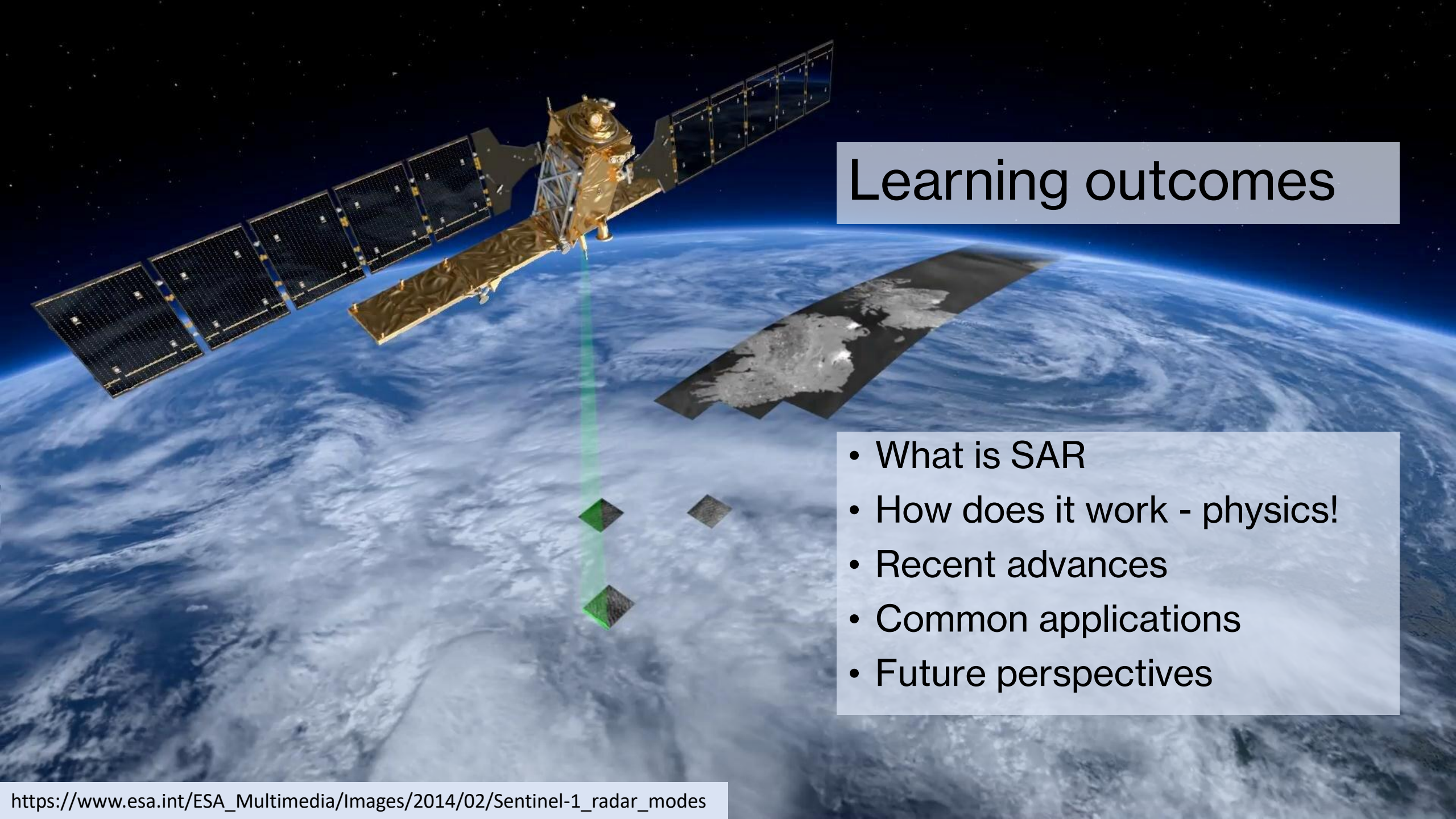
Introduction to Synthetic Aperture Radar

UNBC GEOG457 Advanced Remote Sensing
February 11, 2022

Sentinel-1, Fraser Delta, Floods



Learning outcomes

- What is SAR
- How does it work - physics!
- Recent advances
- Common applications
- Future perspectives

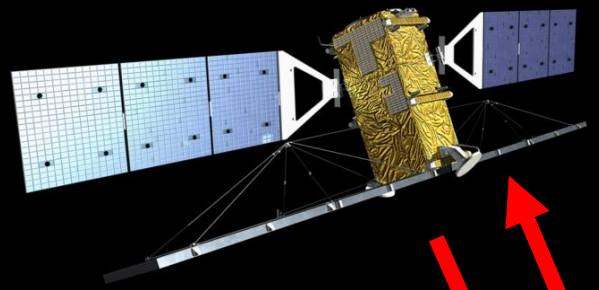
https://www.esa.int/ESA_Multimedia/Images/2014/02/Sentinel-1_radar_modes

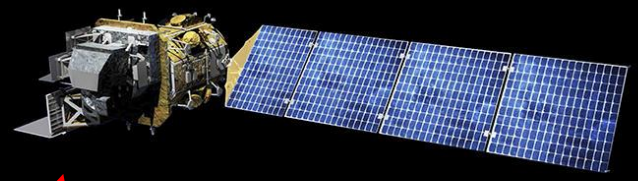
Active

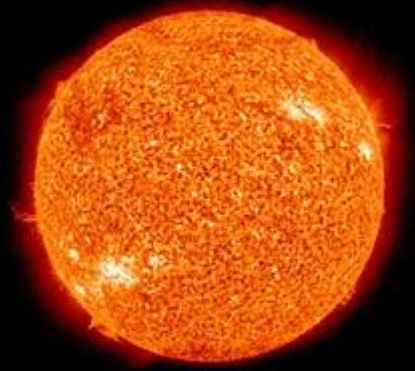
Radar, LiDAR, …

Passive

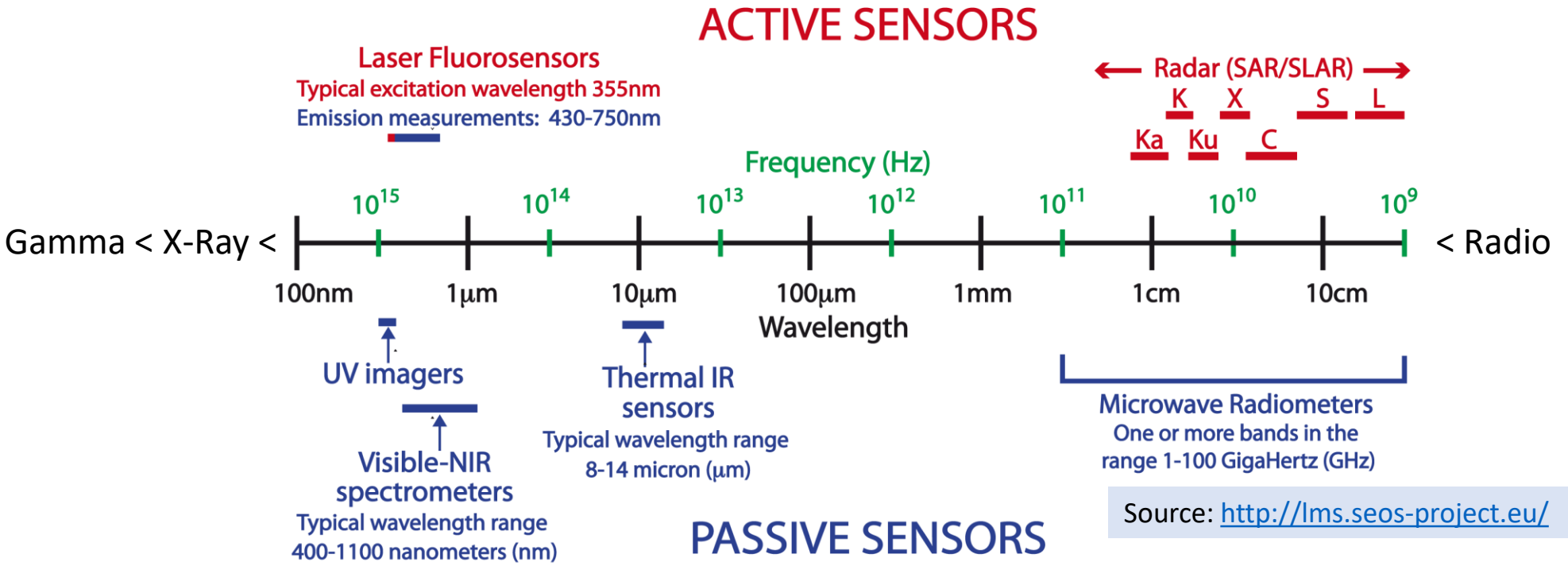
Visible, Infrared, Thermal, …



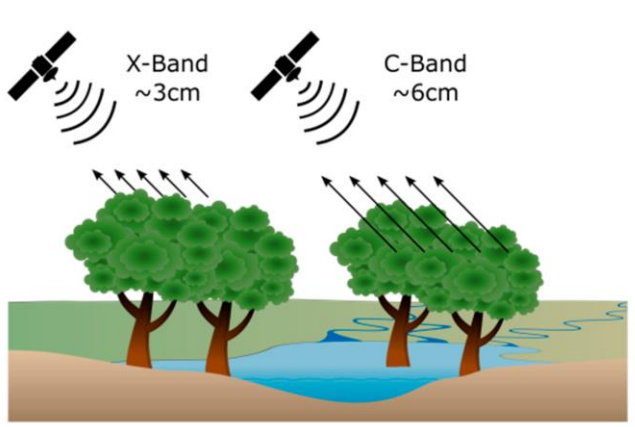


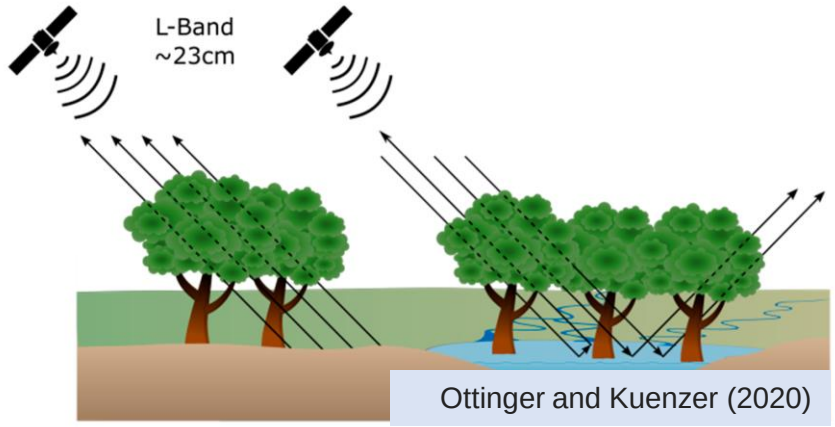


Electromagnetic spectrum



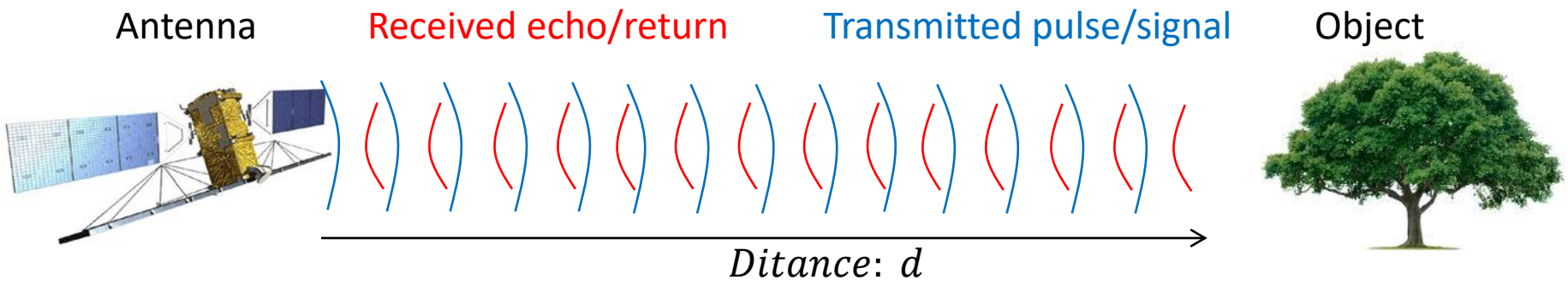
Source: http://lms.seos-project.eu/





Ottinger and Kuenzer (2020)

Radio detection and ranging



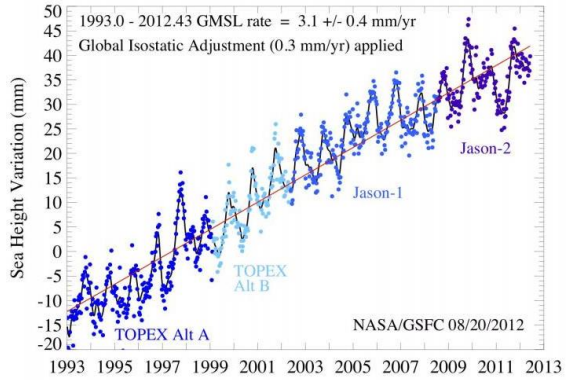
$$Speed\ of\ light: c$$

$$time = \frac{2d}{c}$$

$$d = \frac{time * c}{2}$$

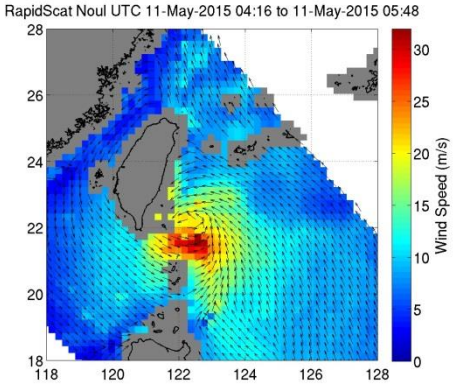
Radar remote sensing

Altimeters: Measures range at nadir (eg. Ocean surface, ice sheet surface, etc.)



Global mean sea level variations (NASA MEaSUREs, 2017)

Scatterometers: Measures surface roughness (eg. Ocean surface winds, waves, etc.)

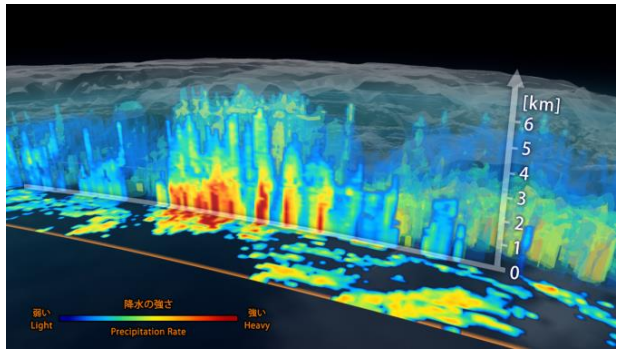


Typhoon seen with a scatterometer (NASA Winds, 2017)

Synthetic Aperture Radar: 2D imaging radar (eg. Change detection, hazards, dem, etc.)

SAR image of Capitol building, Washington. *(IEEE, 2017)*

Weather Radar: 3D images of clouds and precipitation (eg. Rain, snow, etc.)



Weather radar image of a cyclone *(JAXA/NASA, 2017)*

Radar resolution

- Two factors control the spatial resolution of radar data
  - **Duration of the radar pulse (x axis, or perpendicular)**

$$P_r = \frac{c\tau}{2}$$

$\boldsymbol{P_r} = range\ resolution$	***5 m***
$\boldsymbol{c} = sp.of\ light$	***3.0 x 10^5***
$\boldsymbol{\tau} = pulse\ duration$	***3.3 x 10^{-5}***

Realistic!

  - **Antenna size (y axis, or parallel)**

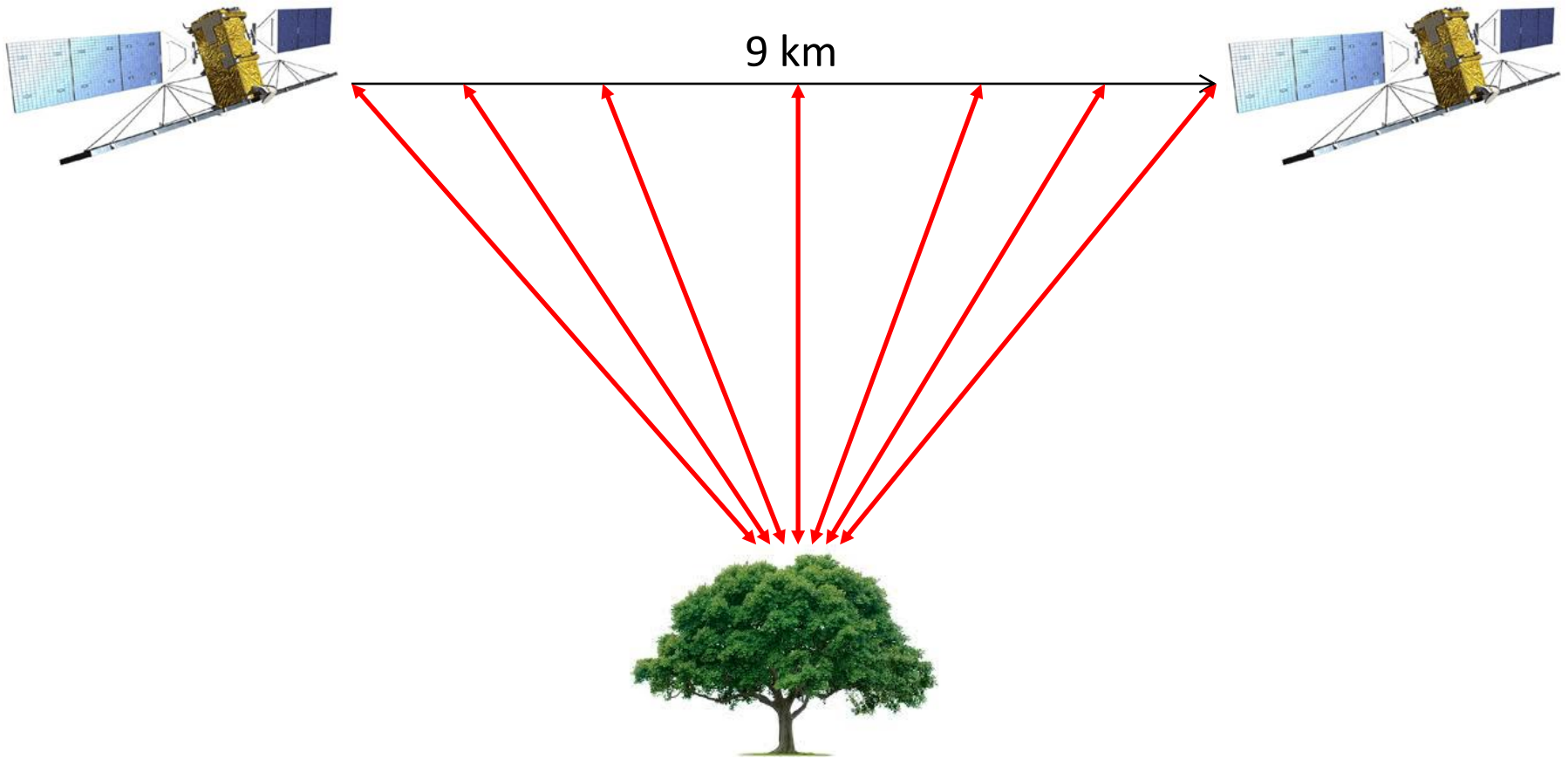
$$\rho_\alpha = R\frac{\lambda}{l_\alpha}$$

$\boldsymbol{\rho_\alpha} = azimuth\ resolution$	***5 m***
$\boldsymbol{R} = distance\ from\ object$	***800 km***
$\boldsymbol{\lambda} = signal\ wavelength$	***5.6 cm***
$\boldsymbol{l_\alpha} = antenna\ size$	***9 km***

Unrealistic!

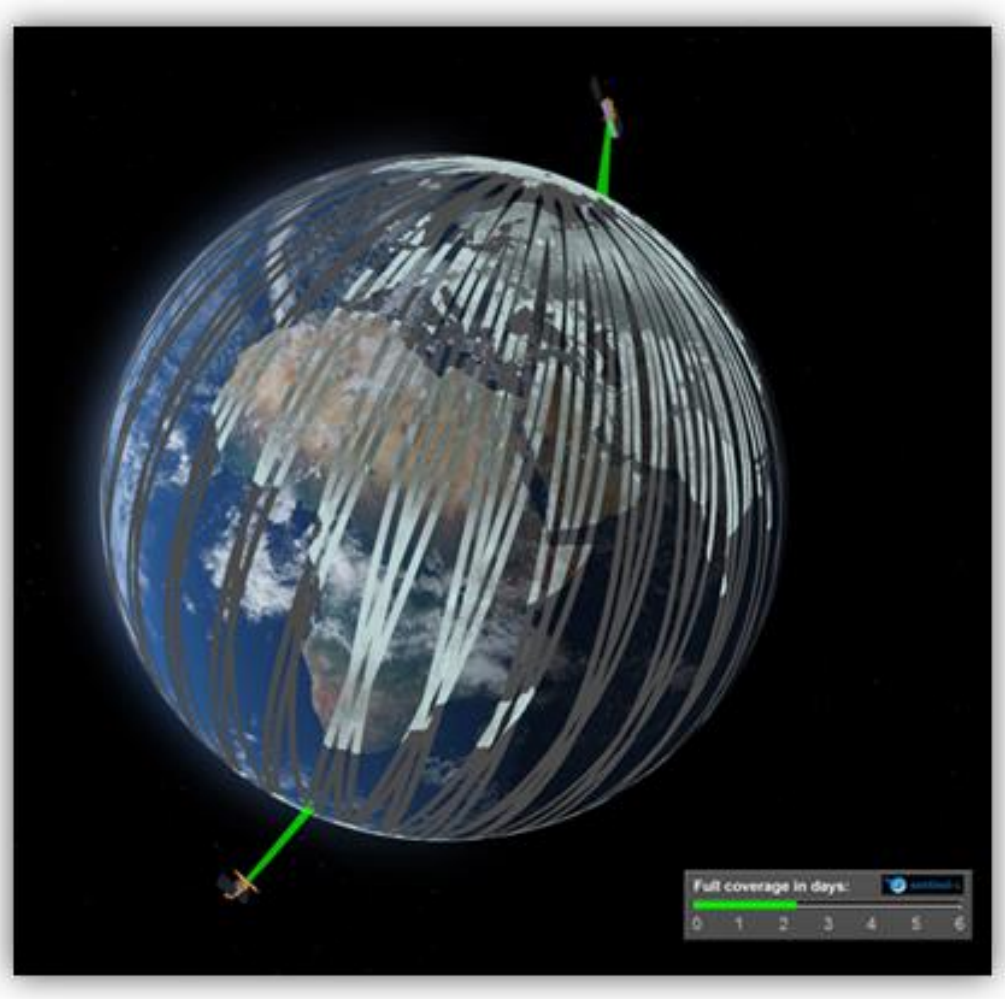
Synthetic Aperture Radar

- Combines the radar data from every pulse while an object is in view of the satellite. Acquires radar images. Synthetic antenna is 9 km!



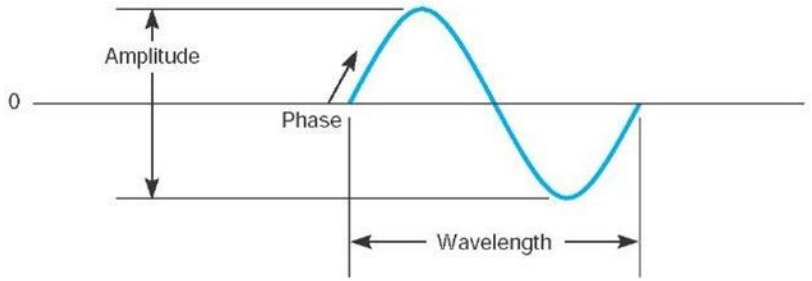
Orbit

- **Why side-looking?**
- **Ascending vs Descending?**



What does SAR see?

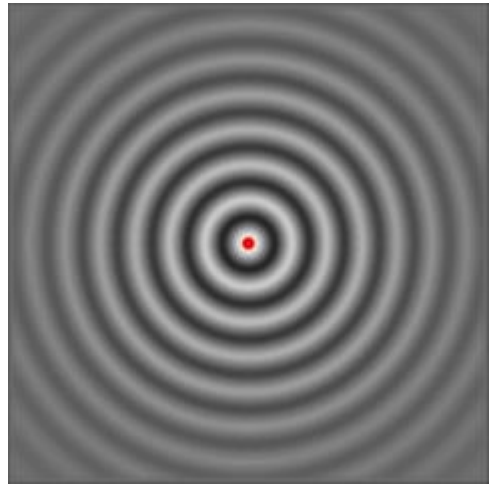
- **Records:**
  - **Amplitude (A)**: Strength of the echo
  - **Phase (P)**: Echo compared to reference



- **Image characteristics:**
  - **Backscatter (σ^{θ})**: Degree to which the signal is scattered, f(A)

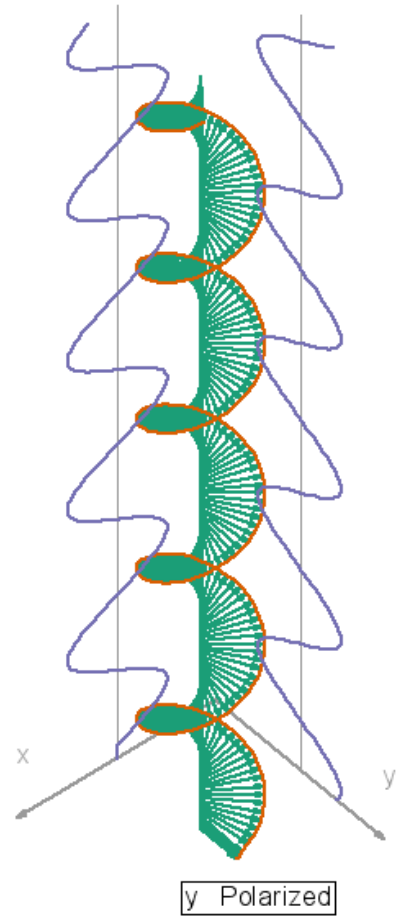
$$\sigma^{\theta} = \frac{amplitude\ received}{amplitude\ expected\ from\ an\ isotropic\ surface}$$

  - **Speckle (..chaos..)**: Speckle is the relation of a pixel characterisation compared to the scene statistics “Salt and pepper”



Polarization

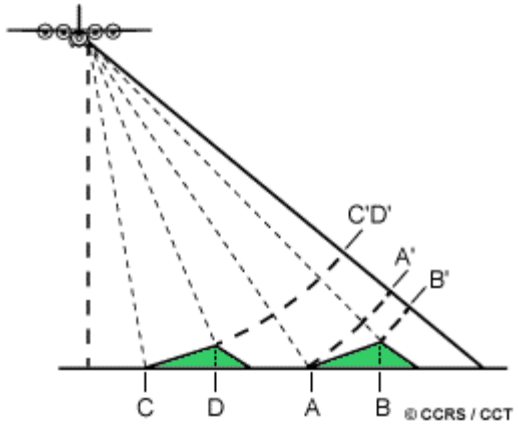
- **Combinations:** HH, VV, HV, VH
- **Single Pol:** Only one combination
- **Dual Pol:** Two combinations possible, simultaneously
- **Quad Pol:** 4 combinations possible, simultaneously

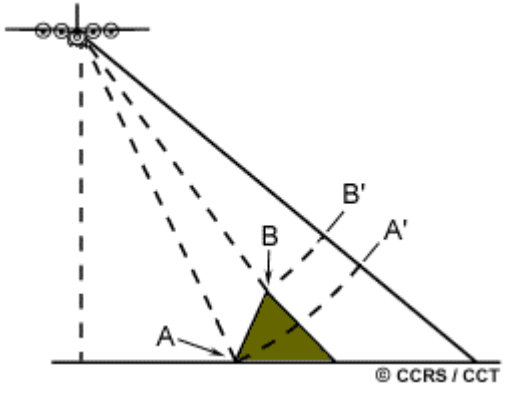


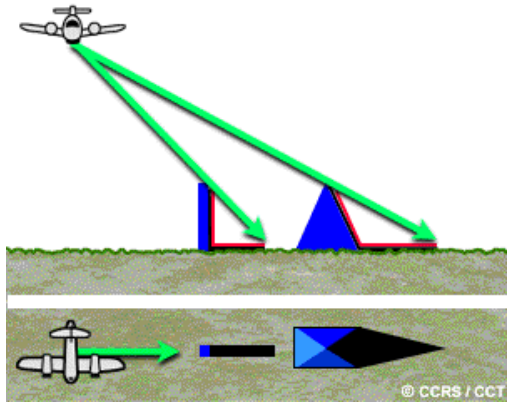
https://nisar.jpl.nasa.gov/mission/get-to-know-sar/polarimetry/

SAR Challenges

- Many distortions
  - **Foreshortening**: Hills facing the radar appear “compressed”, and hills facing away from the radar appear “stretched”
  - **Layover**: Peak (closer to sensor) appears before valley (further from sensor)
  - **Shadow**: No data in hidden areas (sensor is blind)

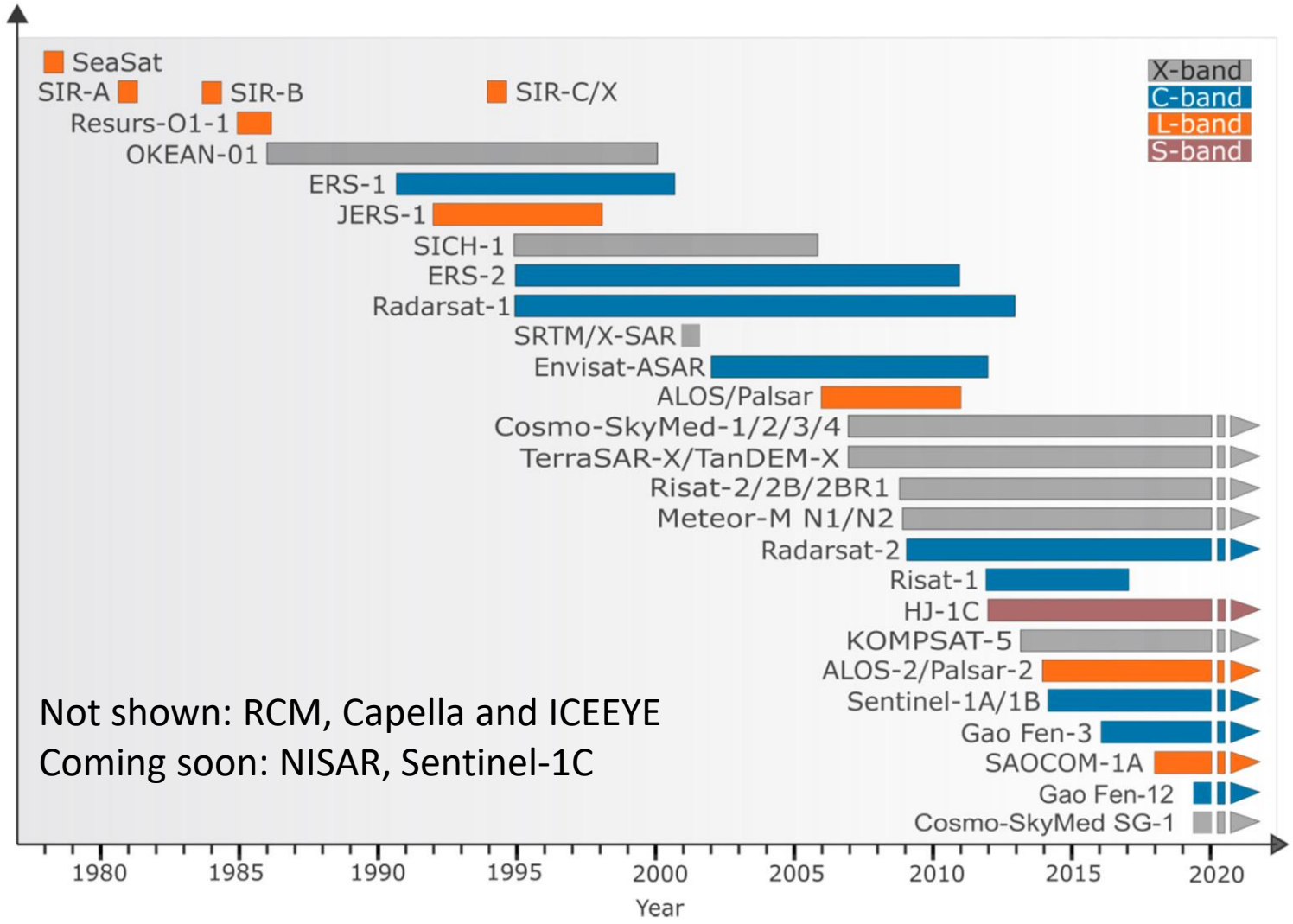






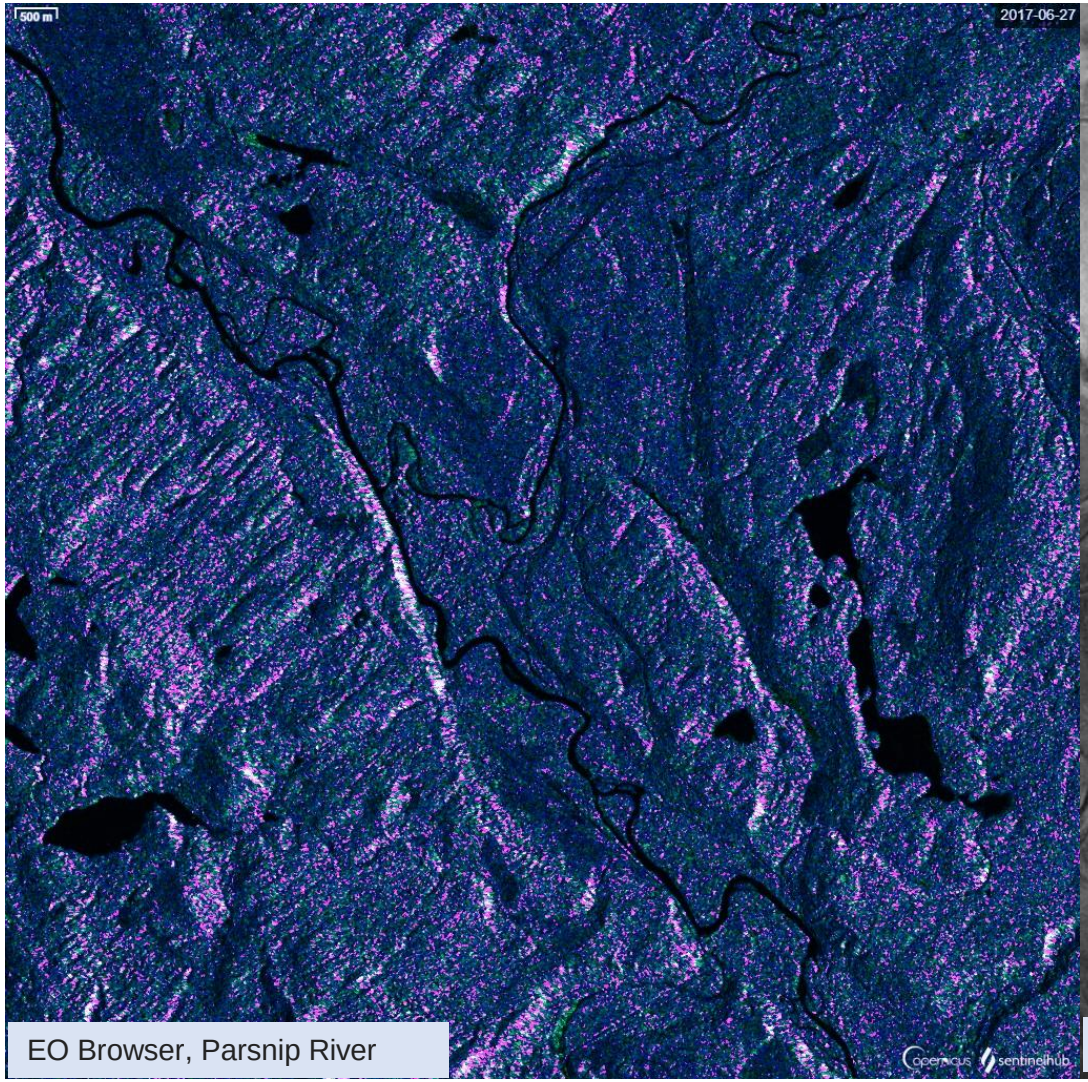
Why Synthetic Aperture Radar

Complimentary to Optical
Continuous monitoring
Penetration into different materials
Fine spatial resolution



Ottinger and Kuenzer (2020)

SAR methods: Change detection/monitoring

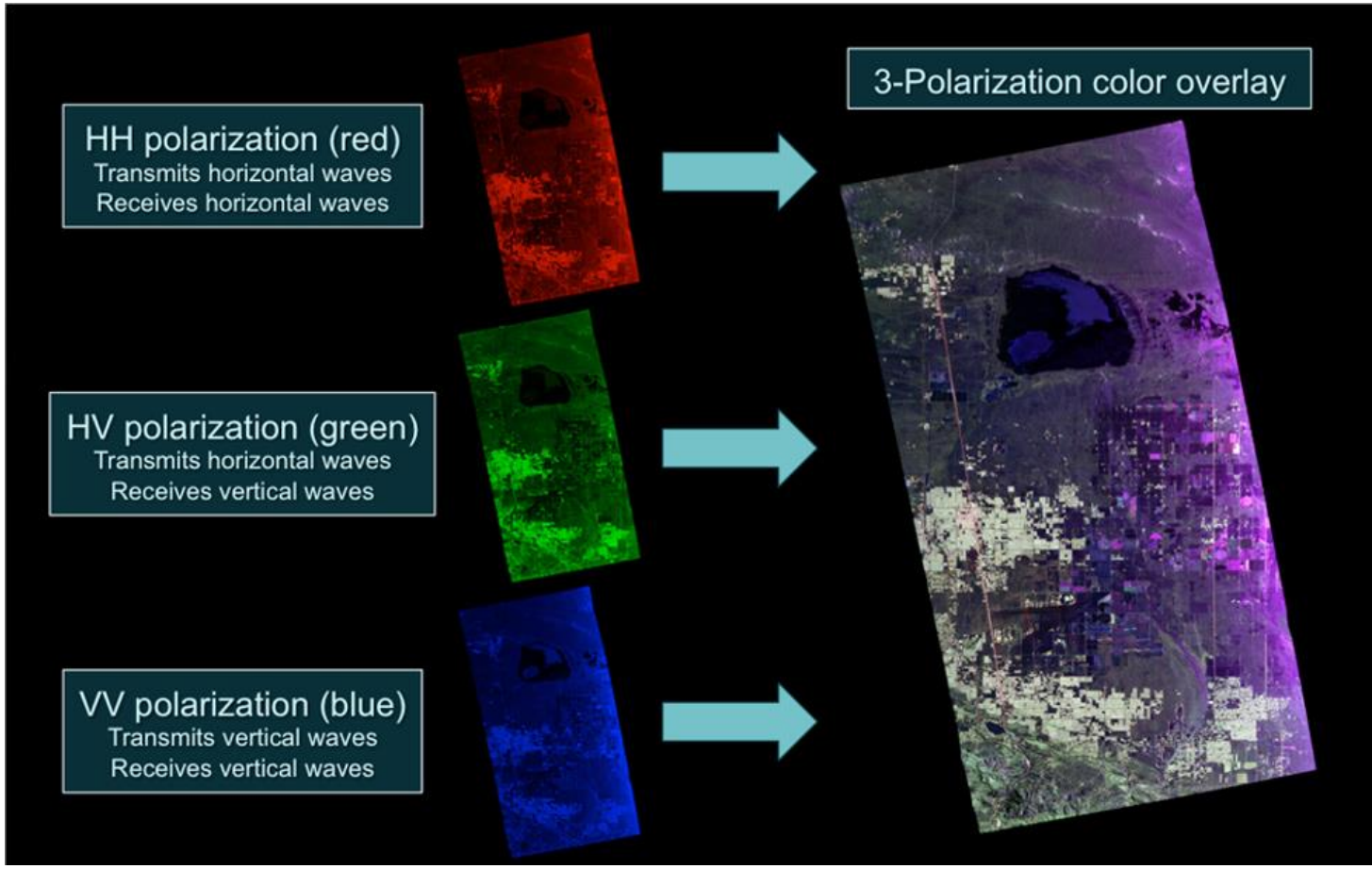


EO Browser, Parsnip River

Capella Space, Kashmir

SAR methods: Polarimetry

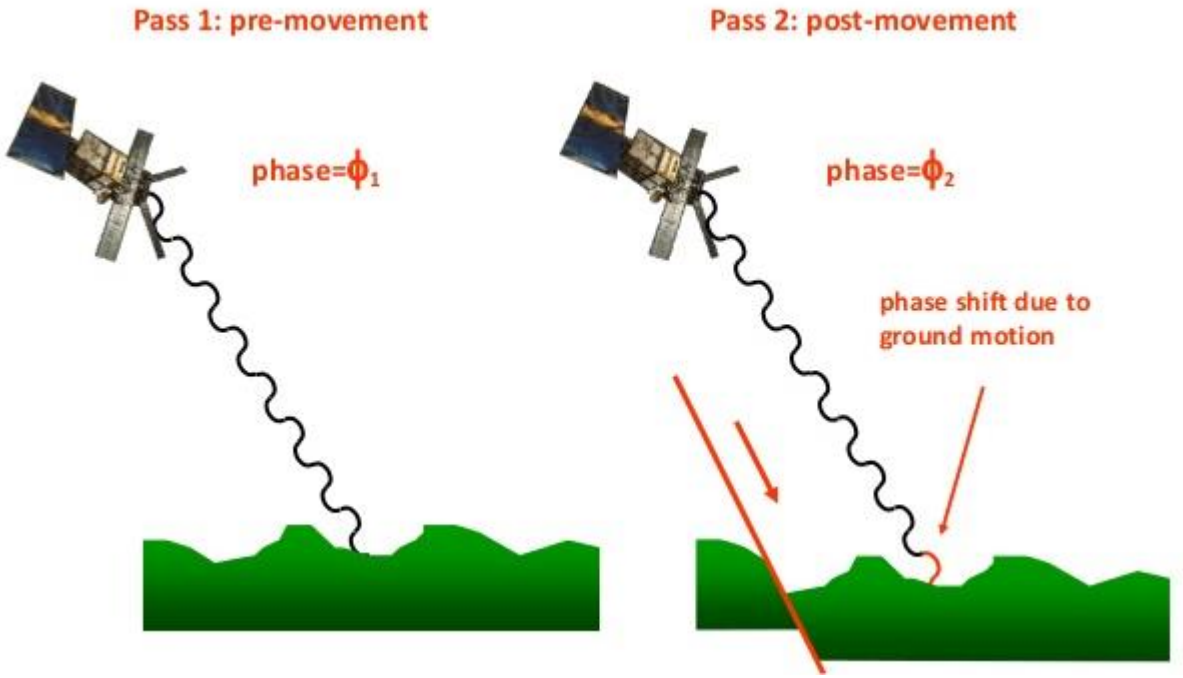
- Classification of images based on multiple polarization.
  - Horizontal (H) and vertical (V) polarisation
  - Essentially you get backscatter and polarisation properties
  - Targets do strange things to polarisation. Good for classification.
  - Single-pol, Dual-pol or quad pol



https://nisar.jpl.nasa.gov/mission/get-to-know-sar/polarimetry/

SAR methods: Interferometry (InSAR)

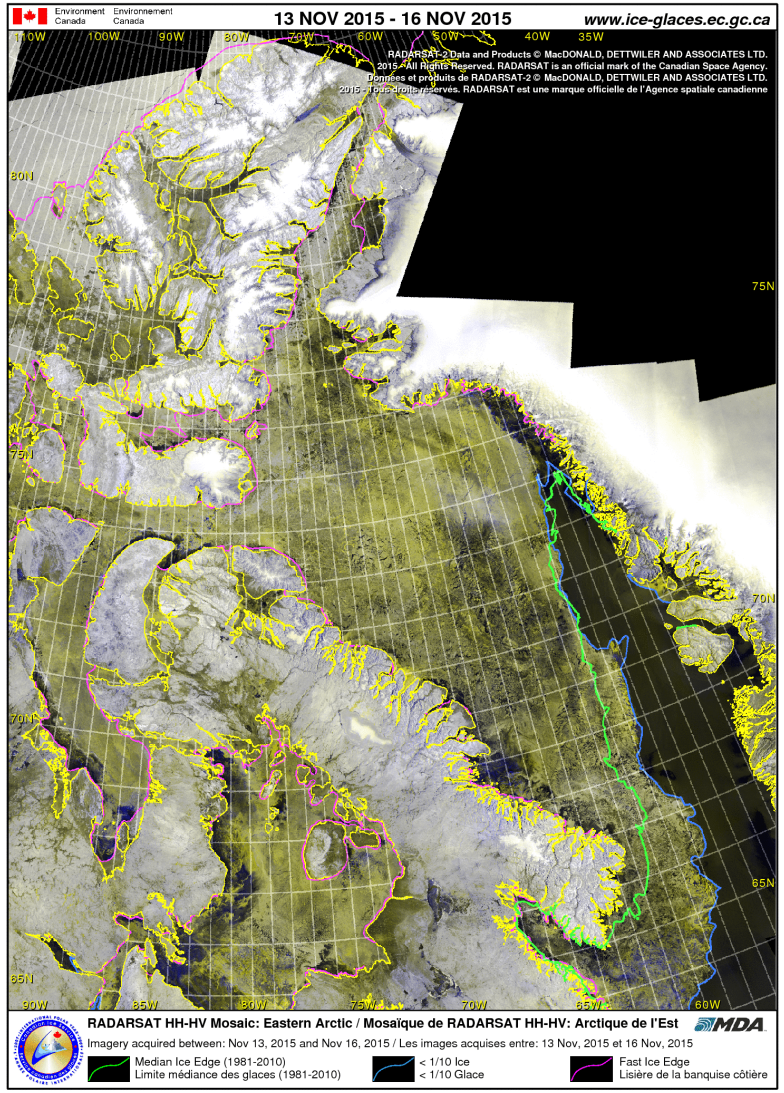
- Difference between two images of the same object from two different satellite passes (phase difference between the images). Measure surface velocity and ground surface change to ½ wavelength.
- If no surface change, we can generate elevation models.



Sea Ice

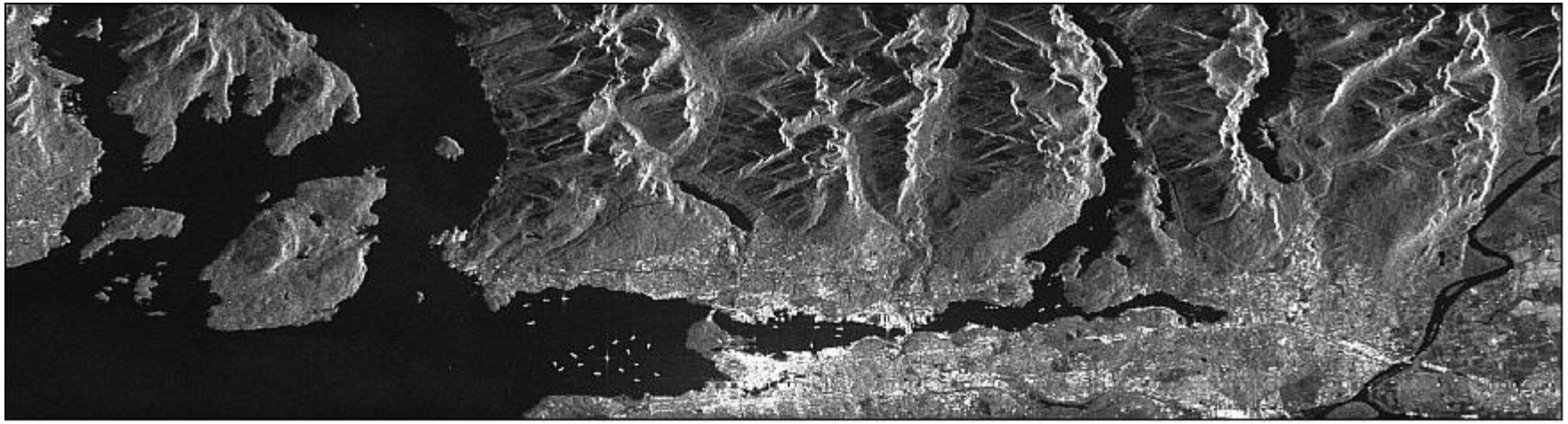
Sea Ice Tracking

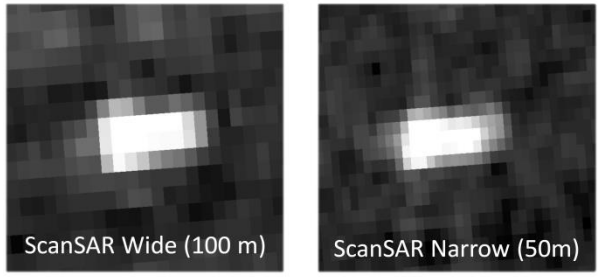
Sea Ice Classification

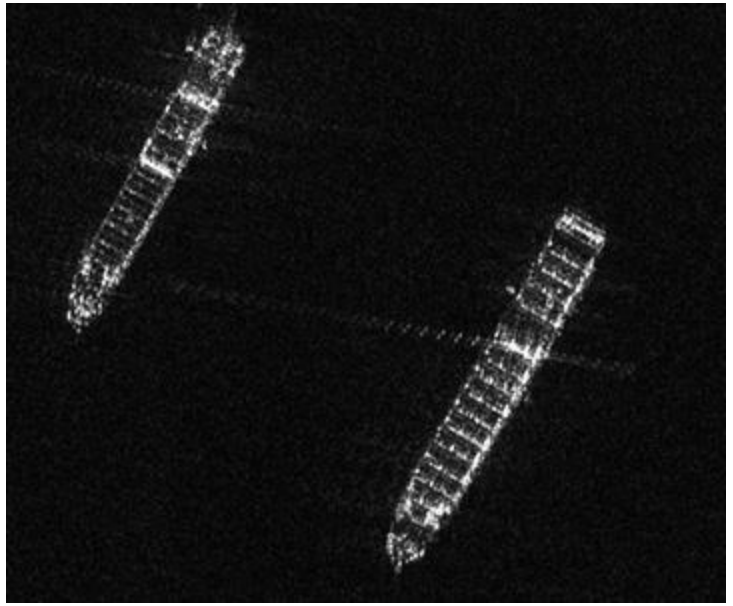


RADARSAT-2 in ScanSAR Narrow B Beam April 28, 2010 at 11:51:29 UTC. A: New Orleans, Louisiana; B: Delta of the Mississippi River; C: Oil slick; D: Close-up of ships and equipment [RADARSAT-2 Data and Products © MDA (2008)]

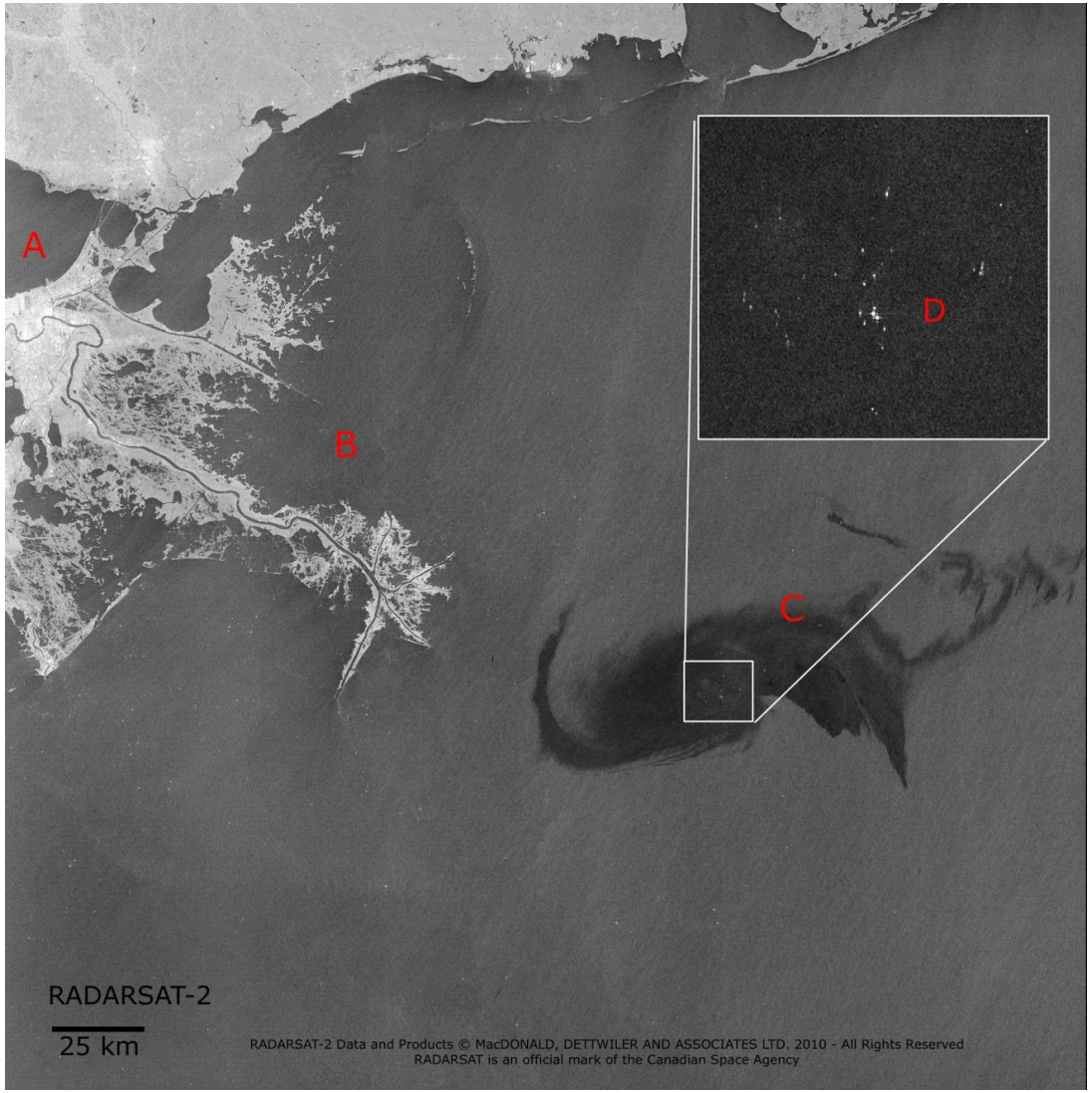
Ship Detection







Oil slick detection



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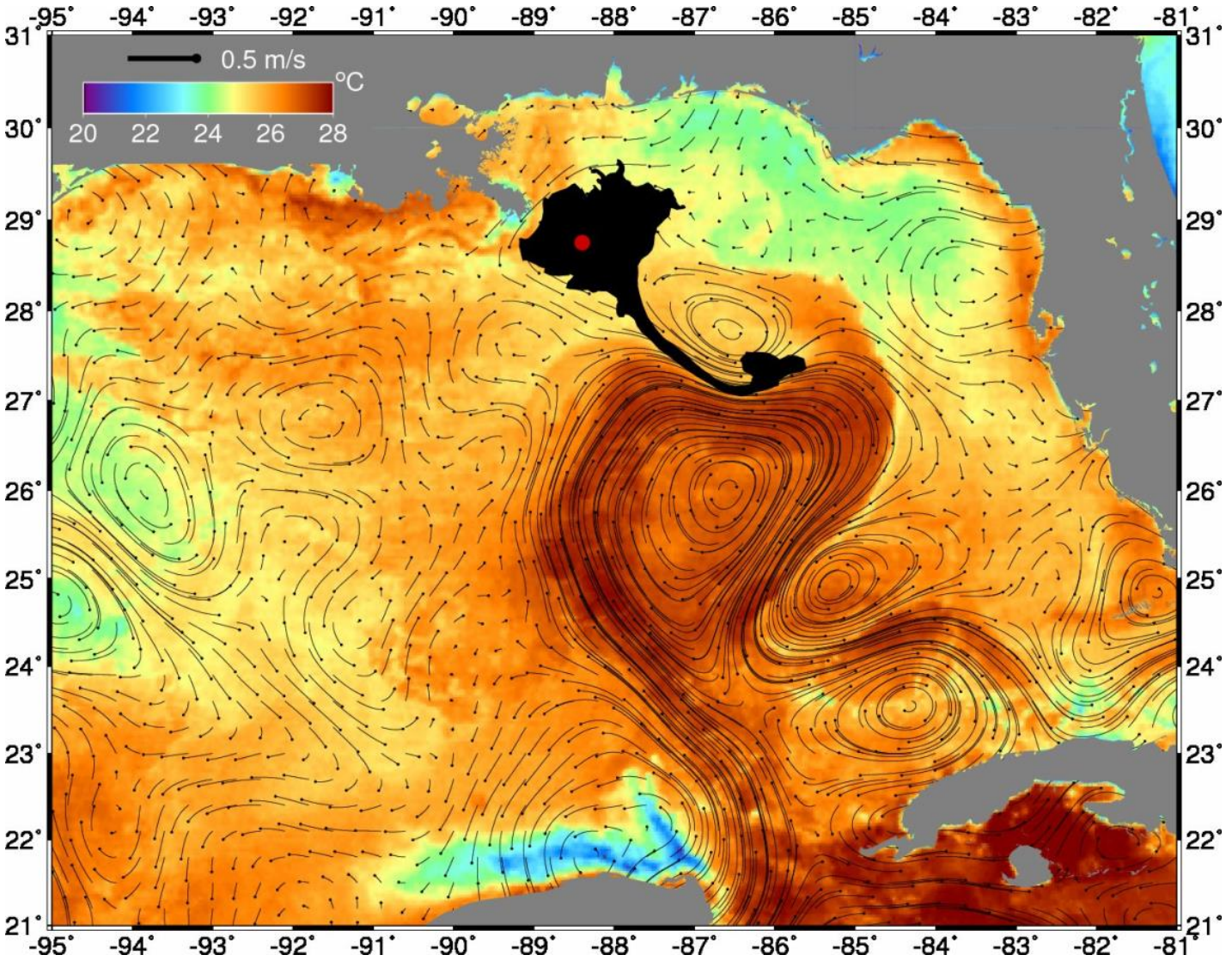

Deepwater Horizon oil spill detected by SAR sensors from the Radarsat-2 satellite (black stain), is pumped away by the Loop Current observed with altimetry (black arrows). With more altimetry data, ocean models can provide a better prediction of such local events. (Univ. Colorado)

How do I get data?

- Google Earth Engine
- EO Browser
- Copernicus Data Hub
- Alaska Satellite Facility

Summary

- Different wavelengths typically include:
  X, C or L band
- SAR data consists of Phase and Amplitude
  - Phase can be used for:
  - Amplitude can be used for:
- Single, dual or quad pol
  - Sends H or V
  - Receives H or V
  - HH, VV HV, VH
- Ascending and descending passes
- Various acquisition modes
- Can see through night and clouds

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