetic microwaves from a satellite or an aircraft (or police car) and detects the return signal

Ranging refers to measuring distance

- The distance from the sensor to the target

Radars are active instruments, sending signals to Earth's surface.

- They do not depend on solar illumination, so radar observations are possible both day and night

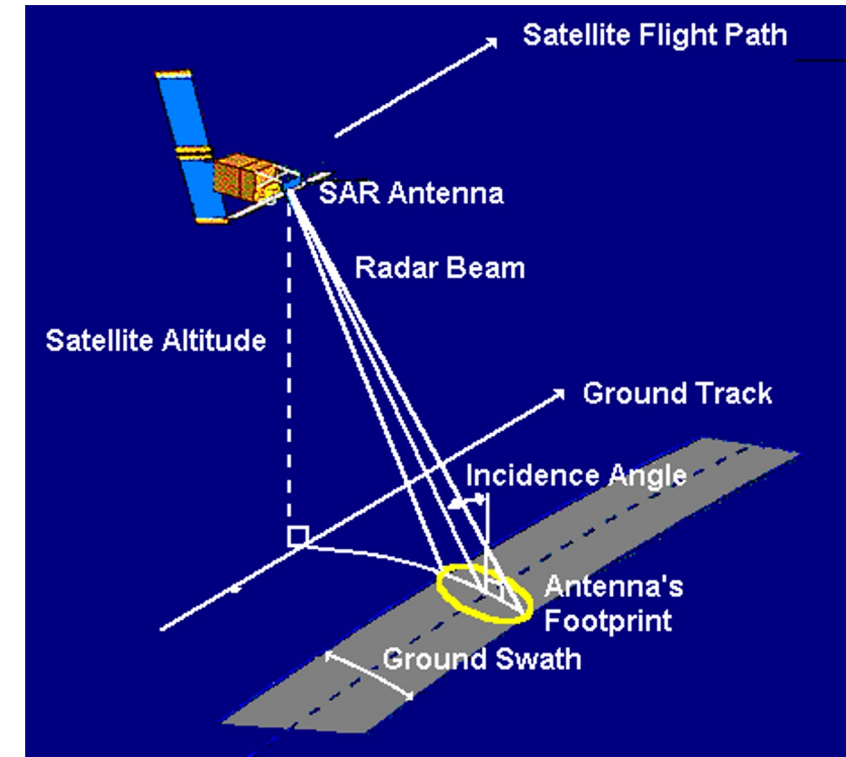
Radars use microwaves, which penetrate through clouds and rain

- Wavelengths are between a few millimeters up to 1 meter
- Radar observations are possible regardless of cloud cover



RADAR is composed of a transmitter, a receiver, an antenna, and an electronic system

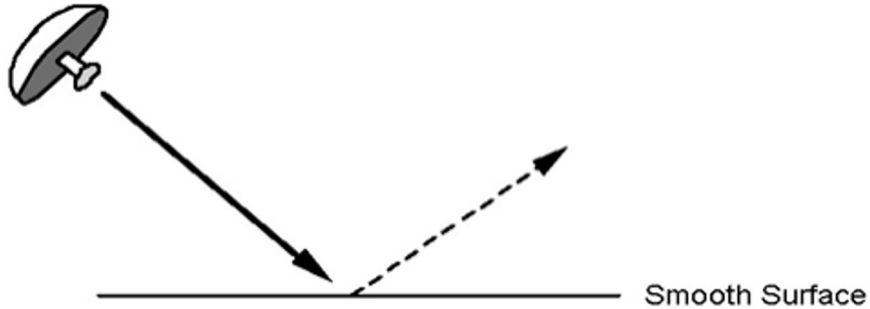
- The transmitter generates pulses of microwaves at regular intervals, which are focused by the antenna into a beam.
- The beam illuminates the surface of Earth.
- The antenna receives a portion of the transmitted signal that is reflected, or backscattered, from the Earth's surface.
- The antenna length is called the **aperture**.
- The electronic system processes and records the data.



<https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-synthetic-aperture-radar>



RADAR measures the portion of the transmitter radar energy that is backscattered to the antenna



Smooth surfaces scatter most of the radar energy away from the radar, so less signal is backscattered to the SAR antenna.

These SAR images appear black.



Rough surfaces backscatter more the radar energy back to the SAR antenna.

These SAR images appear brighter

Normalized Radar Cross Section (NRCS) is the measure of radar backscatter

Images from <https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-synthetic-aperture-radar>



SAR image over the Gulf of Mexico

High backscatter (bright)

- Land, Oil Platforms

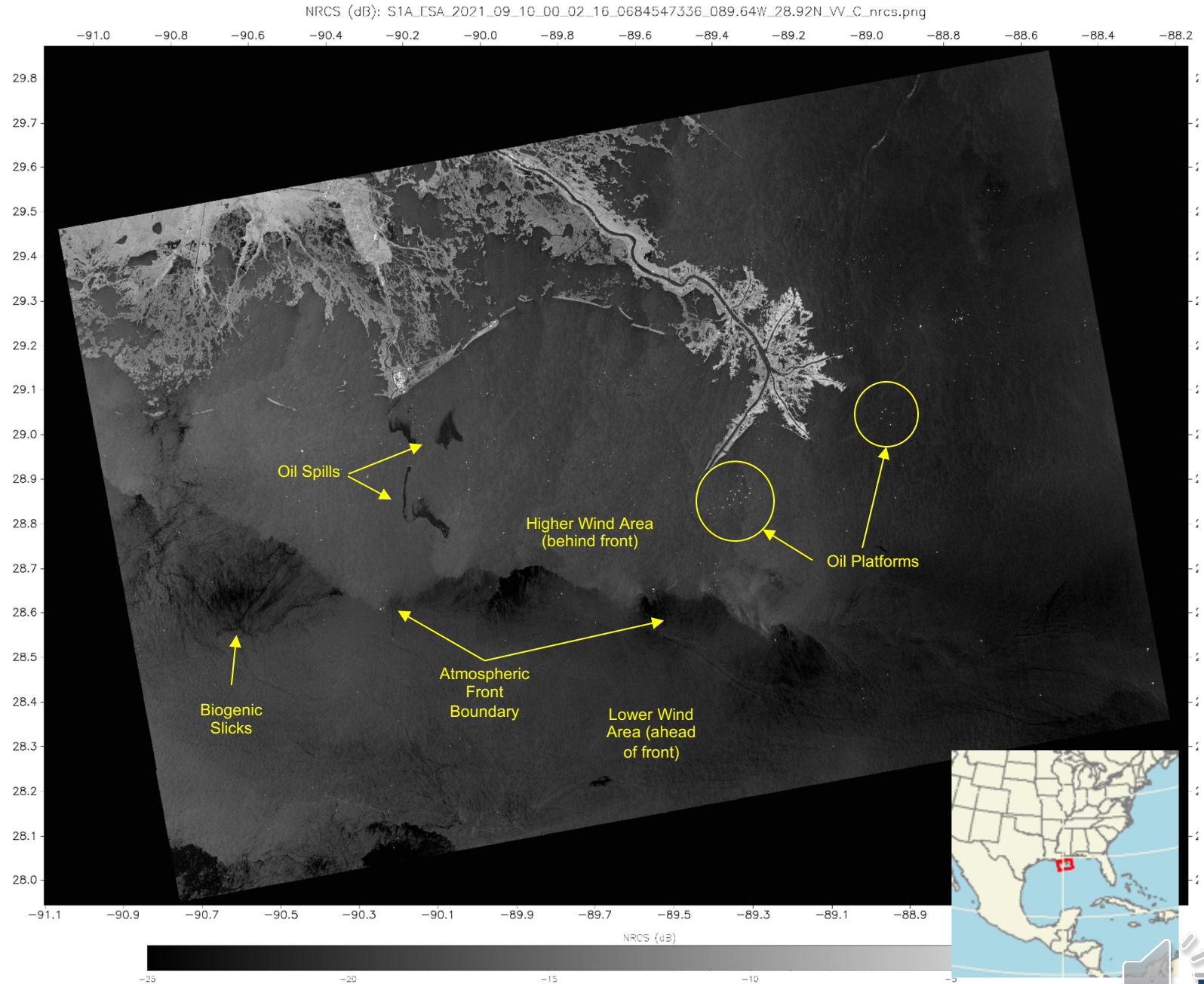
Low backscatter (dark)

- Ocean surface with oil or low winds

Moderate backscatter (gray)

- Ocean surface with moderate wind speeds (5-8 m/s)

Sentinel-1 VV SAR Image,
10 September 2021 00:02 UTC,
Bird's Foot Delta - Gulf of Mexico



Components of ocean surface roughness contributing to backscatter

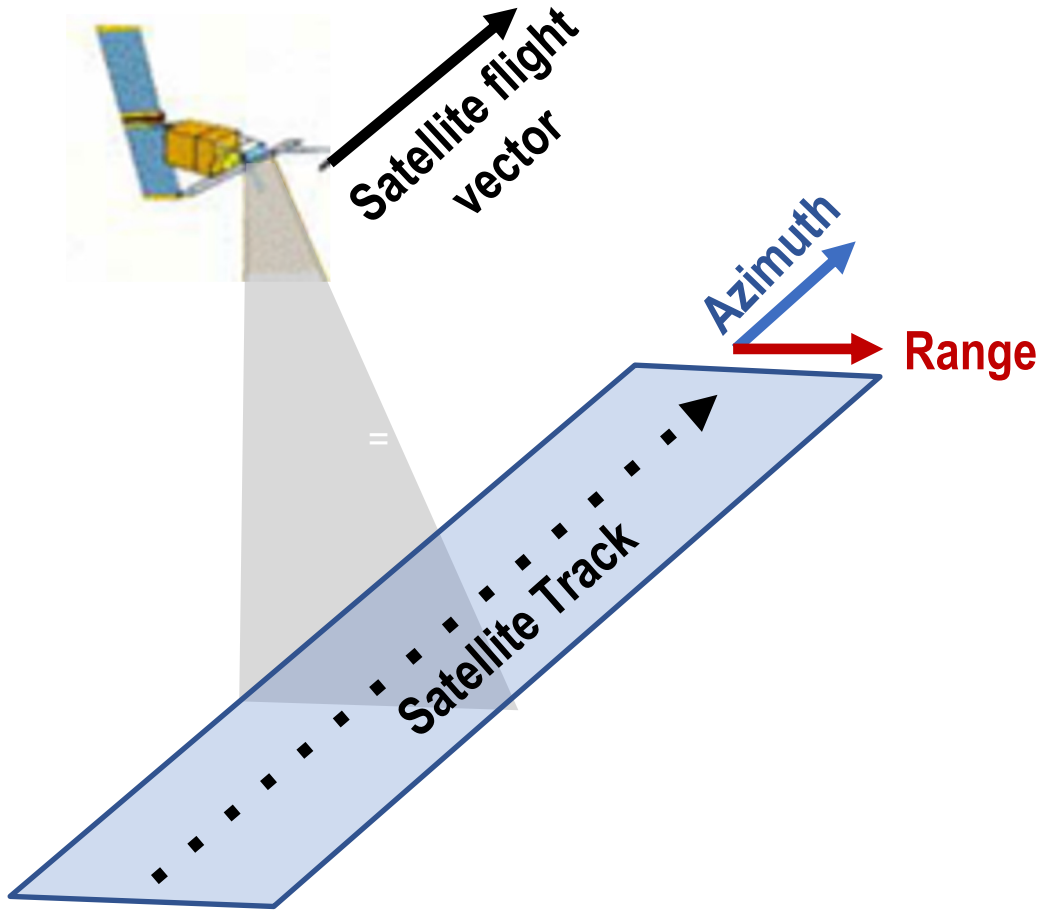
Wind-generated short waves (Capillary to short gravity waves) have wavelengths from a few centimeters to tens of centimeters and periods < 1 second

Therefore, radar wavelengths of a few centimeters are needed to observe ocean surface roughness and thereby obtain a measure of wind speed.

Longer gravity waves, currents, oil slicks, and other phenomena can be identified by the ways they affect the pattern of the wind-generated short waves.



Antenna size and pulse bandwidth determine spatial resolution



SAR systems are side-looking

Azimuth direction (along-track)

- Spatial resolution depends on the beam width
- Beam width is inversely proportional to the antenna length.
- **A longer antenna (aperture) produces a narrower beam and a finer resolution**

Range direction (perpendicular to along-track)

- Spatial resolution depends on the bandwidth of the signal pulse
- Signal pulse length can be controlled for specific applications

Image modified from
<https://earth.esa.int/eogateway/missions/ers/radar-courses/radar-course-1>

High-resolution radar imagery requires a very large antenna

For a “real” aperture radar

Range resolution is on the order of meters

- a 100 MHz bandwidth pulse produces a resolution of ~ 1.5 meters

Azimuth resolution is on the order of kilometers

- a 12 meter antenna operating at 5 GHz gives a beam width of $\sim \frac{1}{4}$ degree
- At 700 km altitude this is ~ 3.5 km on the ground

To produce an azimuth resolution of 30 meters would require an antenna a few kilometers long

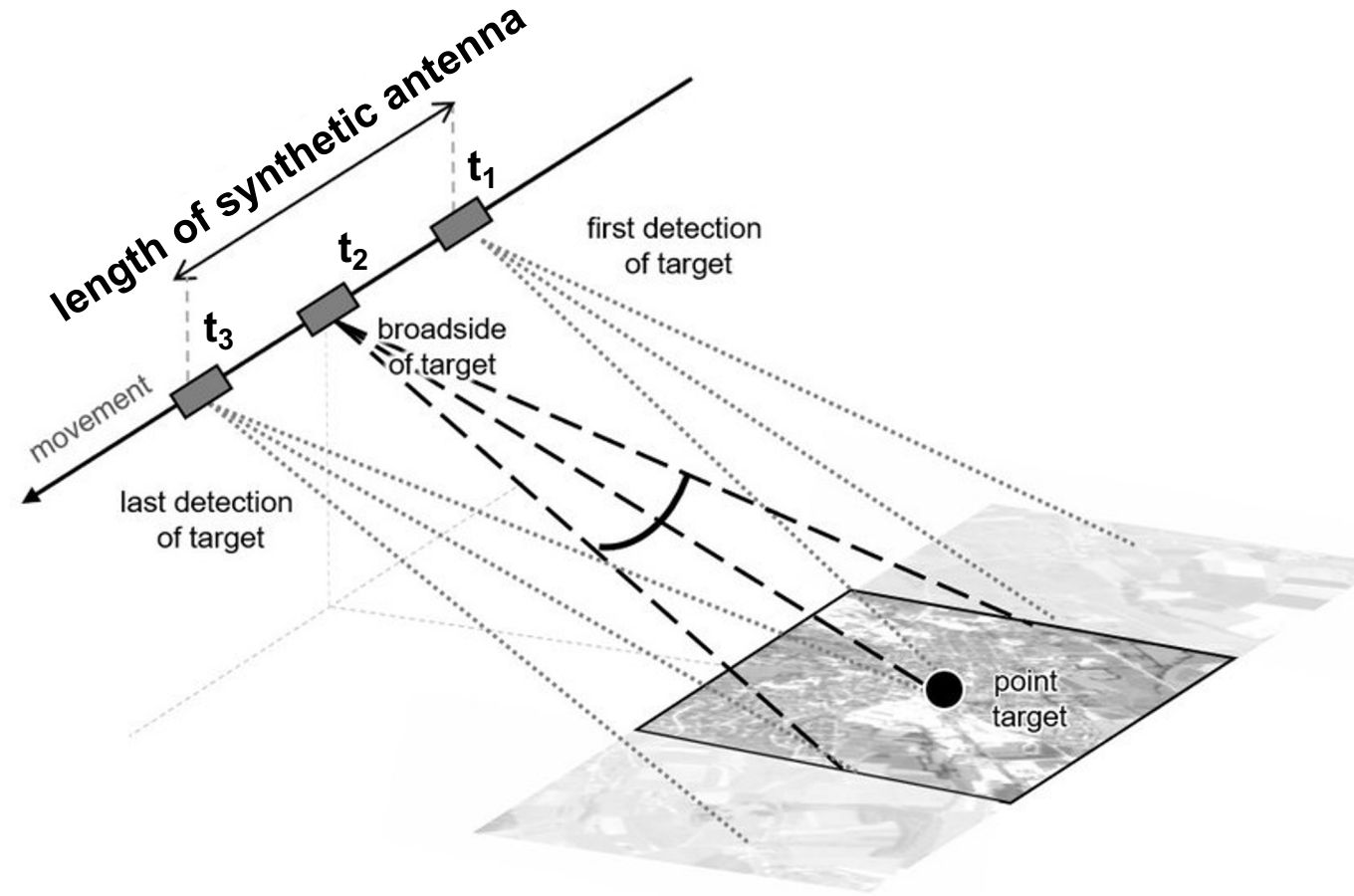
- It is not feasible to have a long (physical) antenna in space.

In a “synthetic” aperture radar (SAR) signal processing combines many individual radar pulses to “synthesize” a larger antenna.



How a synthetic aperture is created

- Signals are transmitted to and received from the same object from successive sensor positions along the orbital path (t_1 , t_2 , t_3 on the figure).
- Signals from successive sensor positions are coherently (preserved amplitude and phase) combined.
- The length of the orbit path where the object is observed is the synthetic aperture (length of the synthetic antenna).



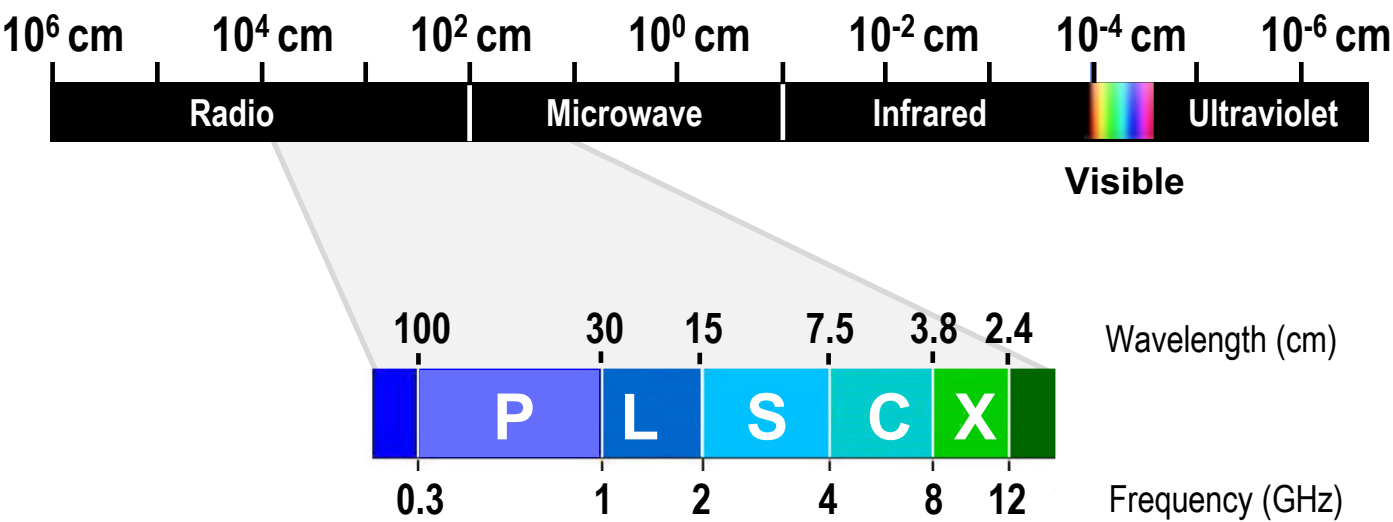
<https://up42.com/blog/tech/sar-data-complementary-optical>

Recap of Synthetic Aperture Radar

- SAR is an active sensor that transmits a radar pulse to the earth's surface and records the energy reflected back to the sensor (backscatter).
- The returned signals are coherently combined over a time interval to produce a 2D image of the normalized radar cross section
- The distance the radar sensor travels in this time interval is the synthetic aperture length.
- The synthetic aperture is much larger than the “real” antenna aperture allowing fine resolution in the azimuth (flight track) direction
 - Azimuth resolution is proportional to the wavelength (λ) over radar aperture (L), i.e. λ/L
 - Range resolution is determined by the bandwidth of the radar pulse
- Radars use microwaves (λ = few millimeters - 1 meter), which penetrate through clouds and rain



SAR wavelengths are grouped into labelled bands



Band	Frequency (GHz)	Wavelength (cm)
X	8-12	2.4-3.8
C	4-8	3.8-7.5
S	2-4	7.5-15
L	1-2	15-30
P	0.3-1	30-100

The labels were made intentionally confusing to deter spies during World War II.

from <https://www.earthdata.nasa.gov/learn/backgrounders/what-is-sar>

≠



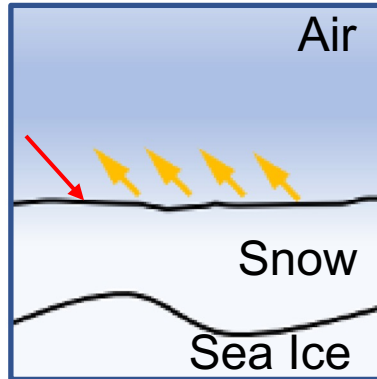
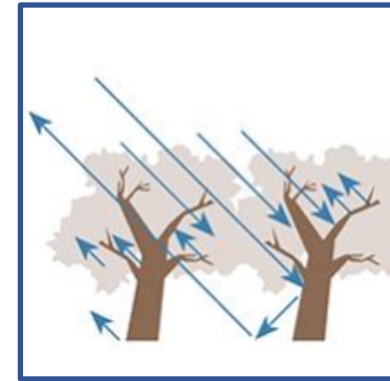
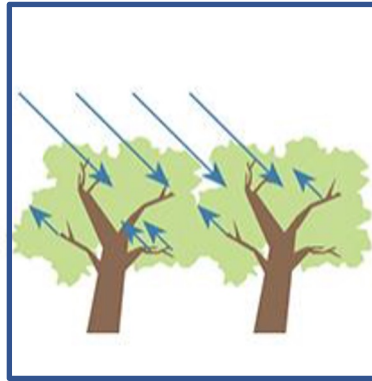
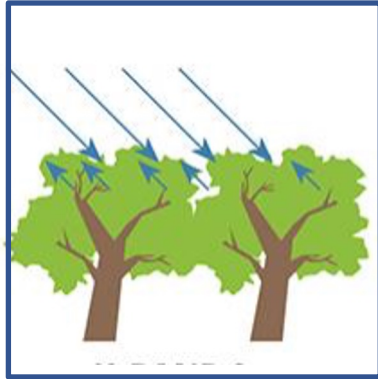
Applications of SAR Bands

Band	Frequency	Application	Satellite Based System
X	8-12 GHz	High resolution SAR (urban monitoring, ice and snow, strong scattering from vegetation cover)	TerraSAR-X, TanDEM-X, COSMO-SkyMed, COSMO-SkyMed (2nd Gen), Iceye, Capella
C	4-8 GHz	Principle frequency for European and Canadian Systems. (ice, ocean maritime navigation)	Radarsat-2, Radarsat Constellation Mission, Sentinel-1A, ERS-1, ERS-2, Envisat ASAR, Radarsat-1, Sentinel-1B
S	2-4 GHz	Limited prior usage for earth observation.	NISAR, ALMAZ,
L	1-2 GHz	Medium resolution SAR (geophysical monitoring; biomass and vegetation mapping; high penetration)	ALOS-2, SAOCOM, NISAR, Seasat, JERS, ALOS,
P	0.3 - 1 GHz	Biomass. Vegetation mapping and assessment soil moisture	Systems in gray are no longer operational

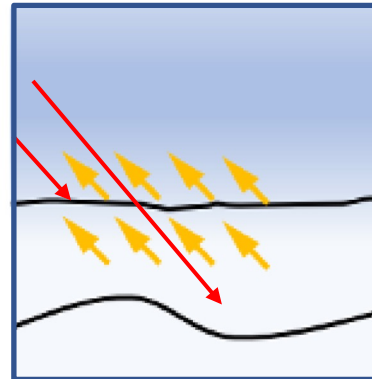


Wavelength changes the penetration depth of the signal

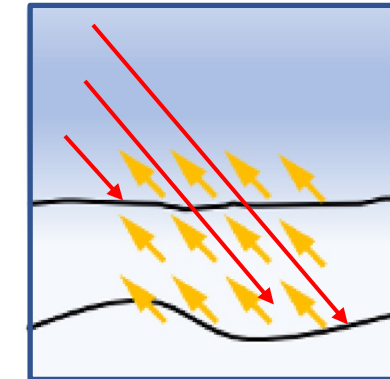
Longer wavelengths allow deeper penetration of the signal



X-Band
(λ ca. 3 cm)



C-Band
(λ ca. 6 cm)

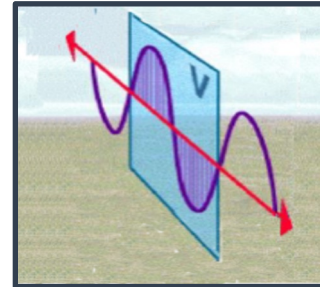


L-Band
(λ ca. 23 cm)

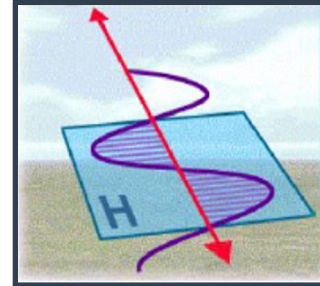
https://elib.dlr.de/145667/1/Master_Thesis_Galassi_20210629_Signed.pdf

Polarization

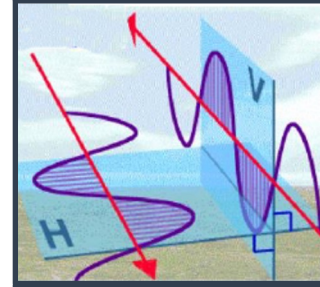
- Polarization refers to the orientation of the plane in which the transmitted electromagnetic wave oscillates.
- The polarization of the transmitted radar sensor beam can be precisely controlled.
- Measurement of the received signal strength in a selected plane of polarization can also be precisely controlled.
- How target surfaces interact with or change the polarization of the transmitted beam can help determine physical properties of the target surfaces.



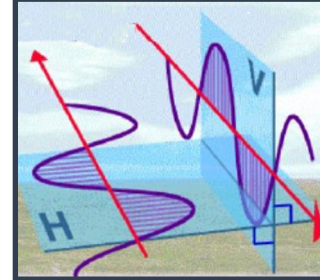
VV: Vertical Transmit, Vertical Receive



HH: Horizontal Transmit, Horizontal Receive



HV: Horizontal Transmit, Vertical Receive



VH: Vertical Transmit, Horizontal Receive

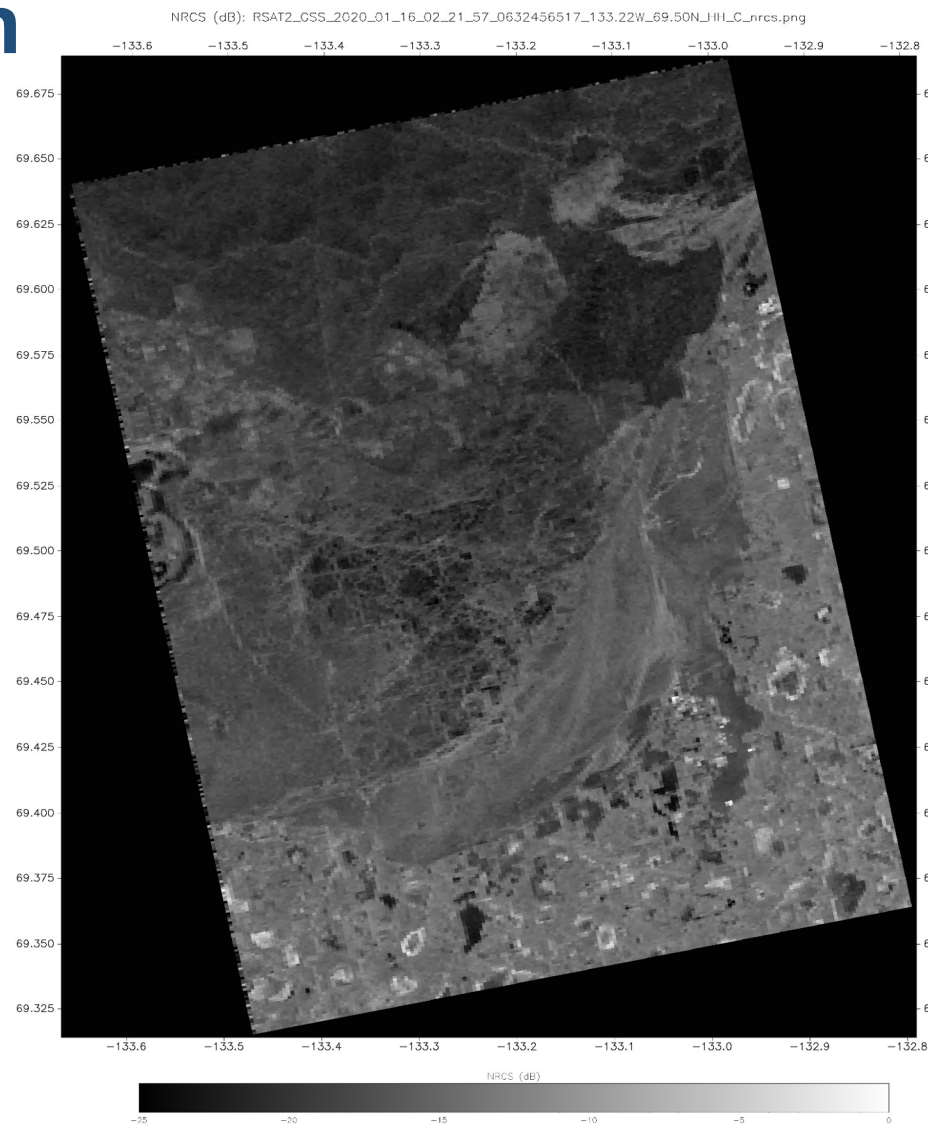
Polarization

Radarsat-2
16 January 2020
02:22 UTC

Sea Ice and
Coastal Canada

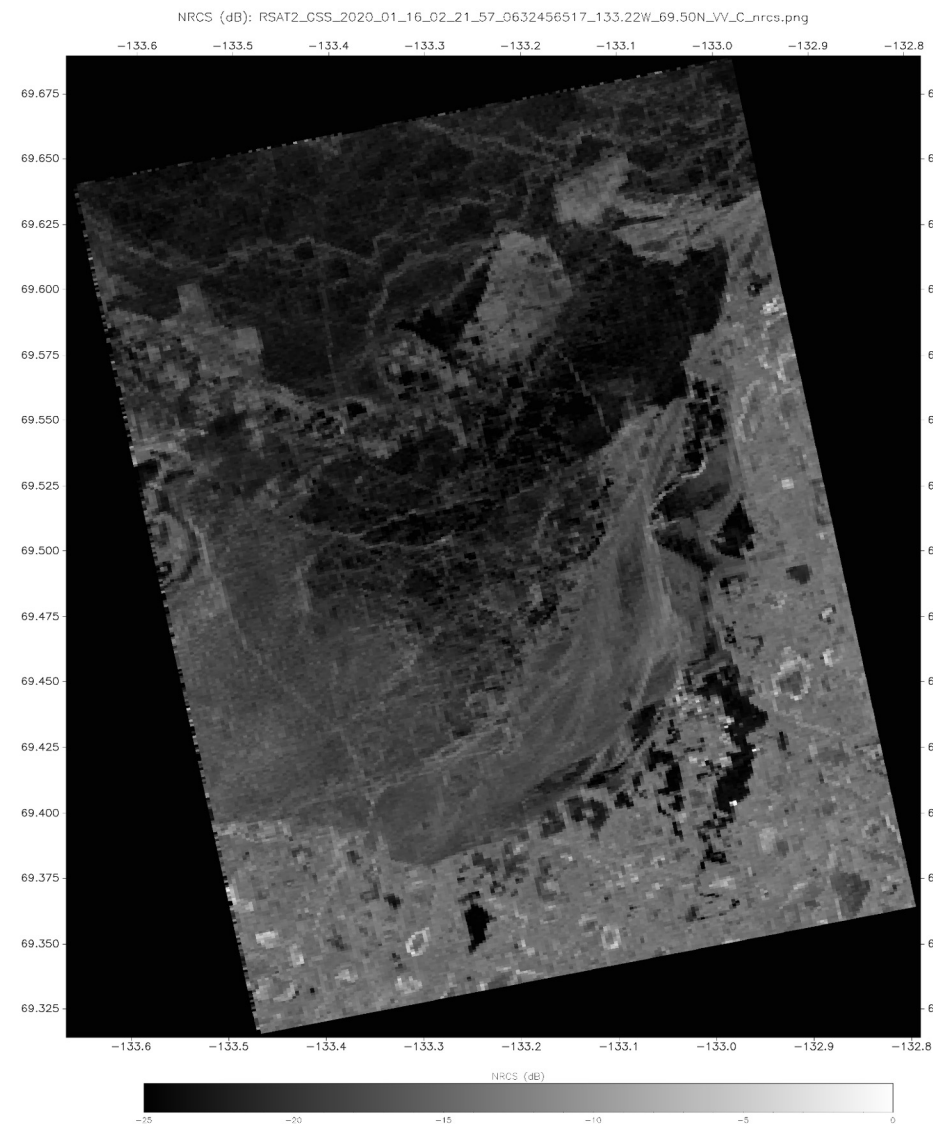


HH Polarization



RADARSAT-2 Data and Products Copyright MDA Geospatial Services Inc. 2022 - All Rights Reserved
RADARSAT is an official mark of the Canadian Space Agency
Processed at NOAA/NESDIS/STAR/SOCD for National Ice Center 2022 Sep 15 03:04:42 UTC

VV Polarization



RADARSAT-2 Data and Products Copyright MDA Geospatial Services Inc. 2022 - All Rights Reserved
RADARSAT is an official mark of the Canadian Space Agency
Processed at NOAA/NESDIS/STAR/SOCD for National Ice Center 2022 Sep 15 03:03:23 UTC



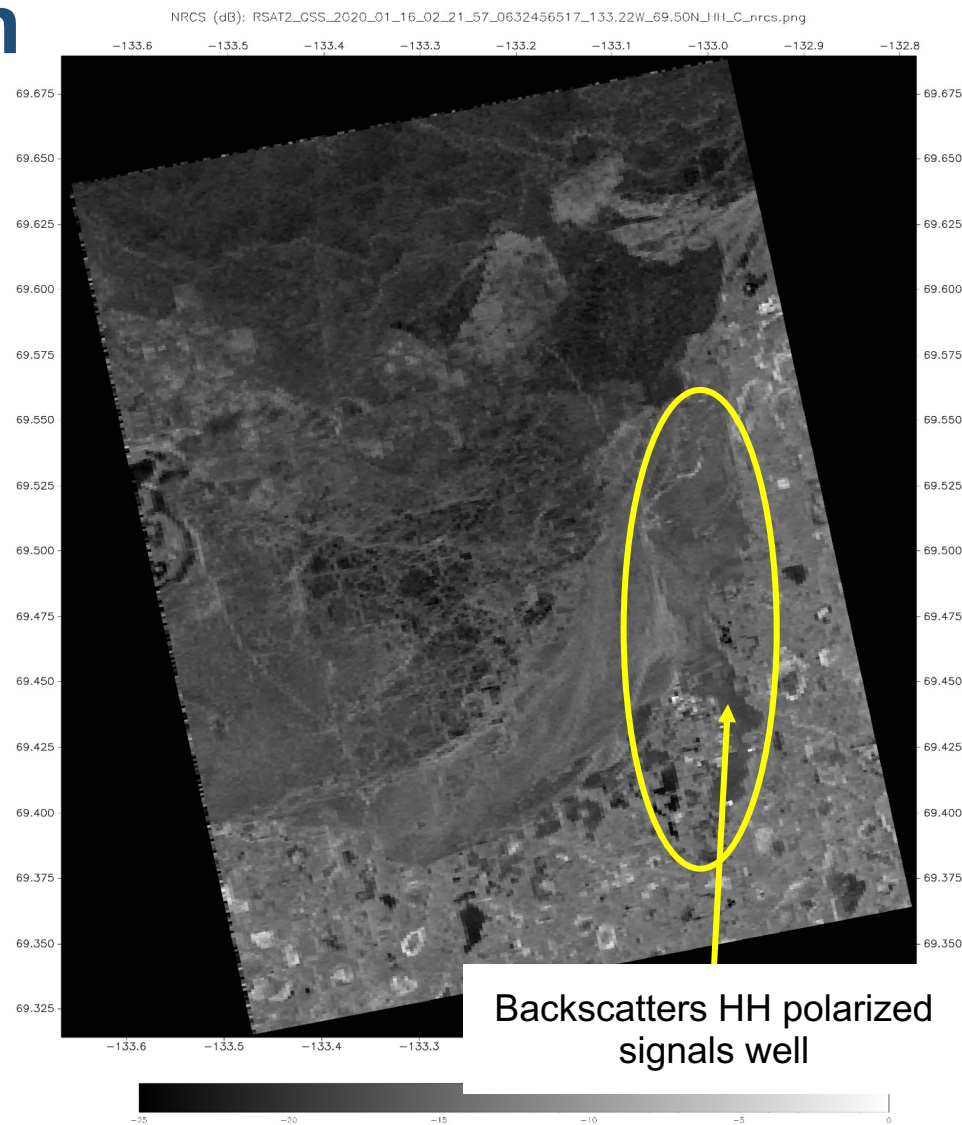
Polarization

Radarsat-2
16 January 2020
02:22 UTC

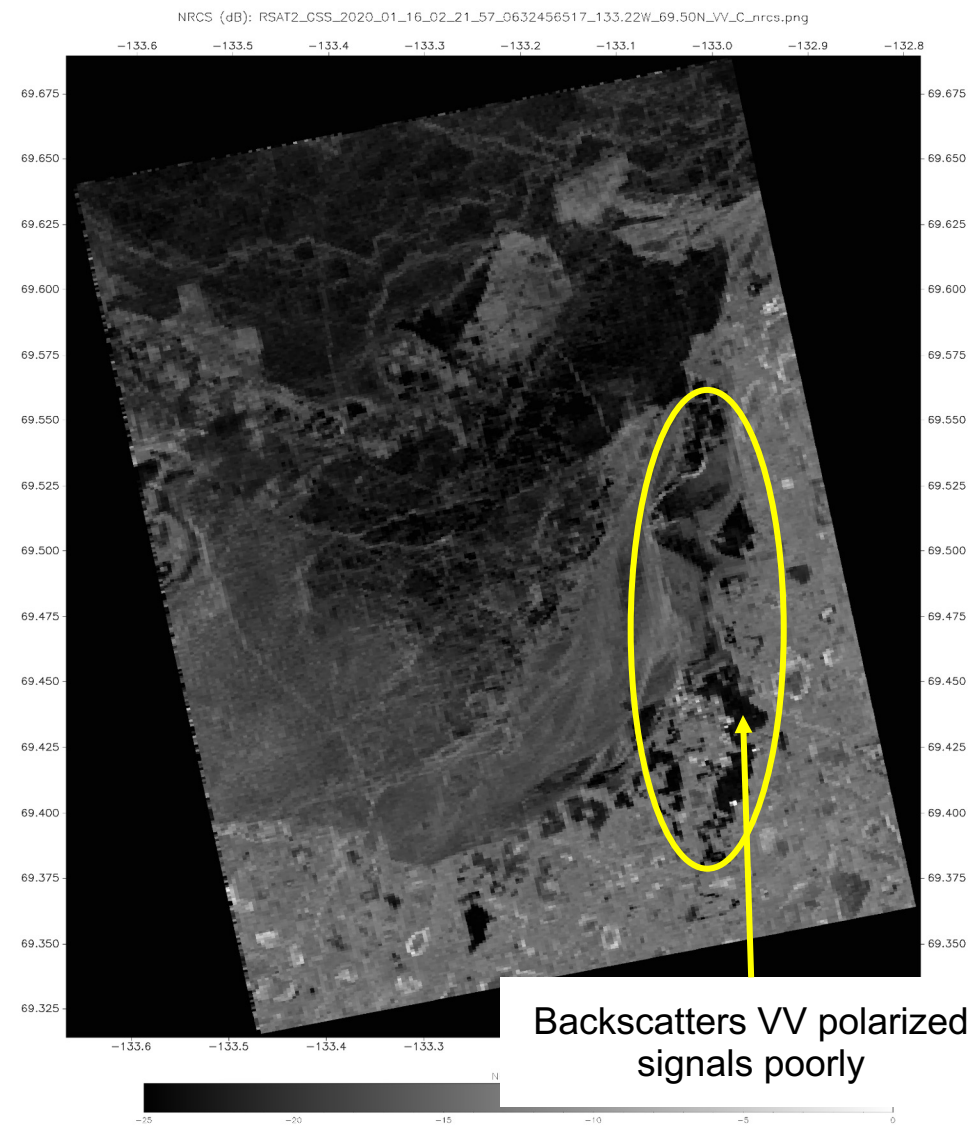
Sea Ice and
Coastal Canada



HH Polarization



VV Polarization

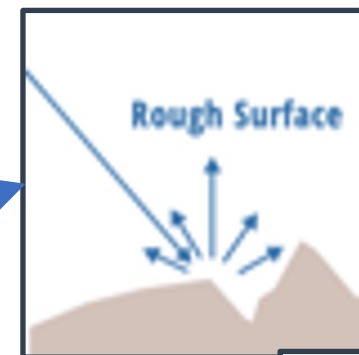


SAR Scattering and Polarization

Examining these different polarizations carries information about the structure of the imaged surface, based on the following types of scattering and how surfaces interact with polarized beam:

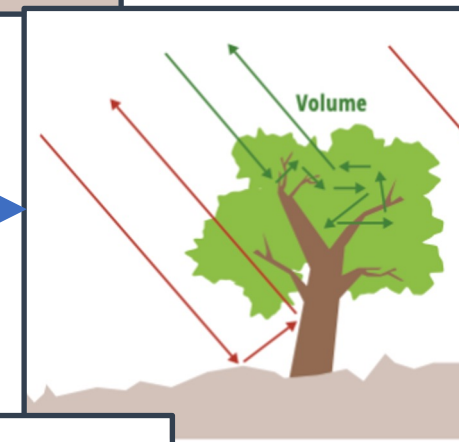
- **Rough surface scattering (single bounce):**

Sensitive to VV scattering. Used for surface wind speeds.



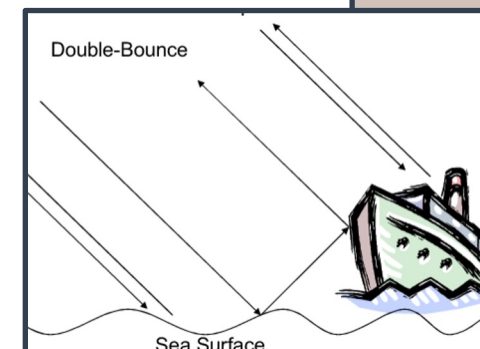
- **Volume (multiple bounce) scattering:**

Volume scattering, (e.g. caused by the leaves and branches in a forest canopy) is most sensitive to cross-polarized data like VH or HV.

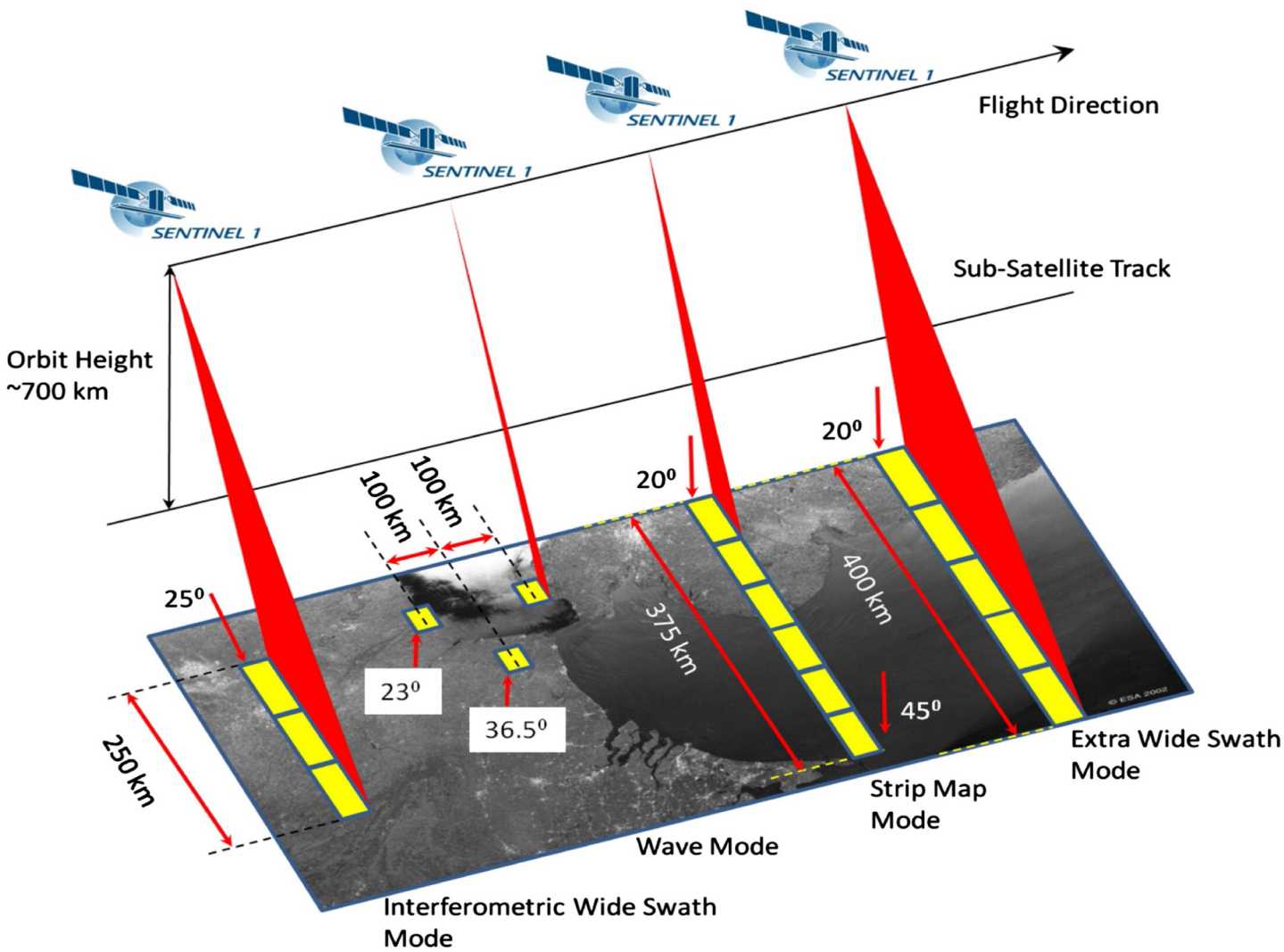


- **Double bounce scattering:**

double bounce, is caused by buildings, tree trunks, or inundated vegetation and is most sensitive to an HH



Sentinel-1 is the current generation of SAR



The latest generation of SAR have very sophisticated capabilities offering a wide variety of data collection modes

For a SAR on a polar-orbiting satellite, this imagery can have fine spatial resolution of <100 meters over a swath that can be as wide as 500 kilometers

- Tradeoffs between coverage area and resolution

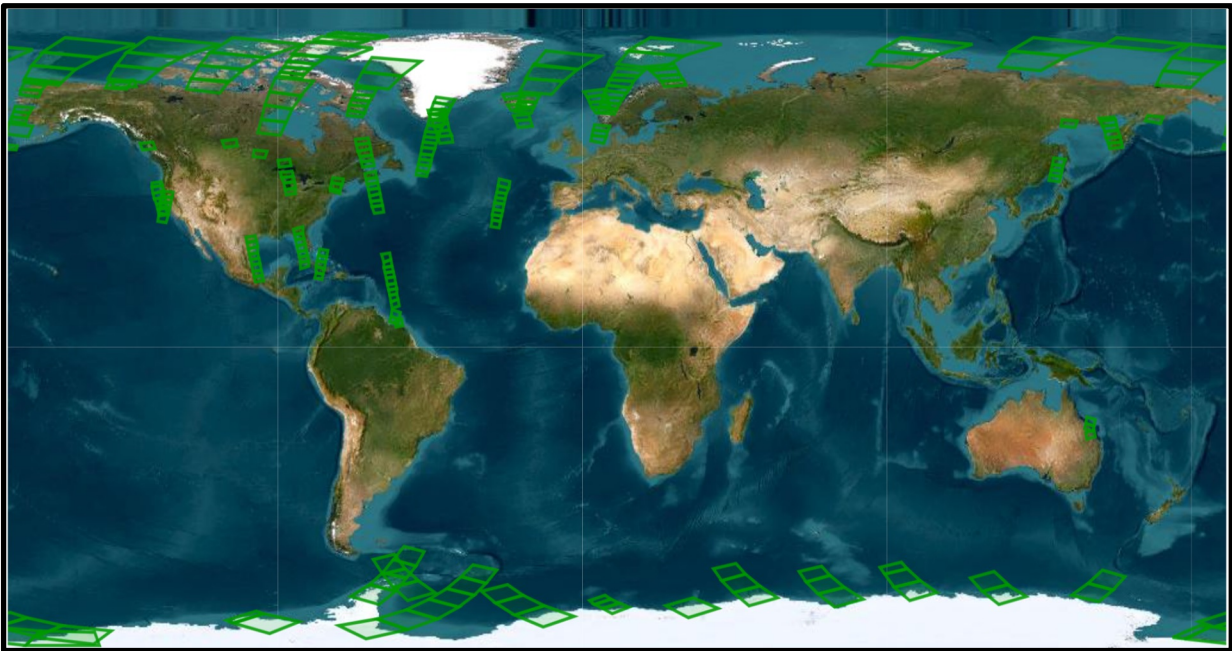
Imaging Modes for Sentinel-1

Beam Mode	Swath	Incidence Angle (deg)	Bean Information
Stripmap (SM)	80 km	18.3 - 46.8	Has 6 possible positions
Interferometric Wide (IW)	240 km	29.1 - 46	Composed of 3 sub - swath
Extra Wide Swath (EW)	410 km	18.9-47	Composed of 5 sub-swaths

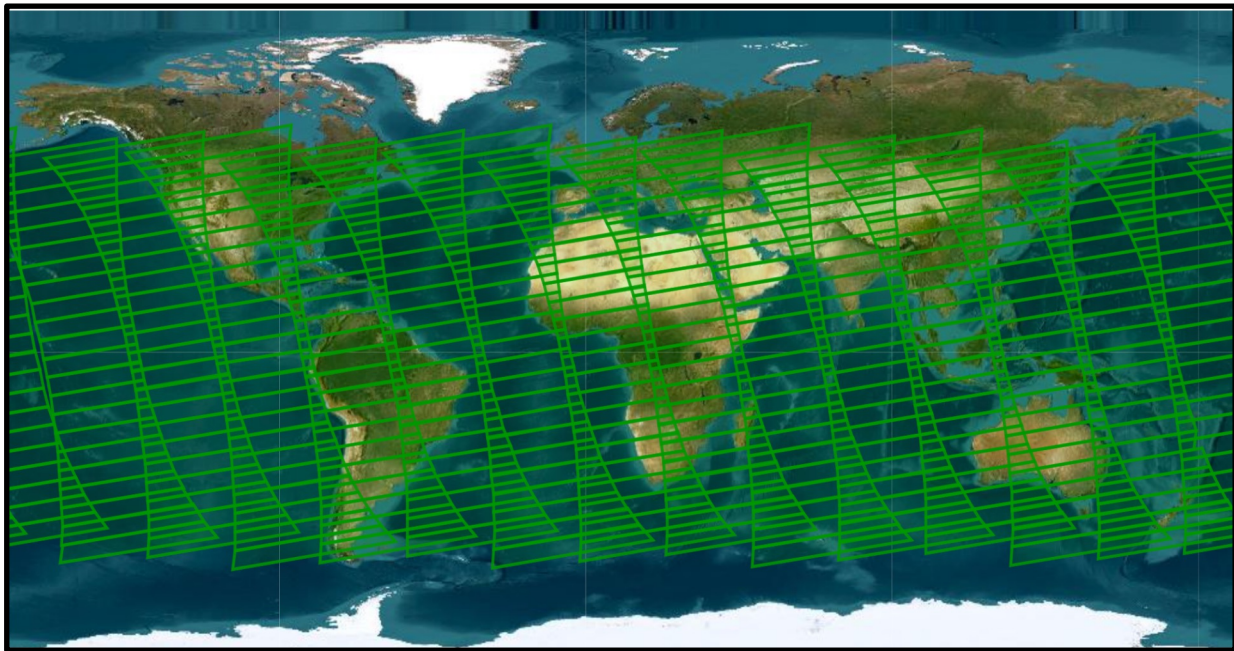


Comparison of a Sentinel-1(SAR) and VIIRS-SNPP (Ocean Color)

Sentinel-1: Scenes collected, 29 March 2021+



VIIRS SNPP: Scenes collected, 29 March 2021*



- SAR data is collected in small footprint over only a portion of an orbit.
- Limited by power, duty cycle and data volume

+Additional S1 scenes over Europe and Asia are not shown
*VIIRS collections over the North and South pole are not shown

	Sentinel-1	VIIRS-SNPP
Swath width	40-400 km	3000 km
Spatial resolution	5-100 m	750 m
Revisit time - Polar	<1-3 days	multiple/day
- Mid-latitudes	12 days	2 times/day
Minutes of collection/orbit	25 min	continuous
Scenes/day	600	240



SAR Data at CoastWatch

The screenshot displays the CoastWatch Data Portal interface. The main map shows a 3D view of the Earth with SAR data overlays. The interface includes a top navigation bar with the NOAA logo, a search bar, and a 'CoastWatch Data Portal' title. On the left, there is a sidebar with various controls: a date/calendar selector set to Jan 27, 2023, an active layers panel, and a 'CoastWatch Data Layers' panel. The 'CoastWatch Data Layers' panel has a 'Layers' tab and a 'L1/L2 Spatial Search' section. Under 'Near real-time:', several layers are listed, with 'S-1A: NRCS' and 'S-1B: NRCS' highlighted by a yellow circle. Other layers include 'S-NPP: Ocean Color', 'S-20: Ocean Color', 'S-2A: True Color', 'S-2B: True Color', 'S-3A: Ocean Color', 'S-3B: Ocean Color', 'NRCS Cross-pol', and 'MCI'. A 'Science Quality / RAN / Delayed:' section is also visible. The bottom of the sidebar shows a 'Search Results' button and a 'Reference Layers' panel. On the right side of the map, there are additional panels for 'User Data', 'Search Results', and 'Info'. The map itself shows a 3D view of the Earth with SAR data overlays, including a 1000km scale bar and a NOAA logo in the bottom right corner.

Sentinel-1 SAR imagery (since 2018) around the U.S. and the Arctic are available at CW
The data are in NetCDF format and can be previewed with PNG images

https://coastwatch.noaa.gov/cw_html/cwViewer.html



SAR Data at Alaska Satellite Facility

The screenshot displays the Alaska Satellite Facility (ASF) Data Search Vertex interface. The top navigation bar includes the NASA logo, 'EARTHDATA', and 'Other DAACs'. The search bar has fields for 'Search Type' (Geographic Search), 'Dataset' (Sentinel-1), 'Area of Interest' (WKT), 'Start Date' (1/27/2023), 'End Date' (1/27/2023), and 'Filters' (1,000 of 595 Files). The map view shows a satellite image of the Arctic region with blue outlines indicating SAR data swaths. The bottom left shows '595 Scenes (595 of 595 Files)' and a thumbnail of a SAR image labeled 'S1A_IW_GRDH_1SDV_20230128T04441... 491F January 28 2023 04:44:10Z'.

- The Alaska Satellite Facility Data Archive host data from a variety of SAR sensors (Sentinel-1, ALOS-1, ERS).
- The data are available in a variety of formats
- Specialized software is needed to read the native data formats
- Requires registration with NASA (free) to download the imagery.

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



Sentinel-1 Data at ESA's Copernicus Scientific Data Hub

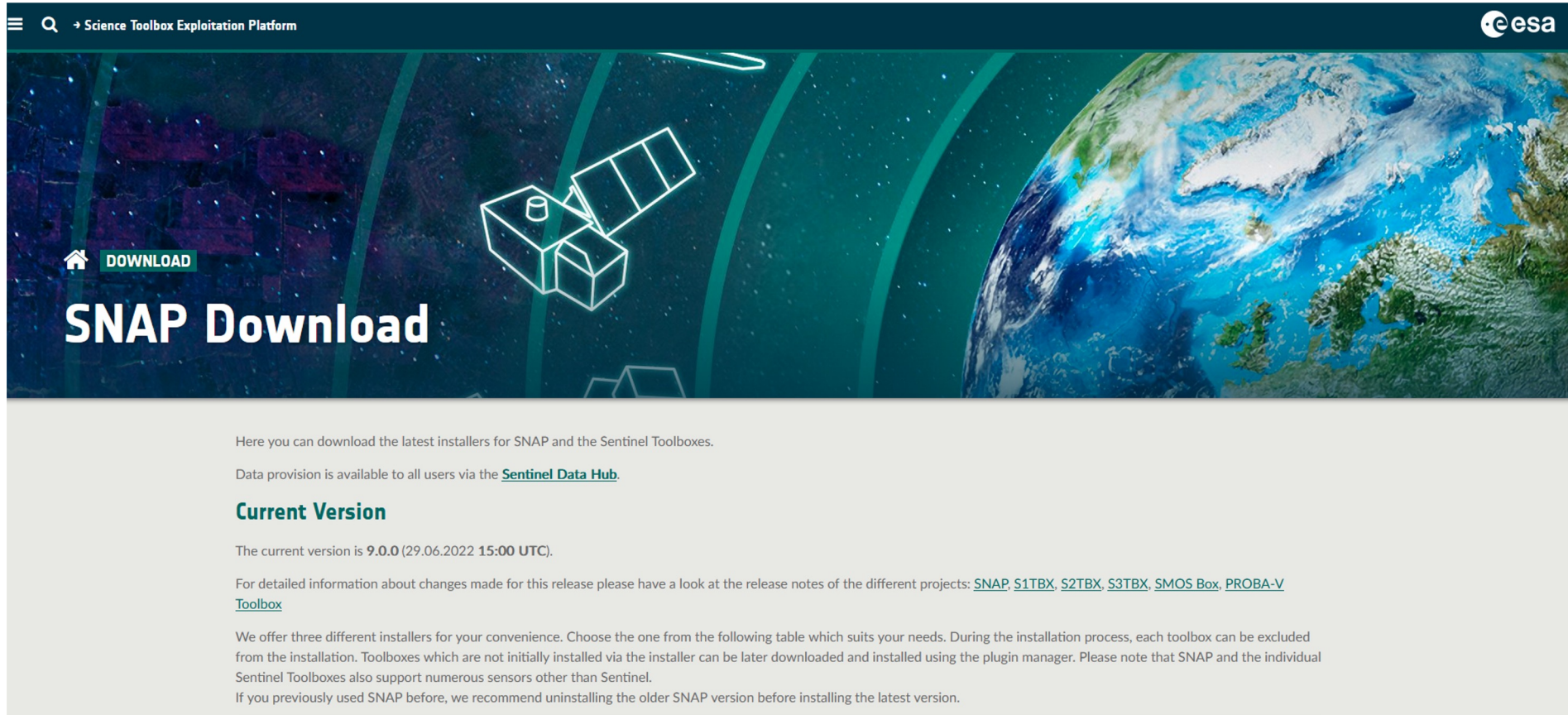
The screenshot displays the Copernicus Open Access Hub interface. On the left, the 'Advanced Search' panel is visible, featuring filters for 'Sort By' (Sensing Date), 'Order By' (Descending), 'Sensing period' (2023/01/27), and 'Ingestion period'. It also includes sections for 'Mission: Sentinel-1', 'Mission: Sentinel-2', and 'Mission: Sentinel-3', each with dropdowns for 'Satellite Platform', 'Product Type', and 'Sensor Mode'. The main area on the right shows a map of Europe with several red rectangular swaths indicating Sentinel-1 data coverage over the North Atlantic and Europe. The map includes labels for various countries and cities.

- Sentinel-1 imagery are available at the Copernicus Scientific Data Hub.
- The data are available in the S1 native format (xml/geotiff)
- Requires registration to download the imagery.

<https://scihub.copernicus.eu/dhus/#/home>



SNAP Toolbox for SAR data



The screenshot shows the 'SNAP Download' page on the 'Science Toolbox Exploitation Platform'. The header includes a search icon, a home icon, and the ESA logo. The main banner features a satellite in space and a SAR image of Earth. A 'DOWNLOAD' button is visible. The page content states that the latest installers for SNAP and Sentinel Toolboxes are available for download. It mentions that data provision is available to all users via the [Sentinel Data Hub](#). The 'Current Version' is 9.0.0 (29.06.2022 15:00 UTC). It provides links to release notes for various projects: [SNAP](#), [S1TBX](#), [S2TBX](#), [S3TBX](#), [SMOS Box](#), and [PROBA-V Toolbox](#). A note explains that three different installers are offered for convenience, and that toolboxes can be excluded during installation or added later via a plugin manager. It also advises uninstalling older versions of SNAP before installing the latest.

Here you can download the latest installers for SNAP and the Sentinel Toolboxes.

Data provision is available to all users via the [Sentinel Data Hub](#).

Current Version

The current version is **9.0.0** (29.06.2022 15:00 UTC).

For detailed information about changes made for this release please have a look at the release notes of the different projects: [SNAP](#), [S1TBX](#), [S2TBX](#), [S3TBX](#), [SMOS Box](#), [PROBA-V Toolbox](#)

We offer three different installers for your convenience. Choose the one from the following table which suits your needs. During the installation process, each toolbox can be excluded from the installation. Toolboxes which are not initially installed via the installer can be later downloaded and installed using the plugin manager. Please note that SNAP and the individual Sentinel Toolboxes also support numerous sensors other than Sentinel.

If you previously used SNAP before, we recommend uninstalling the older SNAP version before installing the latest version.

<https://step.esa.int/main/download/snap-download/>

- SNAP will read the native format of most SAR system
- Users can calibrate and manipulate the data (sub-set or composite)



References and other online trainings

- <https://www.star.nesdis.noaa.gov/socd/mecb/sar/publications.html>
- <https://ntrs.nasa.gov/api/citations/20190002563/downloads/20190002563.pdf>
- <https://www.earthdata.nasa.gov/learn/backgrounders/what-is-sar>
- <https://earth.esa.int/eogateway/missions/ers/radar-courses/radar-course-1>
- <https://appliedsciences.nasa.gov/join-mission/training/english/arset-introduction-synthetic-aperture-radar>
- <https://eo-college.org/courses/echoes-in-space/>



The CoastWatch Synthetic Aperture Radar instructional series

The CoastWatch Synthetic Aperture Radar (SAR) instructional series consists of three (3) training modules:

Module 1: An overview of SAR (this module)

Module 2: Descriptions of available SAR products and where to find them (in development)

Module 3: Examples of how various phenomena appear in SAR imagery (in development)

