30552 – Lecture 11.

Advanced Satellite altimetry. In-SAR for Elevation and Icesat-2 for Bathymetry

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DTU Space,
Geodesy and Earth Observation

DTU Space
National Space Institute

Before we start:

If you feel ill, go home
Keep your distance to others
Wash or sanitize your hands
Disinfect table and chair
Respect guidelines and restrictions

Invitation for virtual S6 launch event
S6_Invitation_Virtual.pdf Under fileshare

DTU Space
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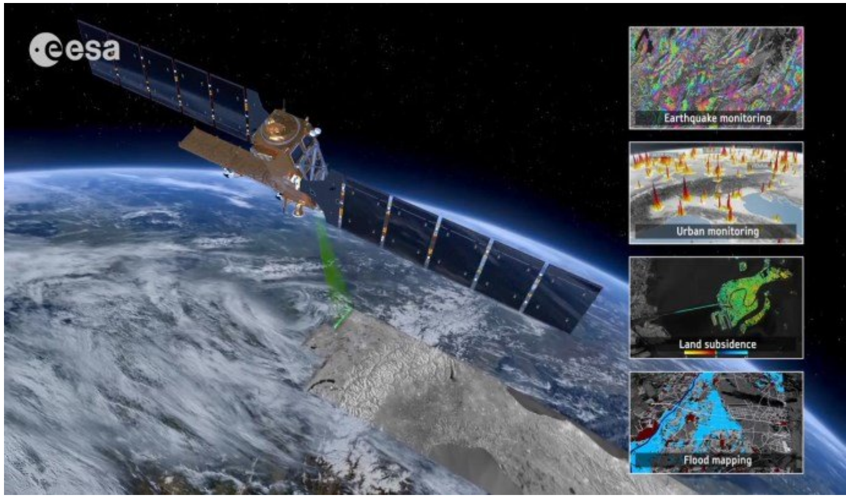
Figure of the Earth.

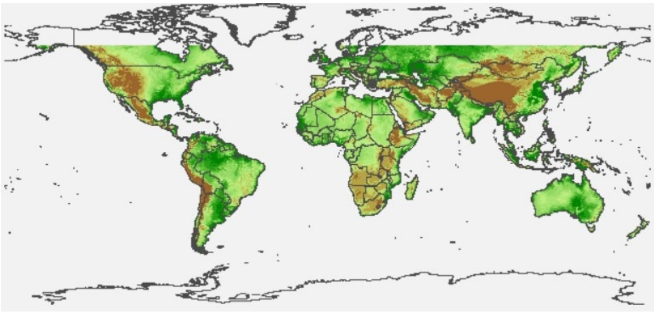
- Lecture 8.
- Bathymetry in the deep Ocean
- (gravity inversion)

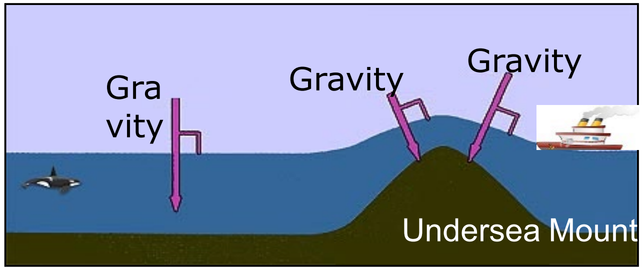
- Today. IN-SAR for topography
- Laser altimetry for coastal bathymetry

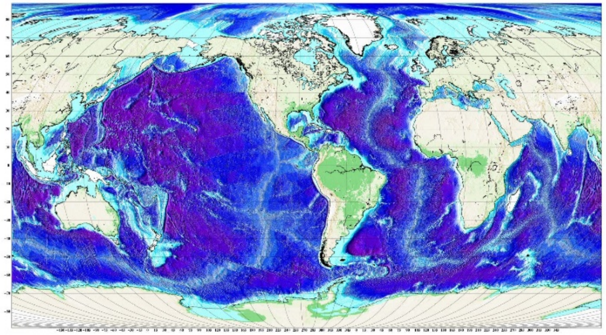


Topography

Bathymetry







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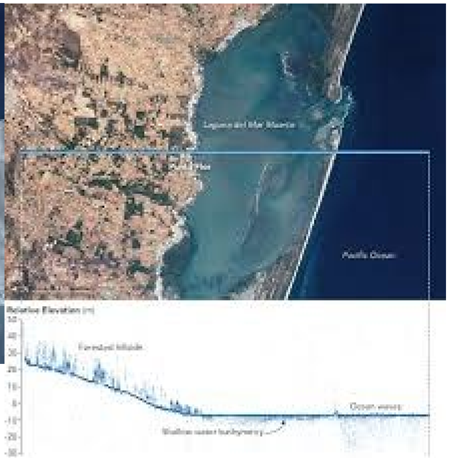


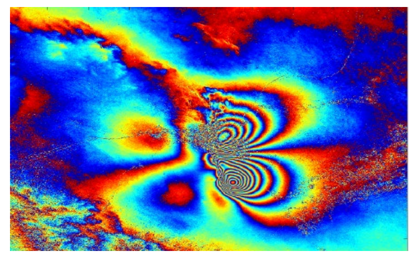
Geodetic changes to figure

DTU

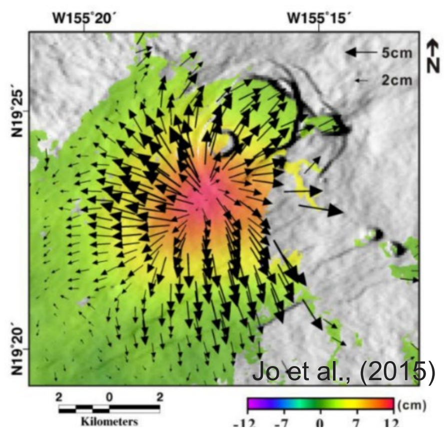
Seeber (2003): SAR does not belong to satellite geodesy, but is usually treated within "remote sensing" - well times are changing...........

Motion ->Geodesy

Large displacements / fast motion

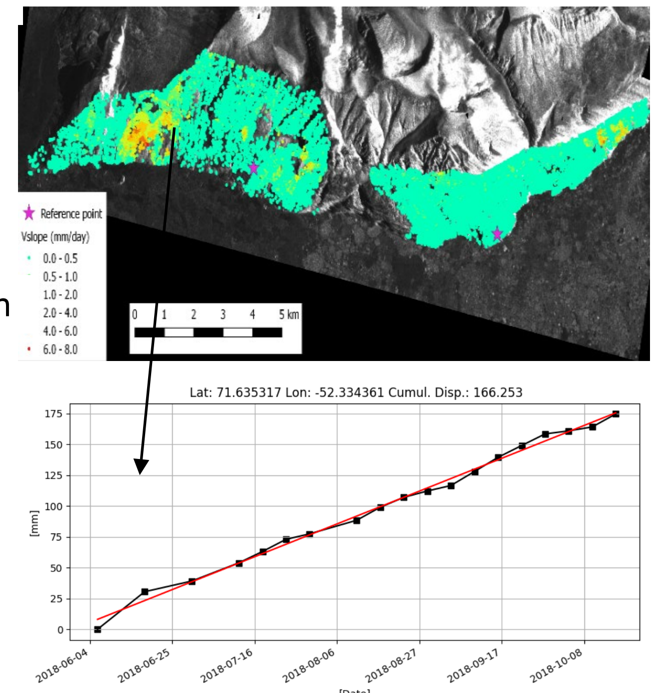


2003 Bam earthquake, Iran



Kilauea volcano, Hawaii

Slow deformations



Karrat fjord, Greenland. Downslope deformation time-series.

Content

- Synthetic Aperture Radar (SAR).
  - "Synthetic Aperture"
  - Azimuth and range accuracy
  - SAR and INSAR systems/satellites.

Interferometric SAR (INSAR)

Observation principle

Height accuracy

Data and Software

Differential INSAR (DINSAR)

Deformation accuracy

Multiple INSAR and Persistent Scatterer and geodesy

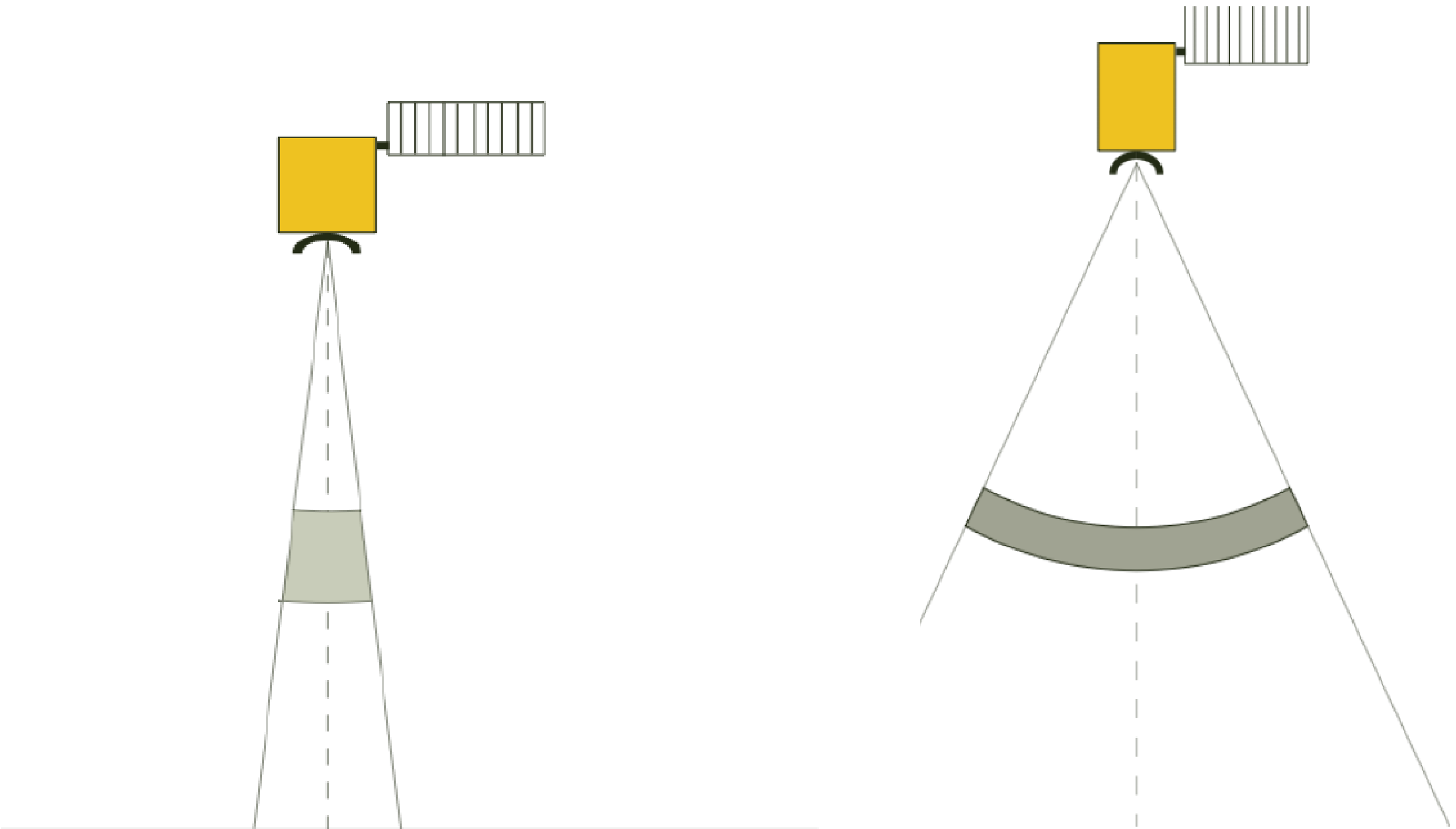
Next Generation altimeter

Surface water and Ocean topography. SWOT

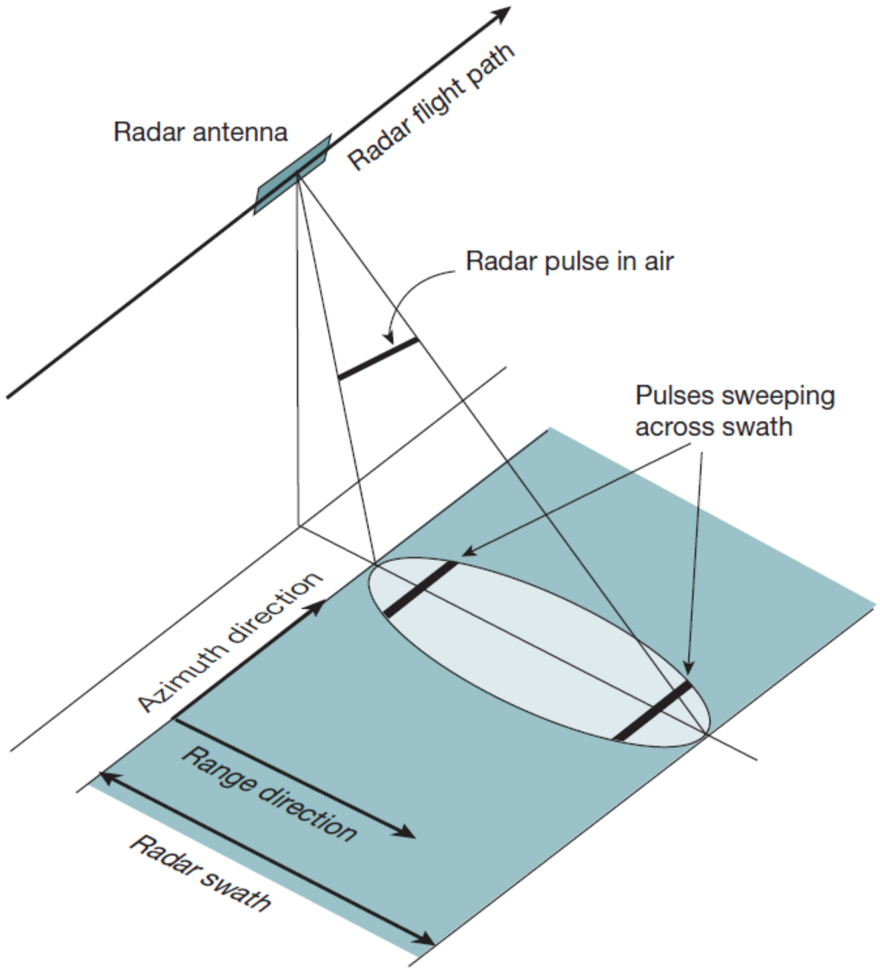
Laser Altimetry for Bathymetry (Heidi Ranndal).

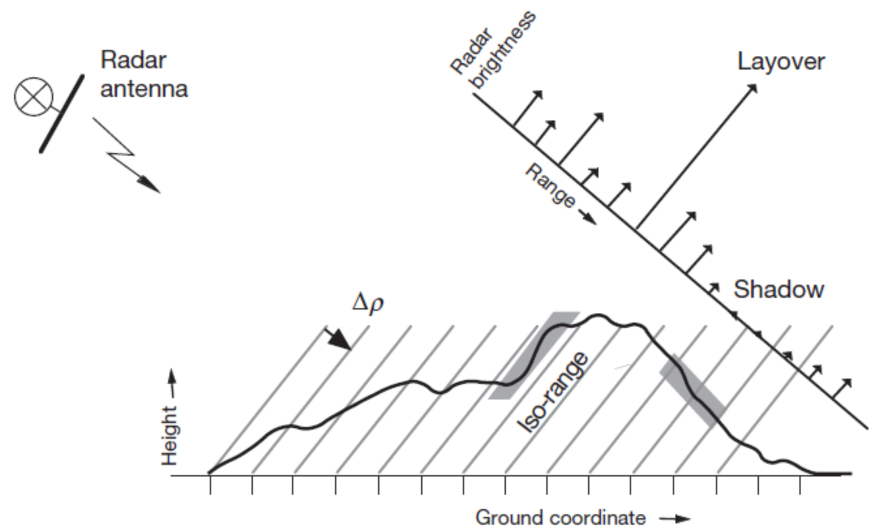
Acknowledging teaching material supplied by John Merryman Baconi(Measurement tech)
Henning Skriver and Le Lueng Fu (NASA)

Beam limited (along)
Pulse limited (across)



SAR receiver detects time and power/backscatter





Azimuth and Range resolution

- Azimuth resolution (Seeber 11.1)

$$\varepsilon \approx \frac{\lambda}{d}$$

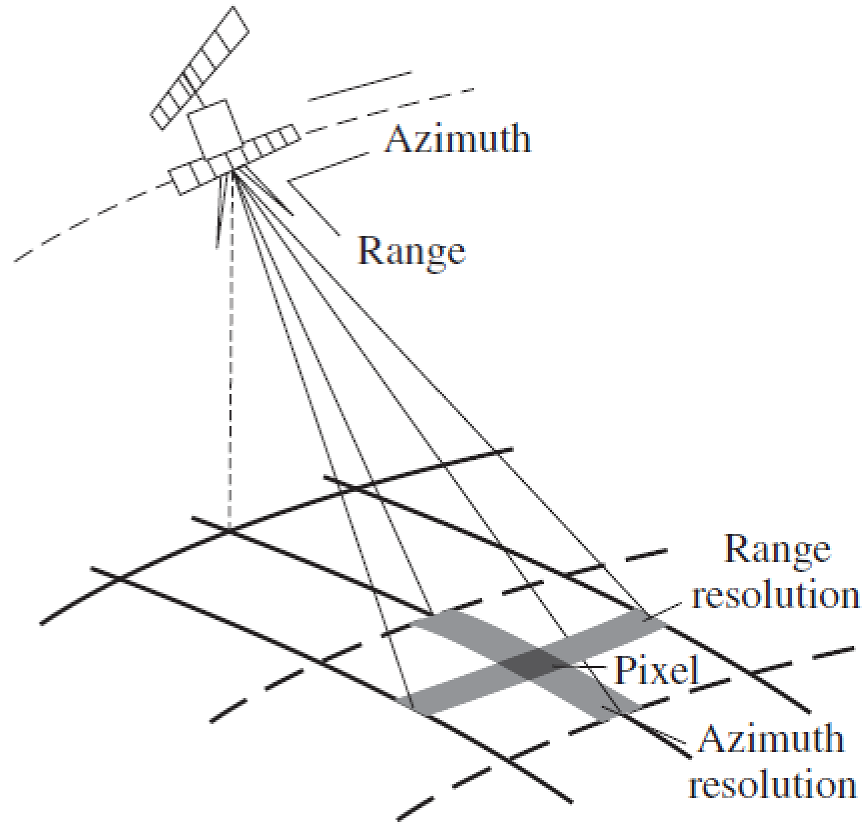
with

ε resolution, (actually beam width)

λ wavelength of the particular radiation, a

d telescope diameter.

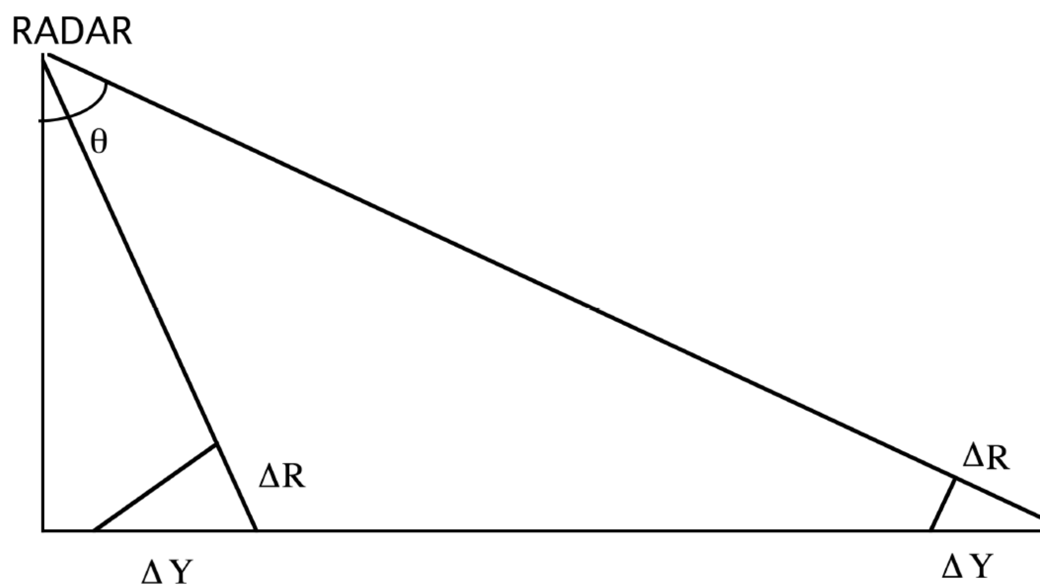
- 100 m resolution requires d> 100 meters



- Range resolution (pulse) (H. Skrive

$$\Delta Y = \frac{\Delta R}{sin\theta}$$

$$\Delta R_{range} = \frac{1}{2} c\, T$$



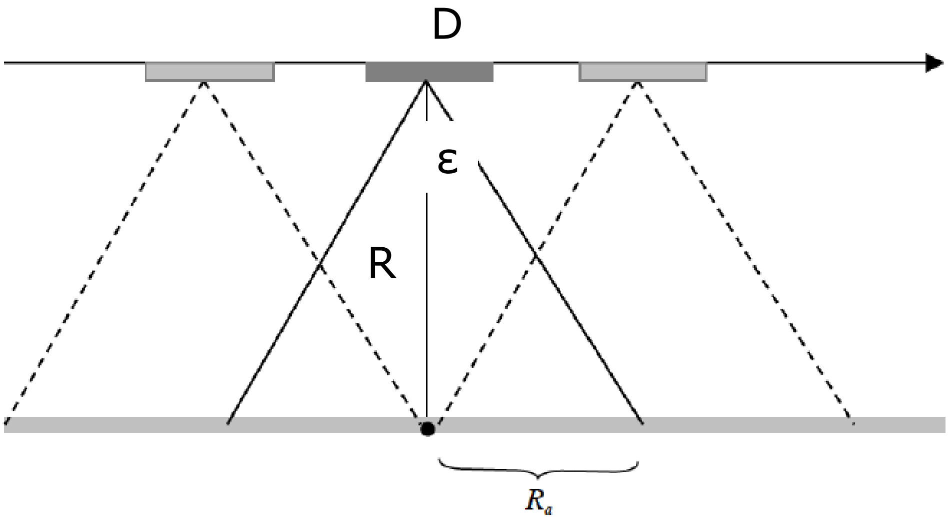
Synthetic Aperture.

Azimutal resolution

$\varepsilon = \lambda / D$

$R_a = R \tan(\varepsilon) = R\,\varepsilon$

$R_a = R\,\lambda / D$



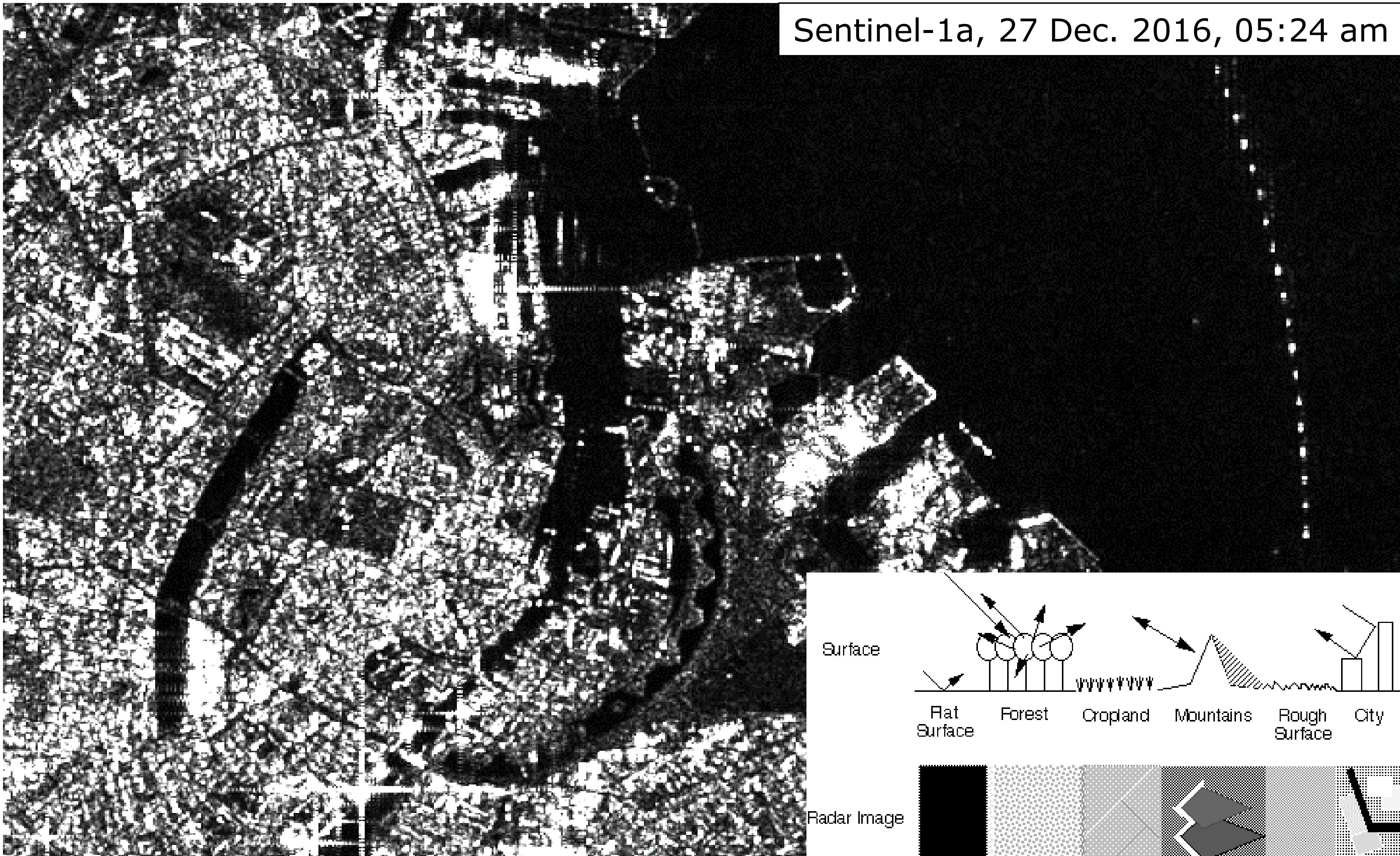
Length of illumination is $2\,R_a$

Assuming that scattere remains stationary while satellite passage.

"Syntetic Aperture" becomes equal to $2\,R_a$.
Hence $R_a{}^* = D\ /\ 2$

Observations from different "bursts" are separated using Delay Doppler.

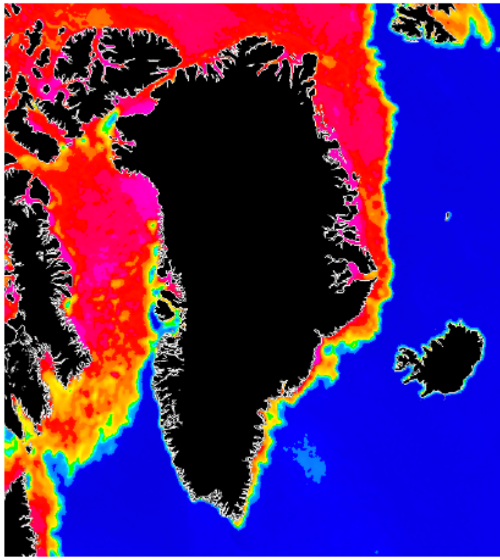
SAR image amplitude

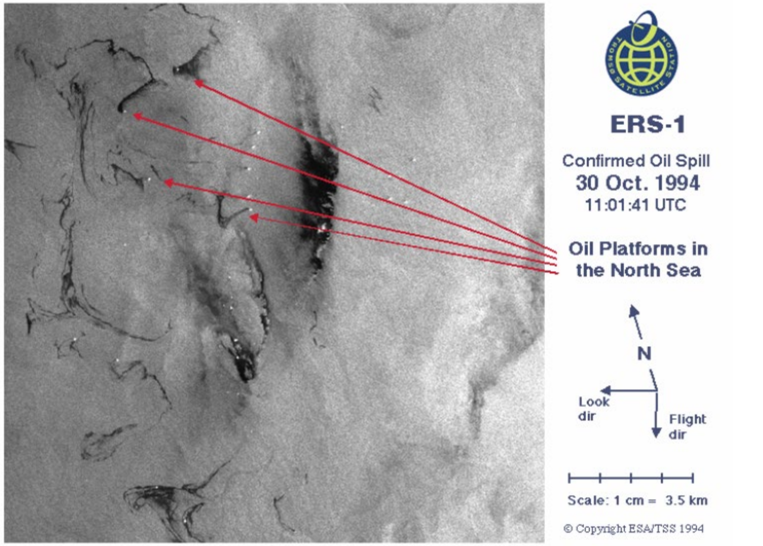


Danjal Longfors Berg (Masters projekt)

- Ship and Iceberg detection in Sentinel-1
- using Deep Learning (Heisenberg and Andersen).

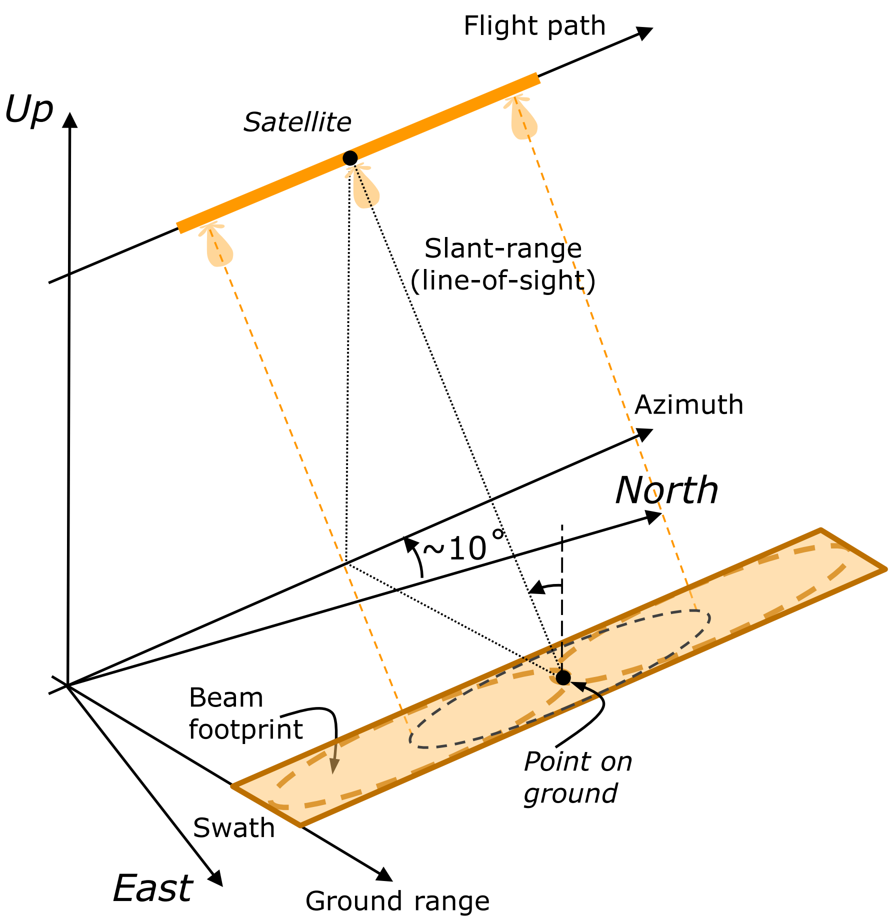
AMSR2 (JAXA)
All Arctic in NRT





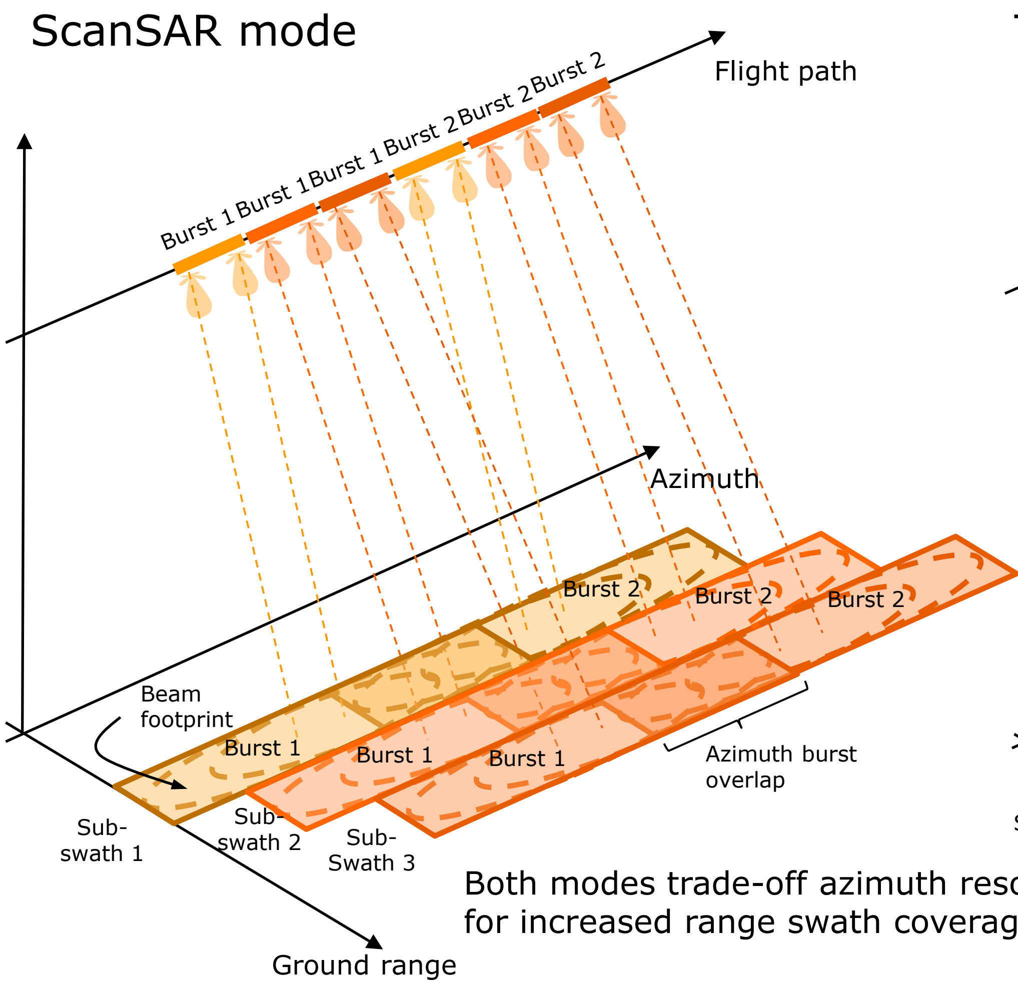
Seaice.dk : State of the art SAR archive.

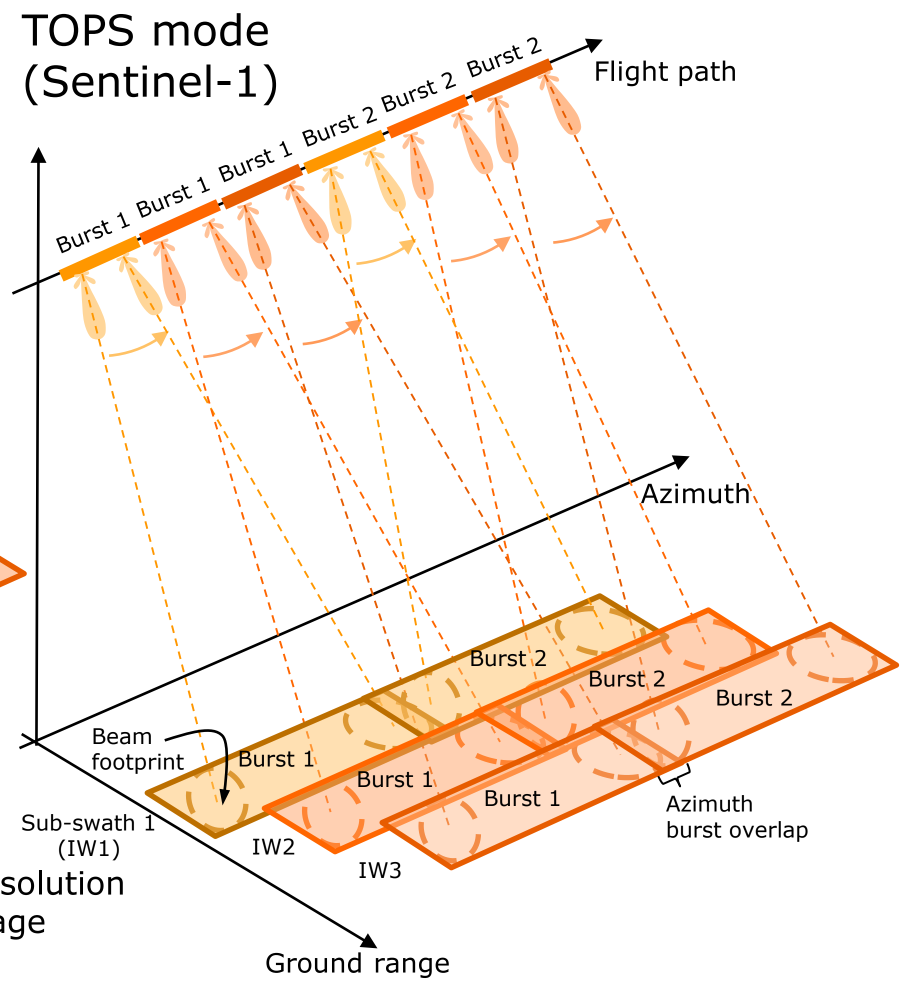
SAR acquisition geometry and orbits



Example: Stripmap acquisition mode, ascending orbit

Wide-area acquisition modes





Both modes trade-off azimuth resolution for increased range swath coverage

ESA TOPS animation: https://www.esa.int/esatv/Videos/2014/03/Sentinel-1_Radar_mission/SAR_scanning_animations_ESA_2013

Different SAR systems uses different wavelength (λ).

Different wavelength or frequencies have different characteristics /advantages.

For ground: little penetration.

For ice:
L band penetrates the
Deepest (up to km)
Ku band penetrate 1-100 cm
Ka band very little.

Band	Frequency [GHz]	Wavelength [cm]
VHF	0.03-0.3	1000-100
UHF, P	0.3-1	100-30
L	1-2	30-15
S	2-4	15-7.5
C	4-8	7.5-3.75
X	8-12.5	3.75-2.4
Ku	12.5-18	2.4-1.7
Ka	18-40	1.7-0.75
V	50-75	0.60-0.40
W	75-111	0.40-0.27

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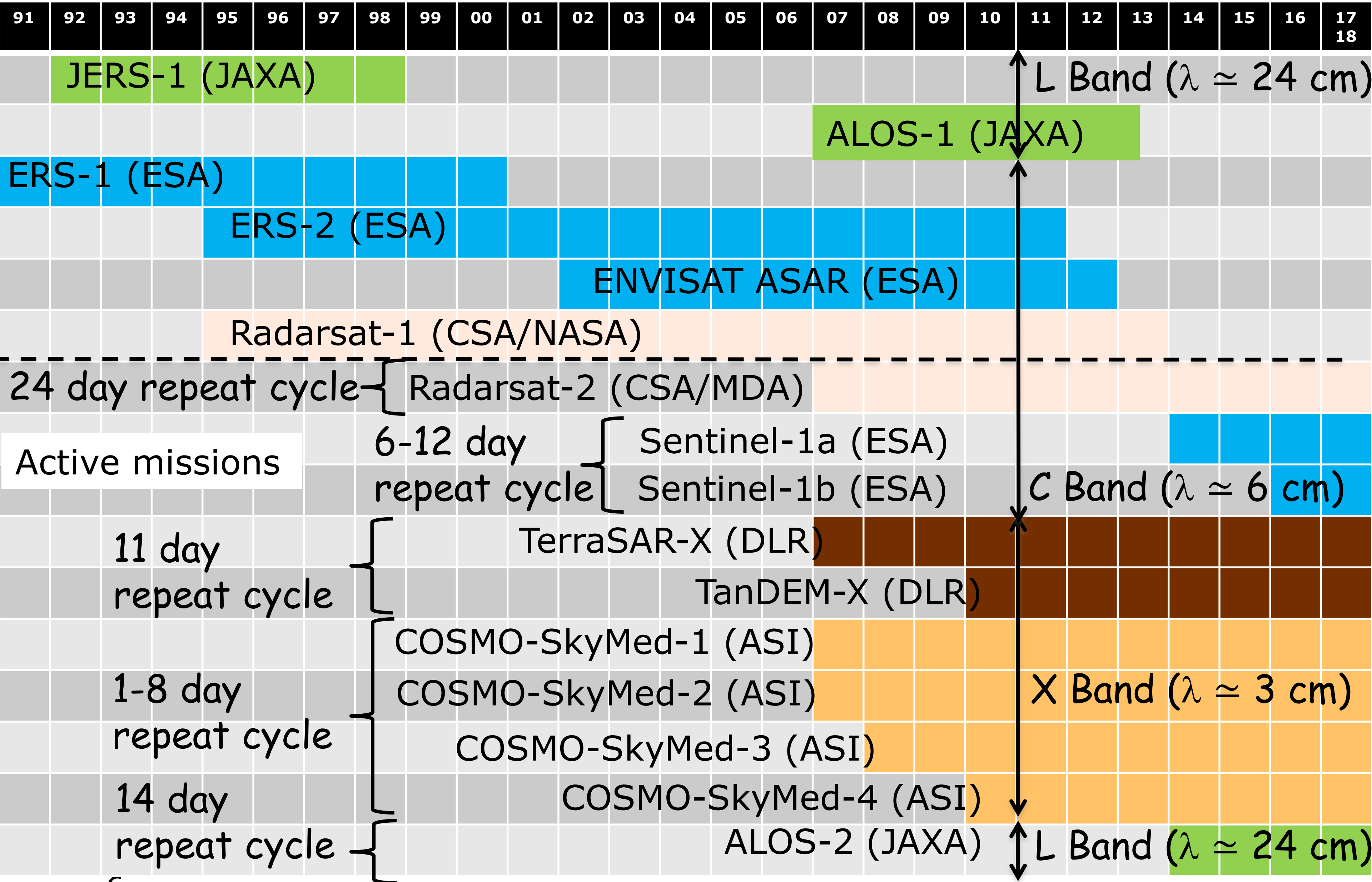
Main spaceborne SAR missions



Selected acquisition mode parameters

Satellite	Launch date	Revisit time (days)	Mode	Wavelength (cm)	Incidence angle (deg)	Image Size (km)		Resolution (m)	
						Ground Range	Azimuth	Ground range	Azimuth
ALOS-2	24.05.2014	14	ScanSAR	24.25	8-70	350-490	350	10-20	57-78
			Stripmap		8-70	50-70	70	3-9	3-5.3
COSMO-SkyMed-1/2/3/4	08.06.2007/09.12.2010	1-8	Stripmap	3.11	20-60	40	40	3	3
Sentinel-1a/b	03.04.2014/25.04.2016	6-12	TOPS	5.55	30-46	250	250	5	20
			Stripmap		22-44	80	80	5	5
Radarsat-2	14.12.2007	24	Stripmap	5.55	10-60	20-170	20-170	2.6-22	2.1-5.1
TerraSAR-X/TanDEM-X	15.06.2007/21.06.2010	11	Stripmap	3.11	15-60	30	50	2	3

Ground range resolutions are computed for an incidence angle of 37 deg (J. Merrymann)

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  - "Synthetic Aperture"
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Interferometric SAR

- Observation principle
- Height accuracy
- Data and Software
- What does phase differences mean

Differential INSAR (DINSAR)

- Deformation accuracy
- Multiple INSAR and Persistent Scattere and geodesy

Next Generation altimeter

- Surface water and Ocean topography. SWOT

Laser Altimetry for Bathymetry (Heidi Ranndal).

Interferometric SAR.

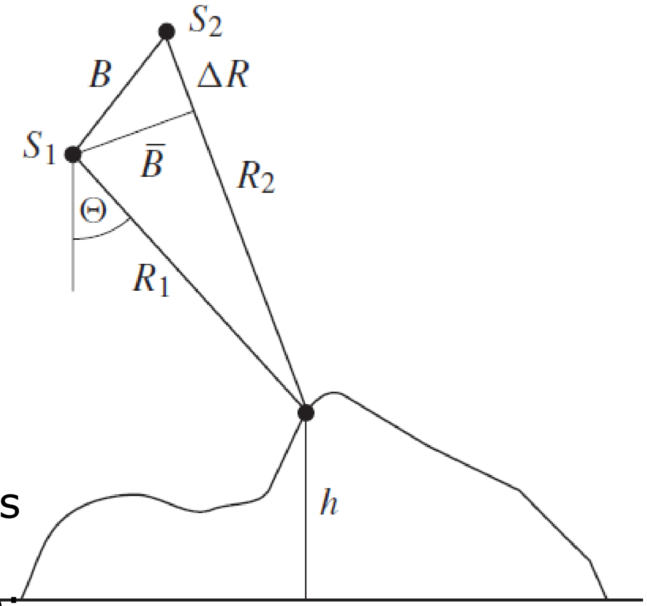


Figure 11.9. InSAR geometry

Requires a Baseline (B) to observe object at different Vantage points
Antenna transmit “bursts” with signal of same phase

Increase Range resolution looking at phase differences

Phase of a pixel ϕ includes scattere and range contrib:
$\phi = \phi_s + \phi_p$

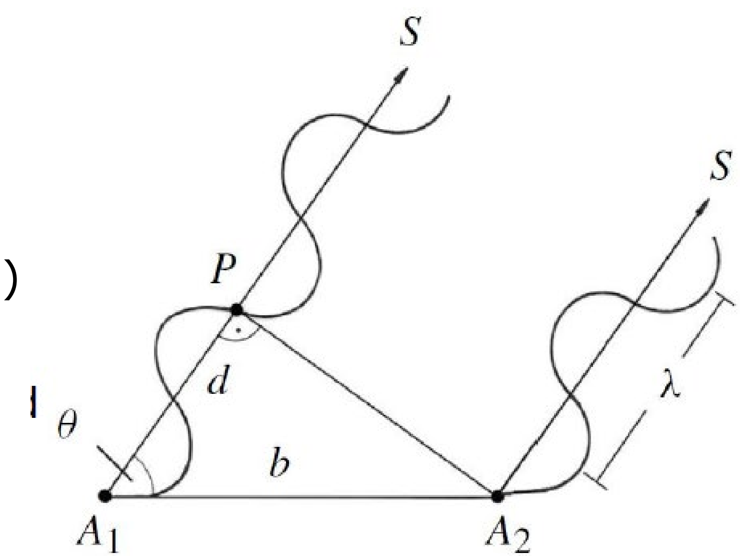
Where ϕ_s = scatter differences (we ignore)

$\Phi_p = R \; 4\pi / \lambda$

ϕ_p can only be measured modulo 2π

Differencing two images (Assuming $\phi s_1 = \phi s_2$)

Interferometric phase will be.
$\Phi_{int} = \Phi_{p2} - \Phi_{p1}$



Main geodetic applications
Digital Elevation models

Two ways of obtaining IN-SAR

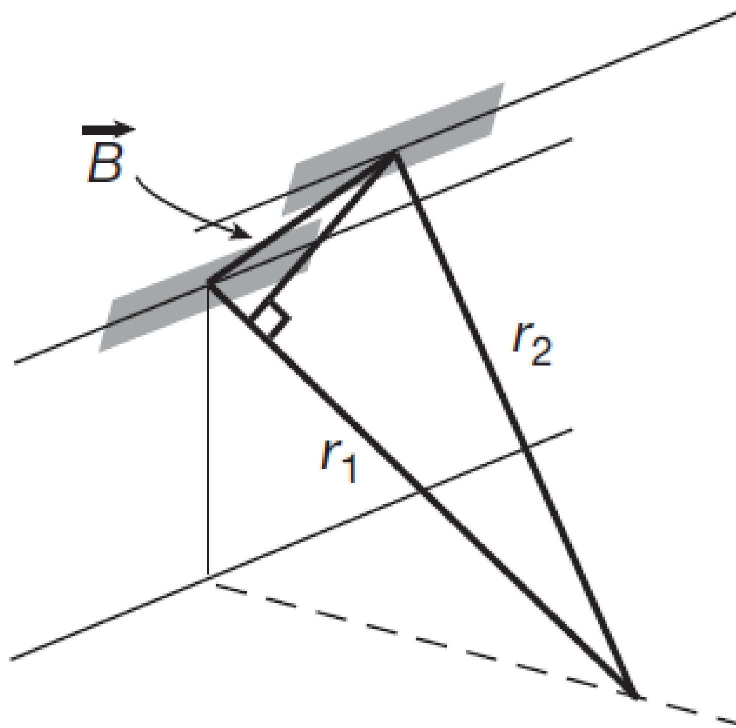
Single pass Across-track interferometry

Good for Digital Elevaion Models(DEM)
Antennas separated.
Height resolution
(from full phase cycle)

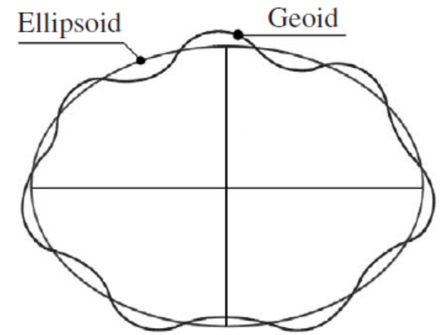
$$\Delta h = \frac{\lambda}{2} \frac{R}{B} \tan\theta.$$

Θ incident angle
Typically 5-10 meters.
(Seeber 11.17)

Limitations:
- accuracy of phase obs
- SAR geometry
- Atmospheric effect



Heights



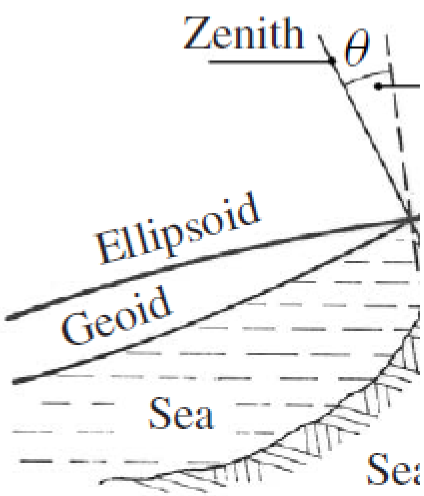
h = H + N for small height.

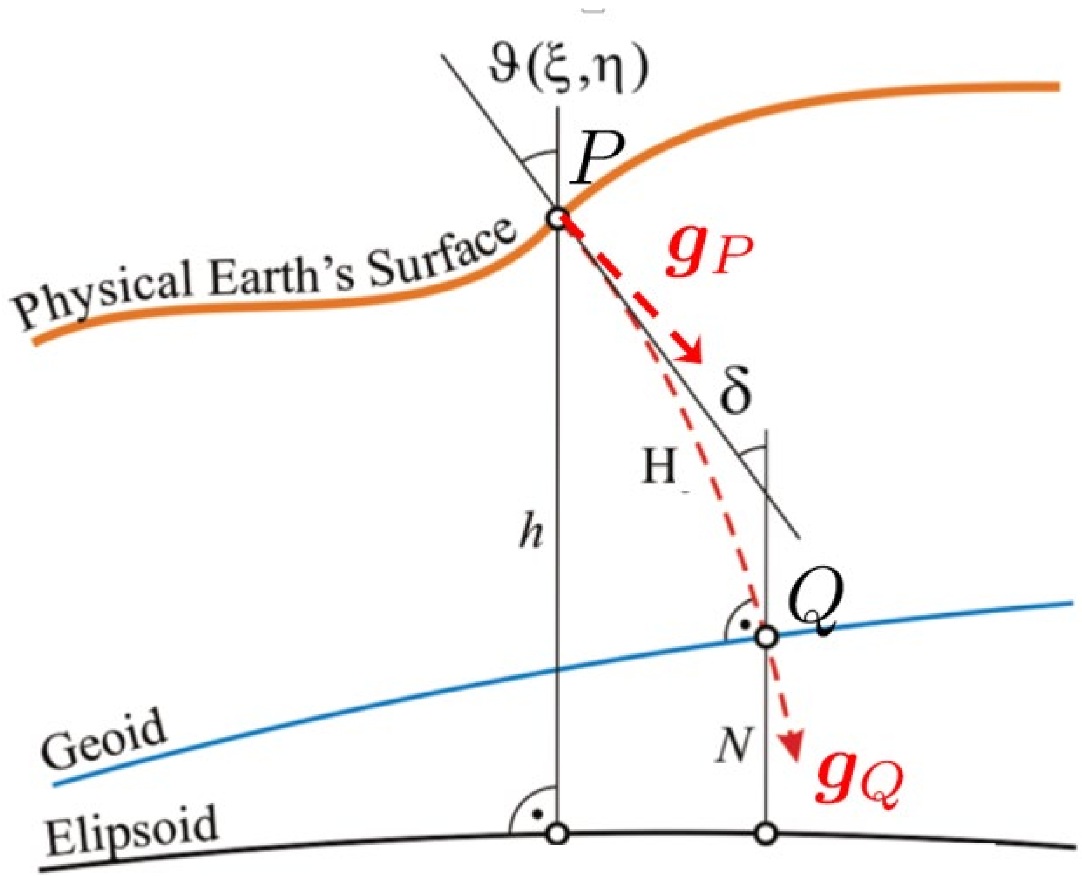
h is ellipsoidal height,

N geoid undulation(Height)

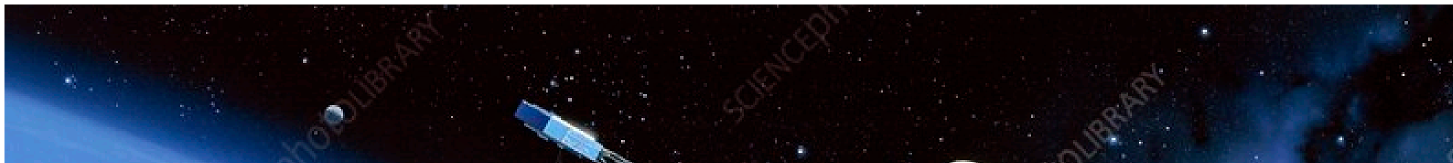
H is orthometric height

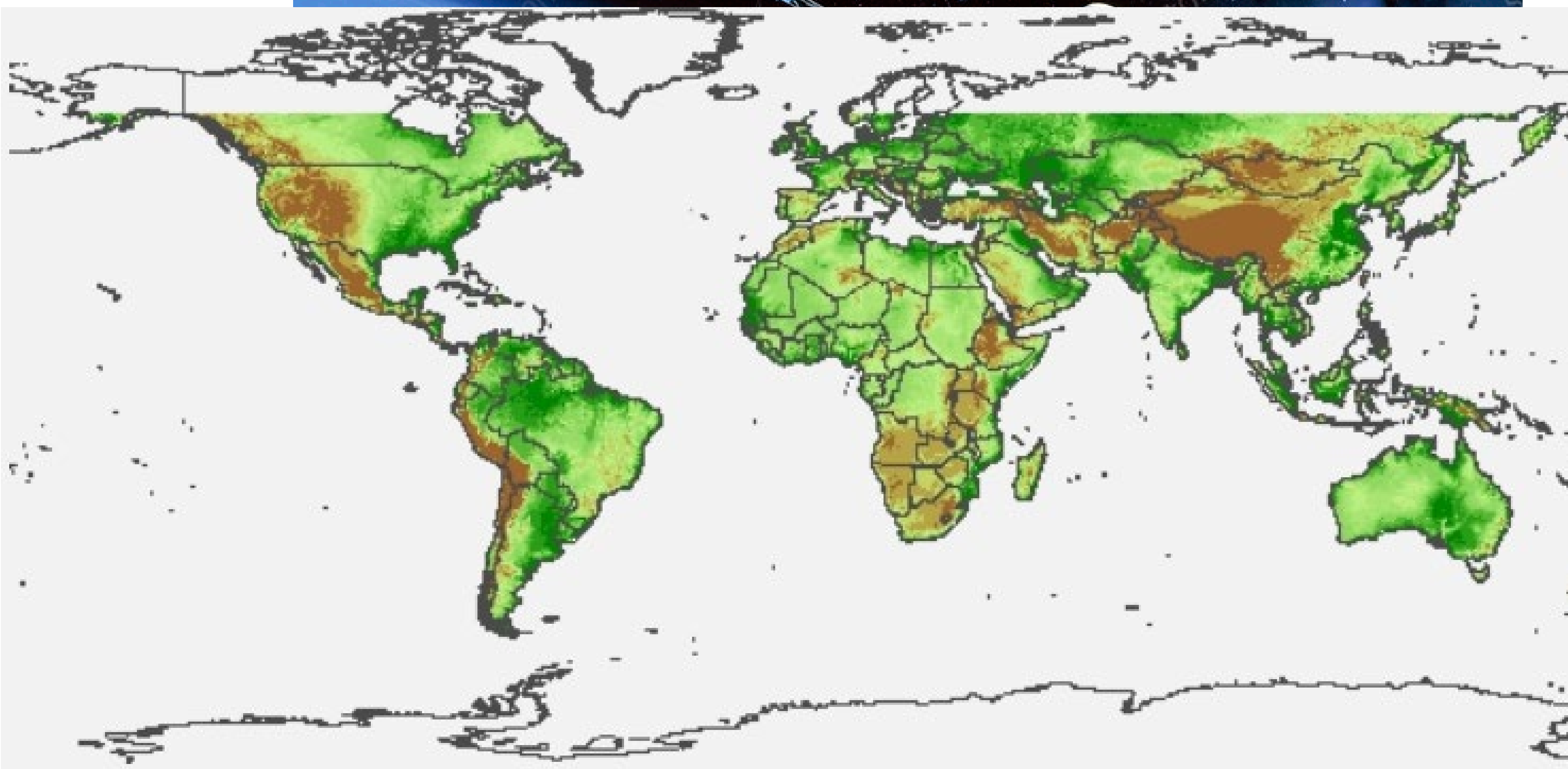
Θ is the Vertical deflection





Shuttle Radar Topography Mission





Basic Geodetic Applications

Geodynamics

Repeat pass interferometry

Several days or month between

Requirement depends “on target”
Target scattering behavior must not change too much.

Baseline must be reasonable short (hence accurate orbit).
Max is around 1 km at 800 km altitude

Othervise Decorrelation.

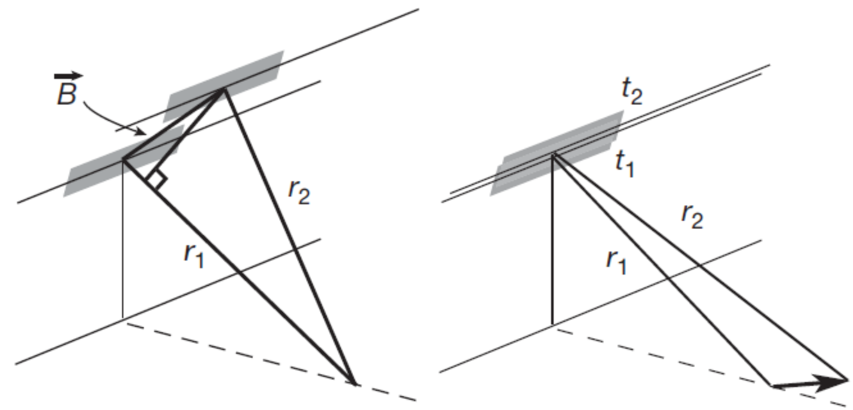


Figure 3 Interferometric SAR for topographic mapping uses two apertures separated by a ‘baseline,’ *B*, to image the surface. The phase difference between the apertures for each image point, along with the range and knowledge of the baseline, can be used to infer the precise shape of the imaging triangle to derive the topographic height of the image point. At left, a range difference exists because the scene is viewed from two different vantage points. This is described by a shift in the point target response as presented in the text. At right, a range difference is generated by a change in the position of the scene from one time to the next, imaged from the same vantage point. This range difference is described by a scene shift, not a point target response shift; the mathematics is the same but for a sign change.

Example of Observation

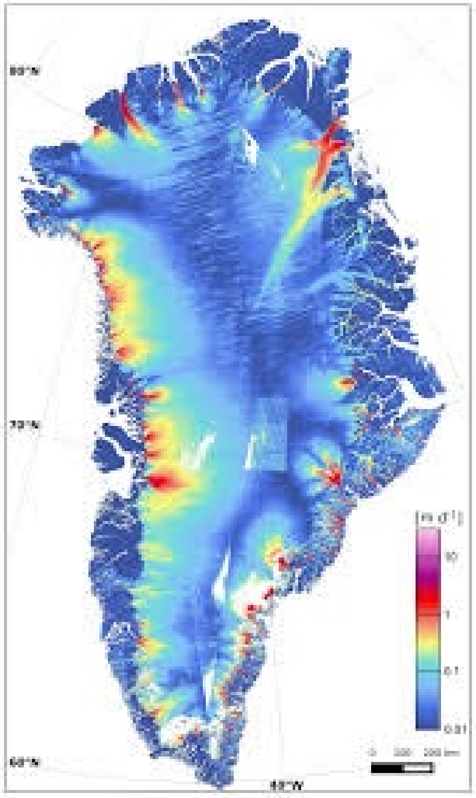


Image containing power and phase will be Complex image

Looking at one returned Single Look Complex Image (SLC)

ESA SNAP toolbox.

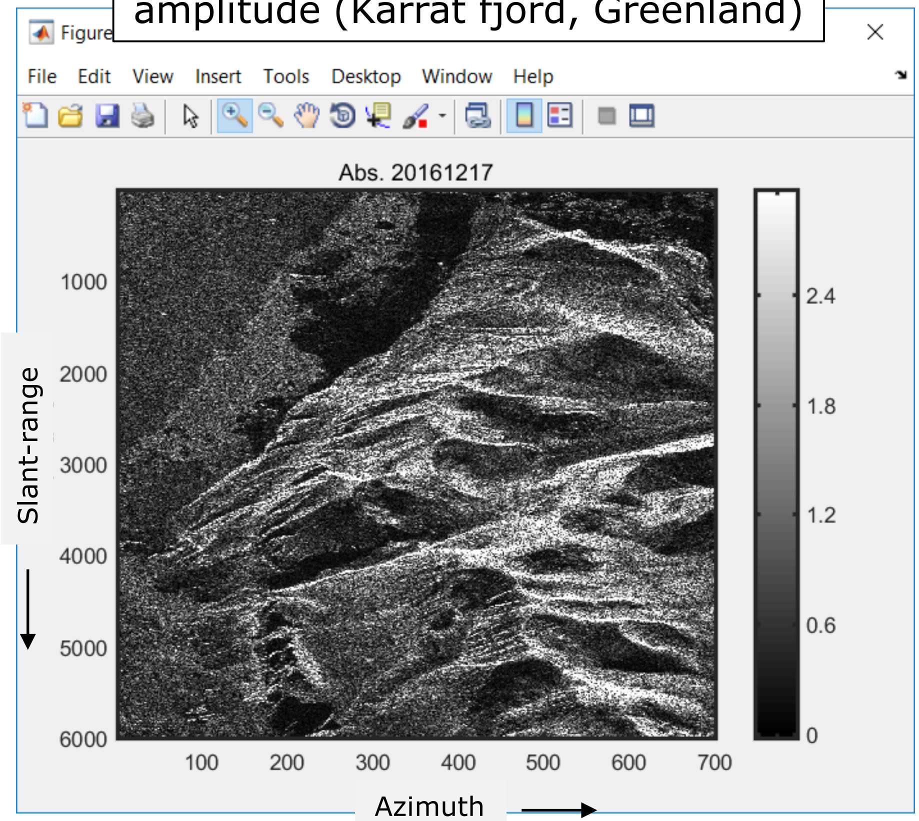
https://step.esa.int/main/toolboxes/snap/

It can help you with a lot of the processing of SAR images i.e. phase unwrapping etc, Atmospheric corrections. And Geo-location. We generally use it for projects.

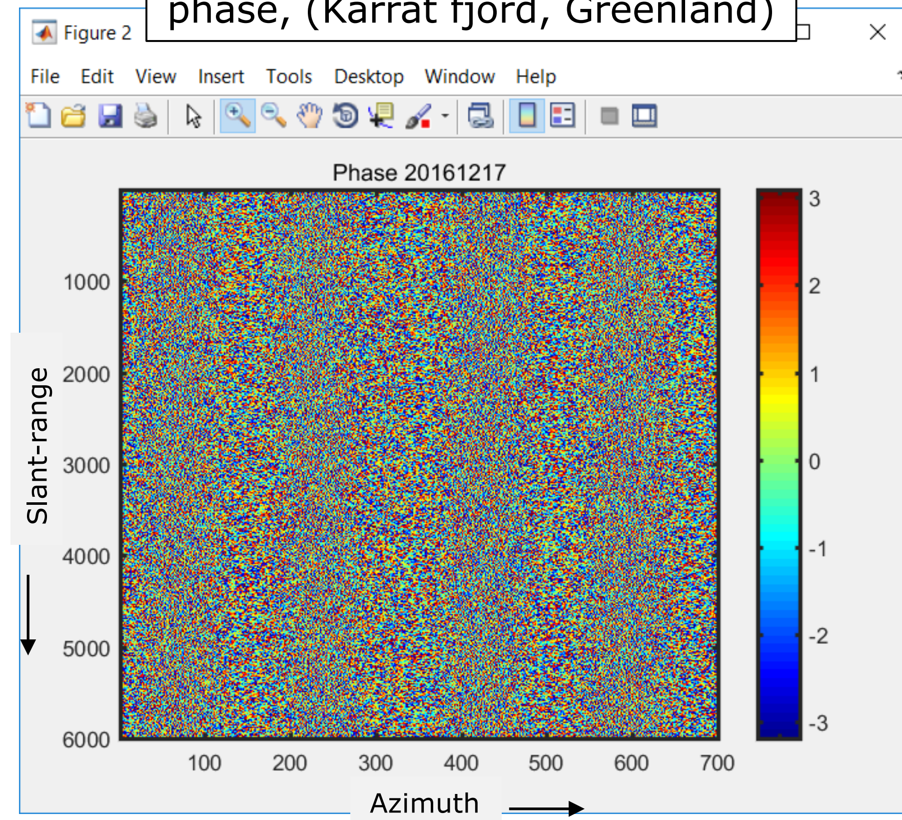
Single Look Complex (SLC) image

(i.e. a focused full-resolution SAR image)

Sentinel-1a, ascending image amplitude (Karrat fjord, Greenland)

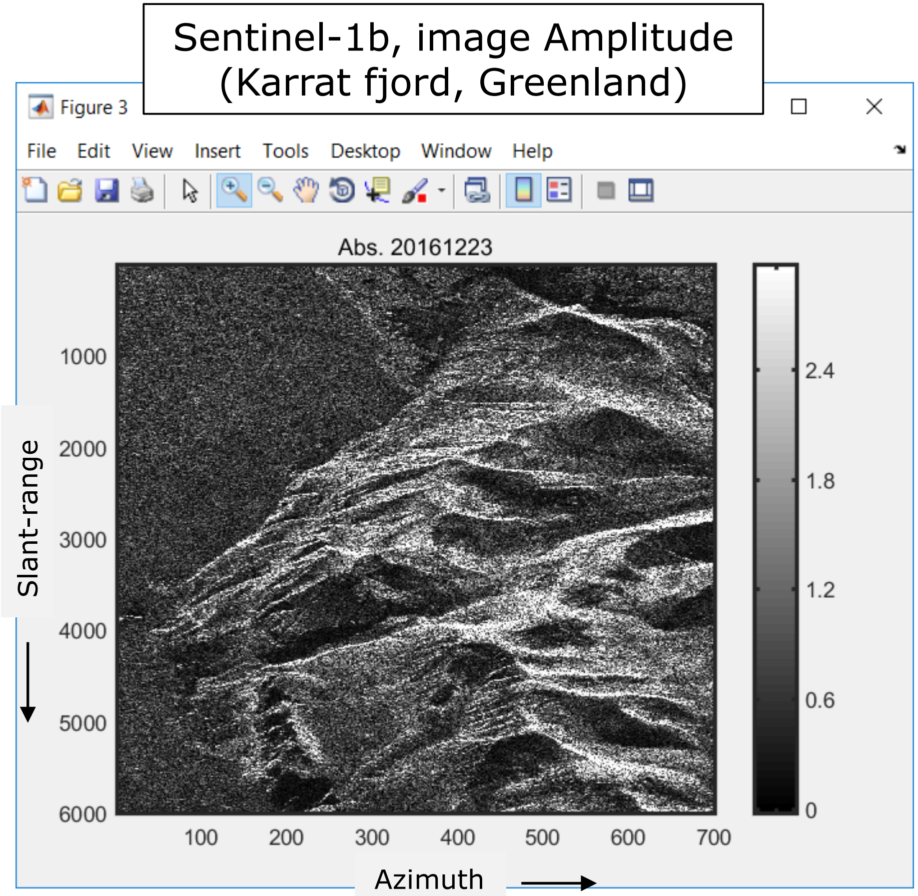


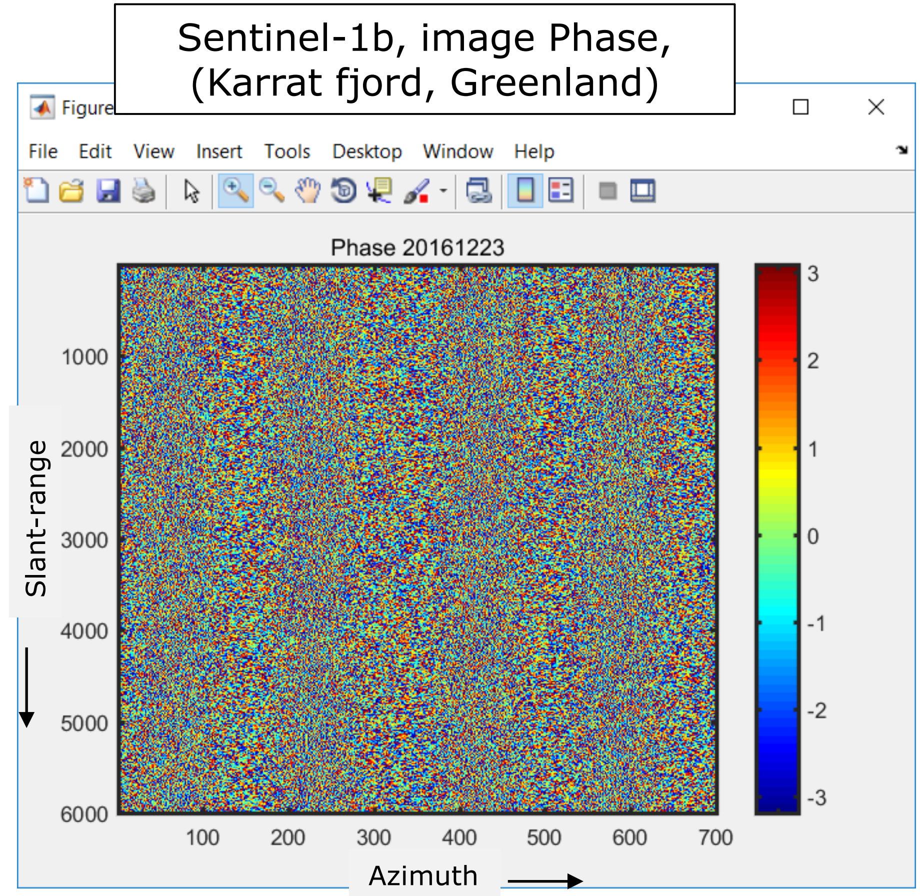
Sentinel-1a, ascending image phase, (Karrat fjord, Greenland)



The phase of an SLC image looks random

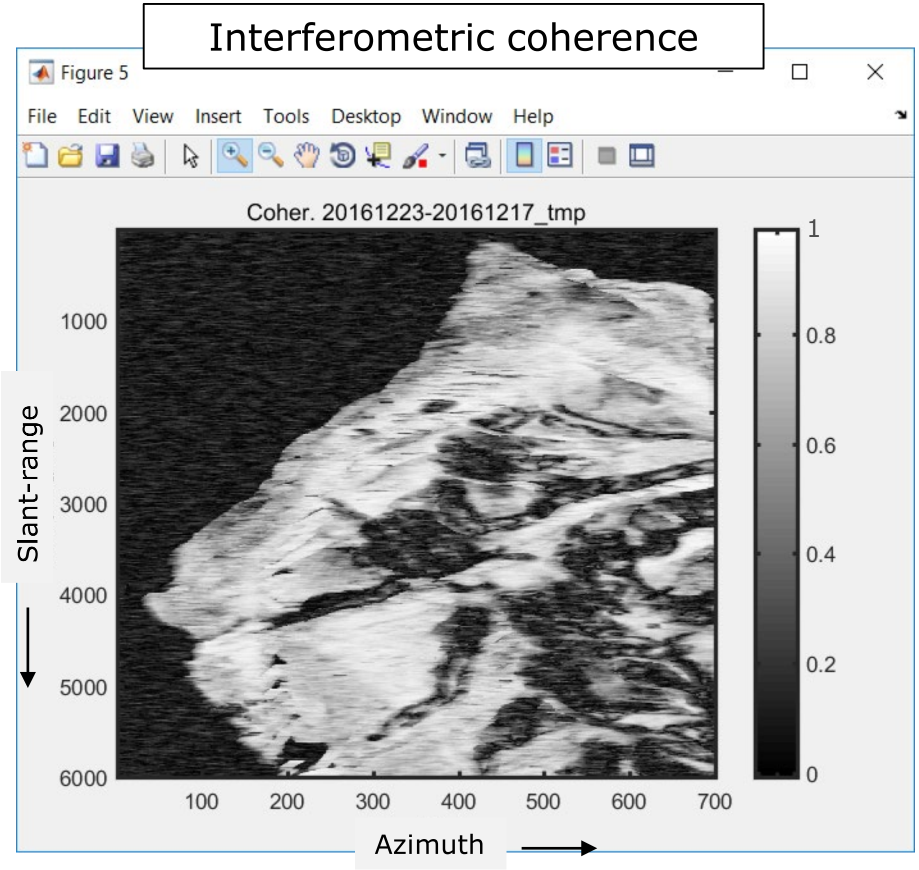
We try again 6 days later ...

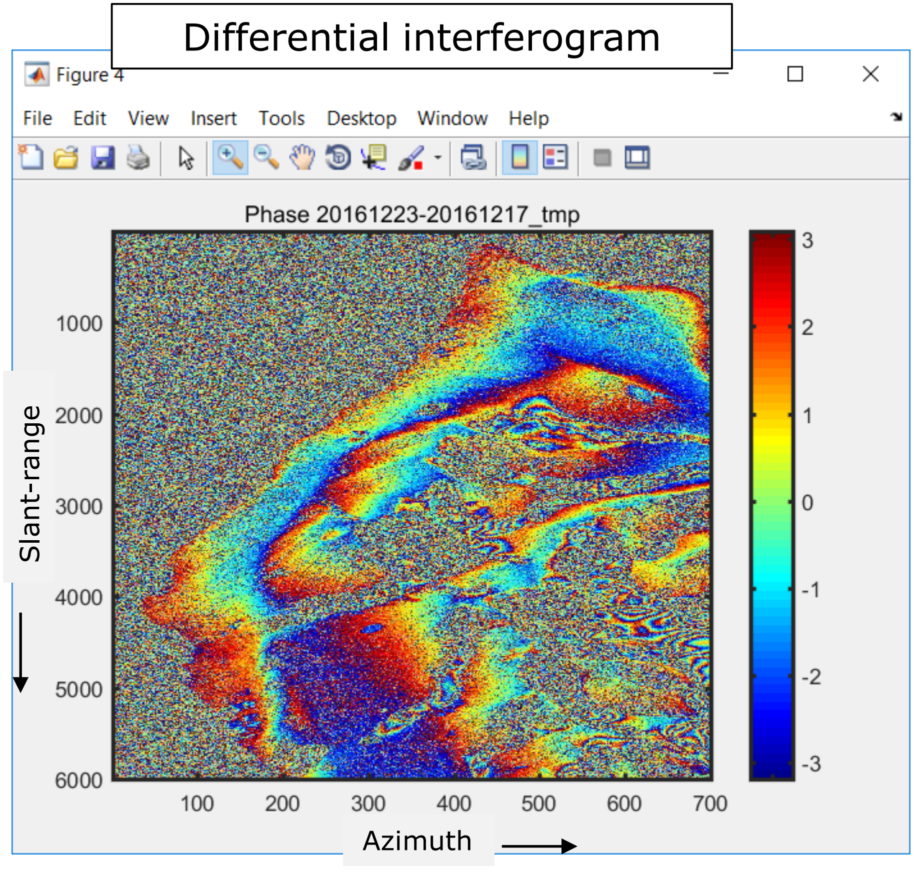




Still random

How about the phase difference?





Luckily the phase *difference* is not random everywhere!

So what are the colours we see in an interferogram?

Spatially-uncorrelated (noisy) term

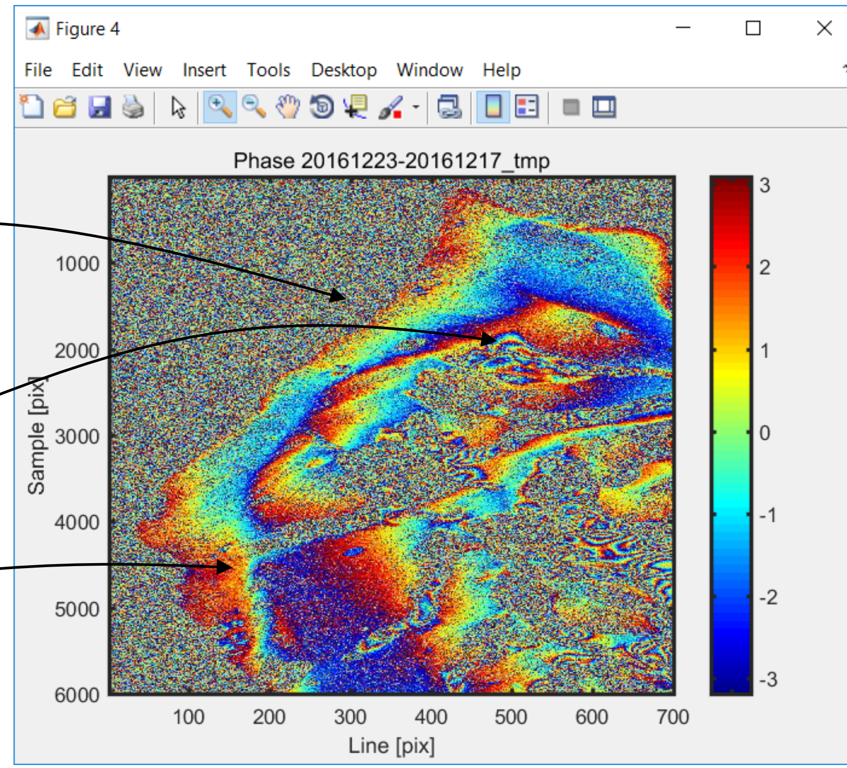
$$\phi_{\mathrm{int}} = \left[-\frac{4\pi}{\lambda}\left(R_0^1 - R_0^2\right) - 2\pi f_c\left(\tau \ldots \tau_{atmo}^2\right) + \phi_b^1 - \phi_b^2 \right]_{\mathrm{mod}\,2\pi}$$

Spatially-correlated terms

$$= \phi_{flat} + \phi_{topo} + \phi_{defo}$$

Area where the random phase contributions prevail -> noisy phase

Areas where the spatially-correlated (more deterministic) phase contributions prevail -> clear phase fringes



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Differential and Multiple INSAR (DINSAR)

- Deformation accuracy
- Persistent Scattere and geodesy

Next Generation altimeter

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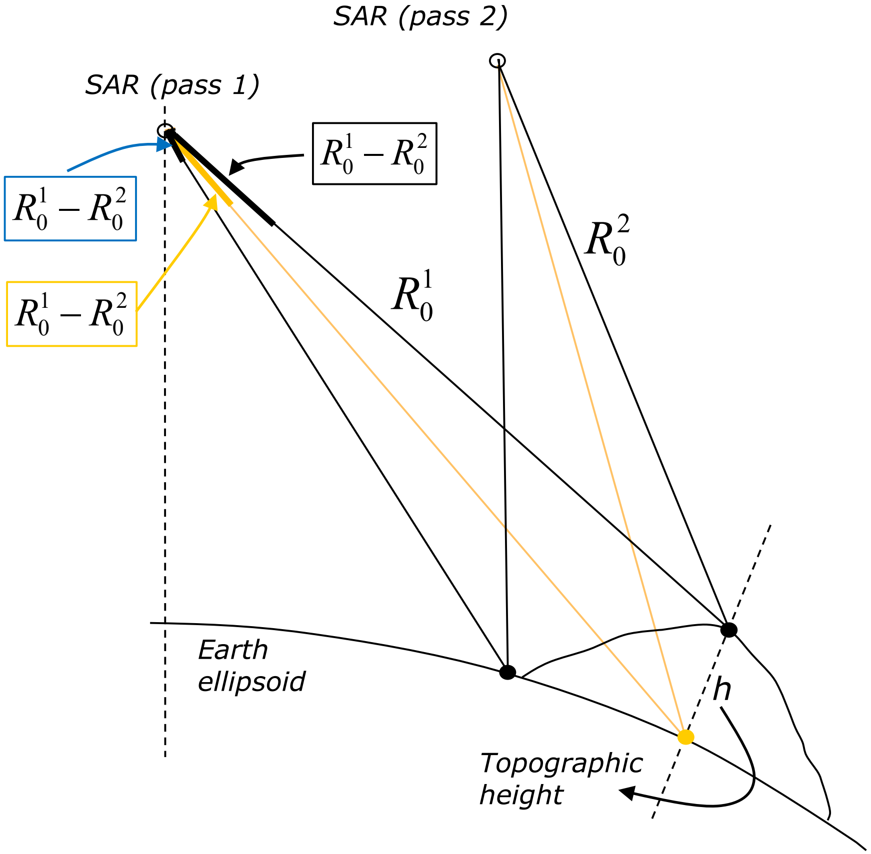
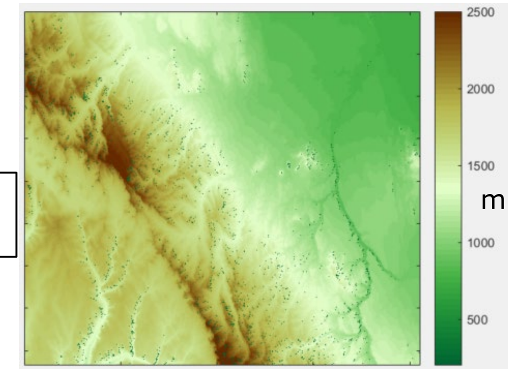
Laser Altimetry for Bathymetry (Heidi Ranndal).

Differential interferograms

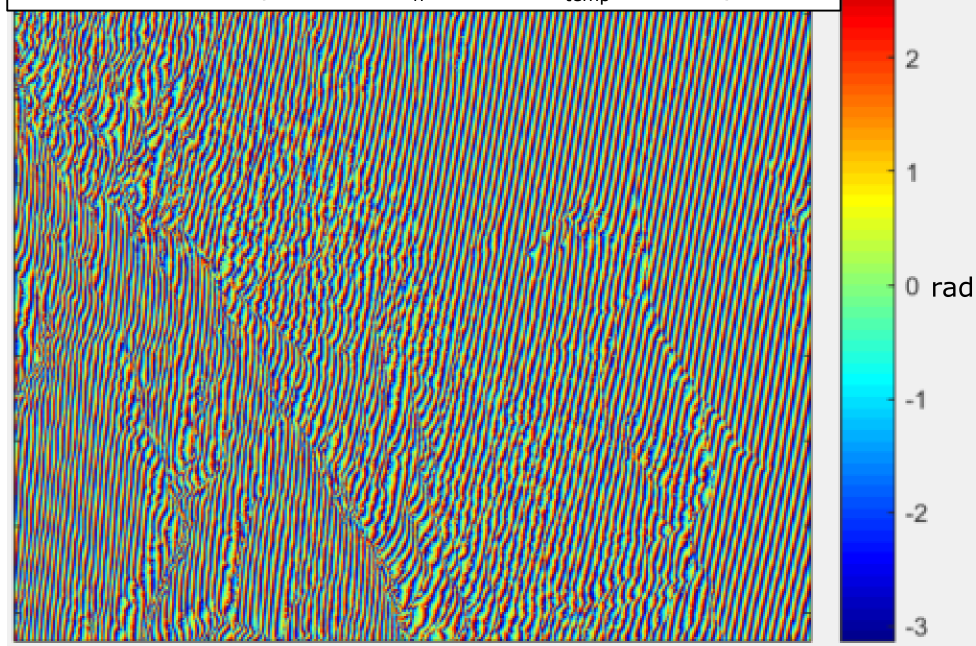
Differencing interferograms (or double difference interferogram) enhances deformations.
In a differential interferogram ϕ_{flat} and ϕ_{topo} are removed based on an Earth ellipsoid and a Digital Elevation Model



SRTM Digital Elevation Model, Rift Valley, Ethiopia



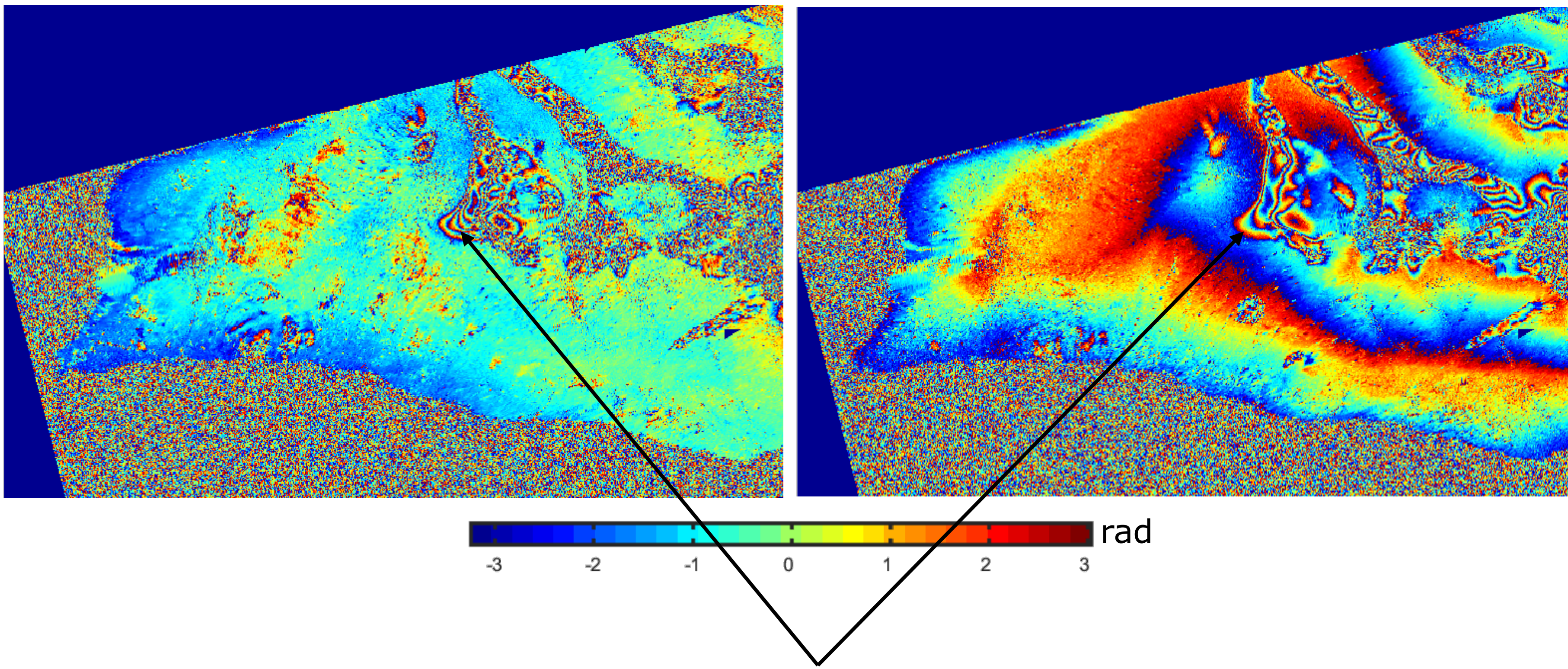
Sentinel-1a (wrapped flattening + topographic phase) 28 Mar. 2015 – 21 Apr. 2015, B_n=-36 m, B_{temp}=´24 days



Sensitivity to motion (in pictures)

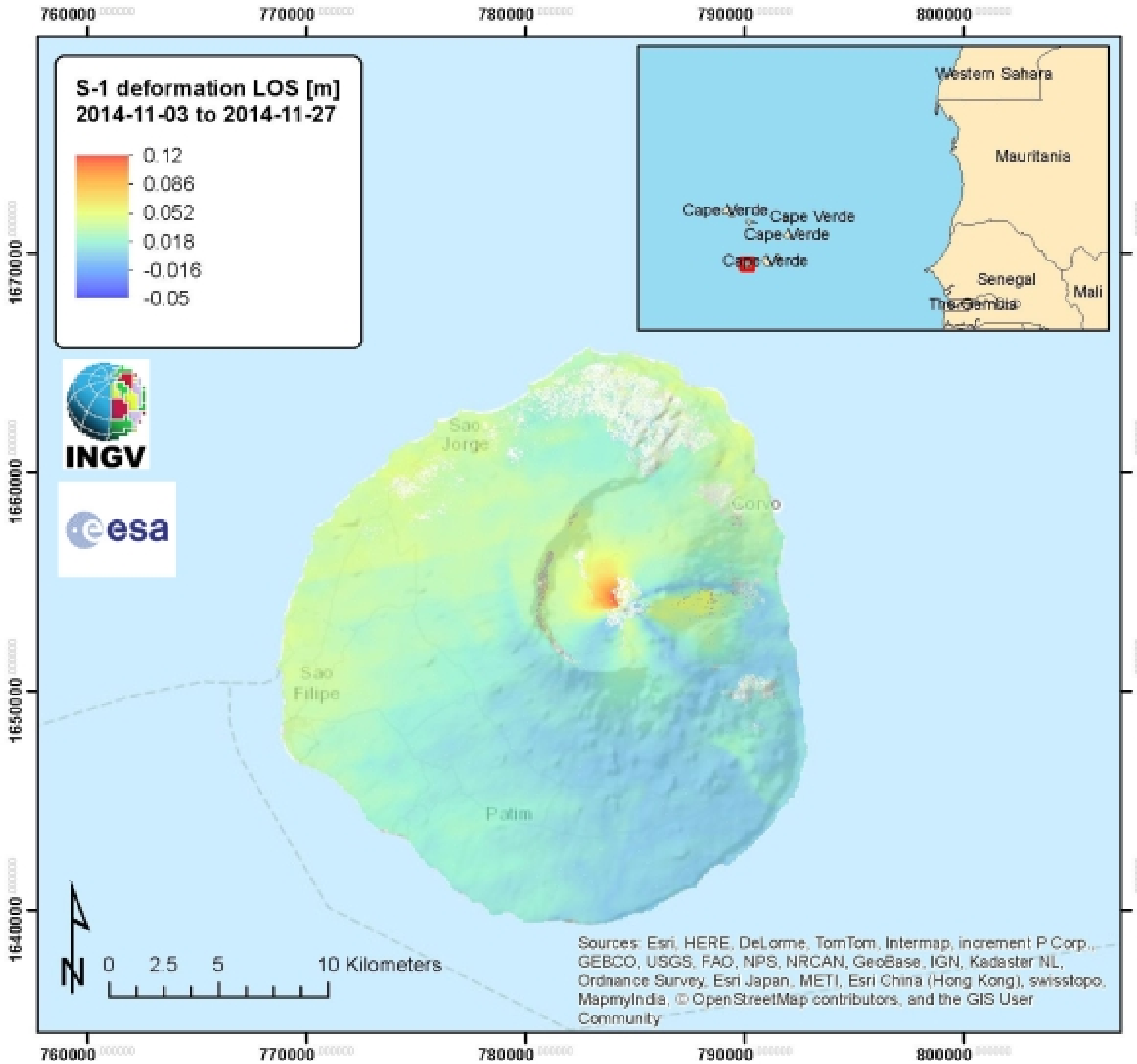
23 Oct. – 04 Nov. 2014, B_n=2 m, B_{temp}=12 days

17 Dec. – 23 Dec. 2016, B_n= -6 m, B_{temp}=6 days



Larger time separation -> more fringes (motion)

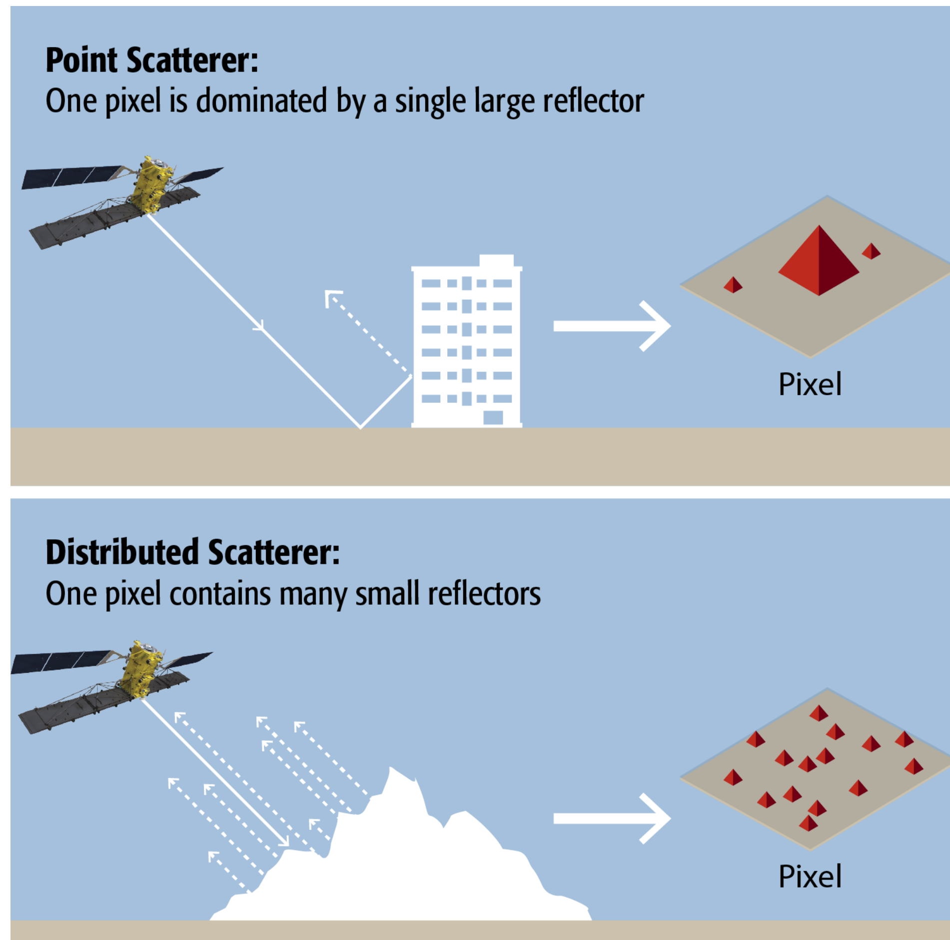
Volcanos


S-1 deformation LOS [m]
2014-11-03 to 2014-11-27
0.12
0.086
0.052
0.018
-0.016
-0.05
INGV
esa
Western Sahara
Mauritania
Cape Verde
Cape Verde
Cape Verde
Cape Verde
Senegal
Mali
The Gambia
Sao Jorge
Corvo
Sao Filipe
Patim
760000
770000
780000
790000
800000
1670000
1660000
1650000
1640000
N
0 2.5 5 10 Kilometers
Sources: Esri, HERE, DeLorme, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Multi-temporal DINSAR

Requires stable DOMINATING scatterer over time.
Could be buildings

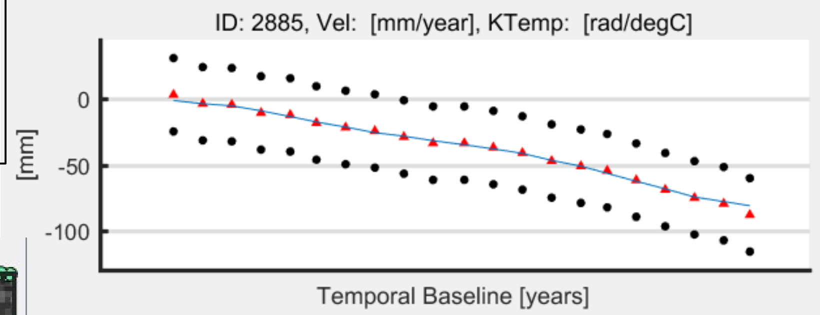
If these are geodetic tied to ground (using i.e. GPS) then deformation on Cm or better can be determined.



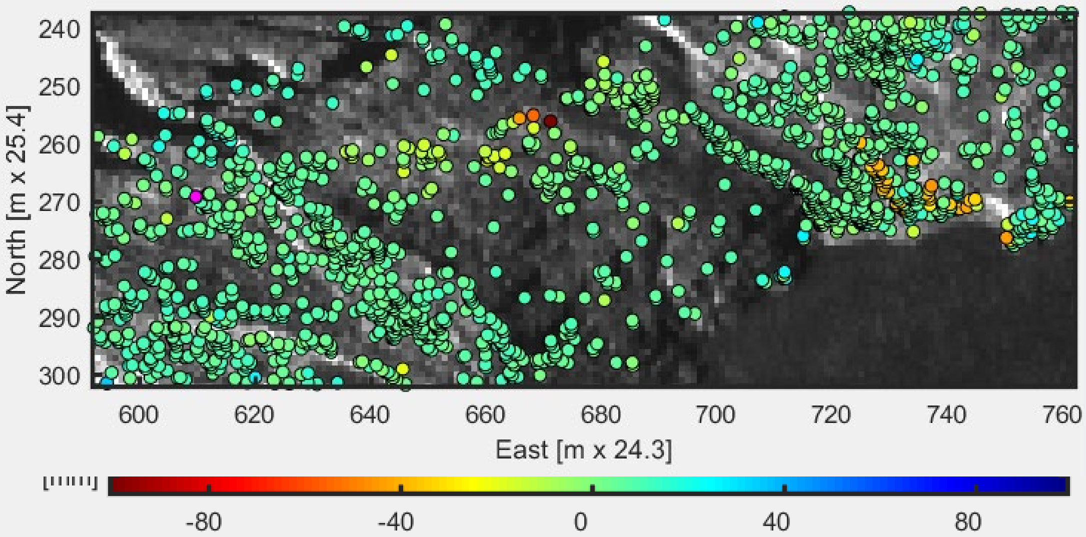
Multi-temporal D-INSAR

Motion can be distinguished from error sources (e.g. atmosphere) by analyzing a set of sparse points with stable radar returns (PSs or DSs) and several (tens of) DInSAR interferograms

Deformation time-series



Cumulative deformation



Deformations are relative
- in space (reference PS/DS)
- in time (first processed image)

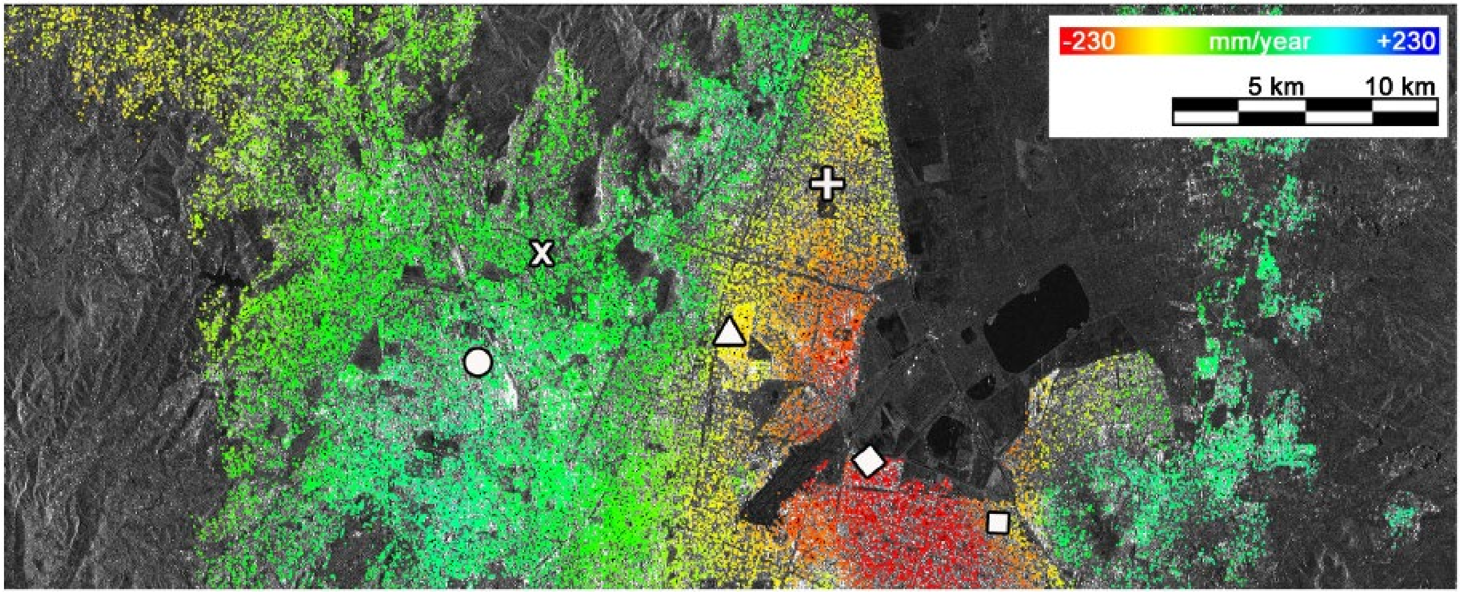
Away from the radar

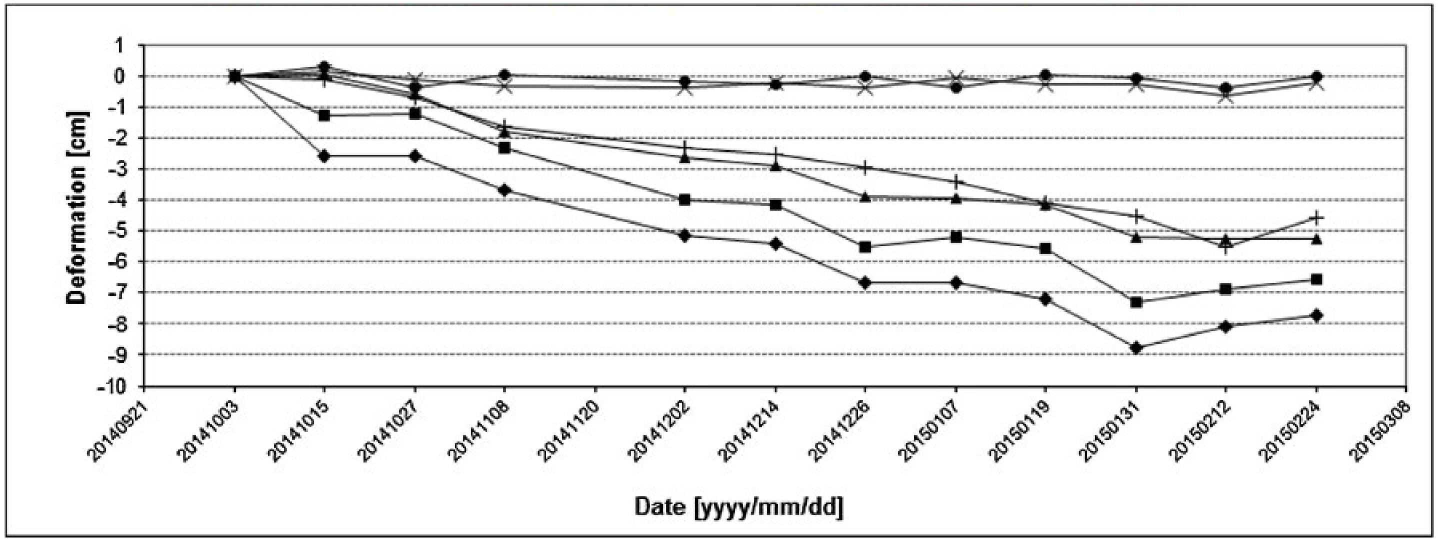
Towards the radar

Measurements are 1D (projection of 3D deformation along the SAR line-of-sight)

Multitemporal D-INSAR

- Deformation (subsidence) of Mexico City (i.e. due to extraction of fresh-water)





Content

- Synthetic Aperture Radar.
  - "Synthetic Aperture"
  - Azimuth and range accuracy
  - SAR and SARin systems/satellites.

Interferometric SAR

Observation principle

Height accuracy

Data and Software

Differential INSAR (DINSAR)

Deformation accuracy

Multiple INSAR and Persistent Scattere and geodesy

Next Generation altimeter

Surface water and Ocean topography. SWOT

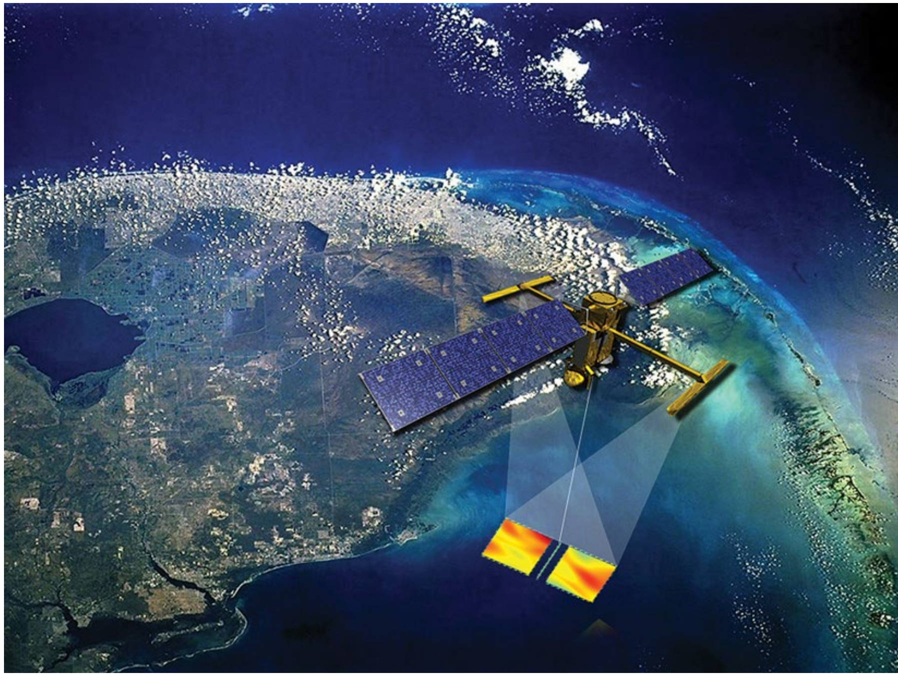
Laser Altimetry for Bathymetry (Heidi Ranndal).

Future……

Precise height at NADIR using satellite altimetry (points).

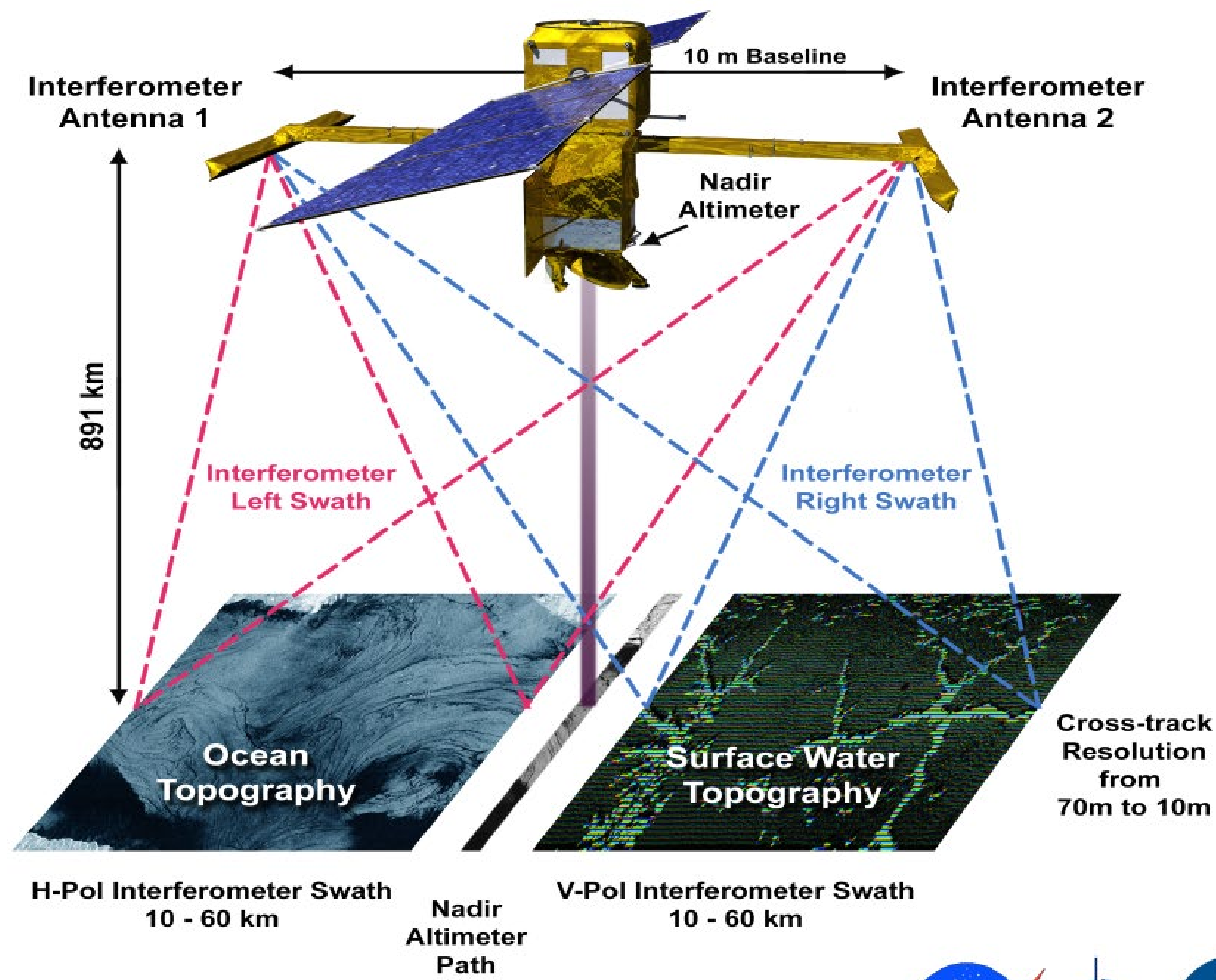
Precise height variations away from NADIR using INSAR (pictures)

Why don't we merge these
to get accurate height everywhere in the pictures



SWOT
Surface water & Ocean topography

SWOT -2D measurement of surface water topography



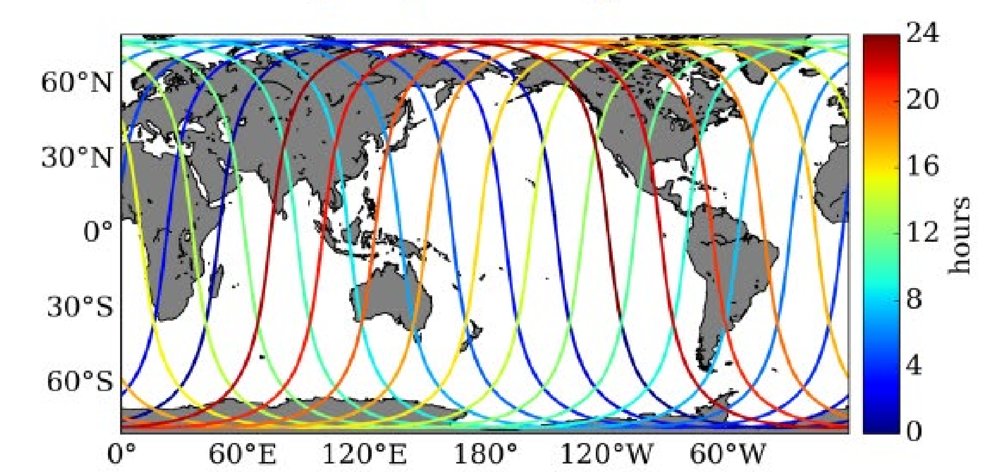
SWOT orbits

Nominal Launch date : Sept 2021
First 6 months : 1-day orbit :

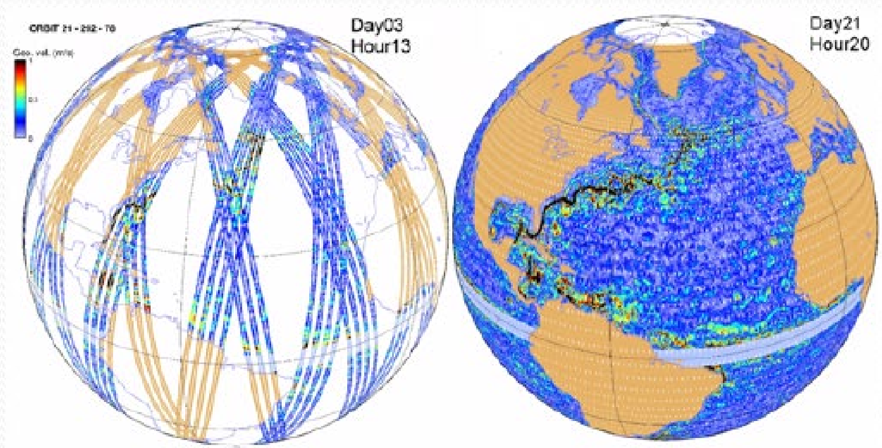
1st 3 months – instrument checkout

2nd 3 months - Dec-Feb 2022 – Science orbit

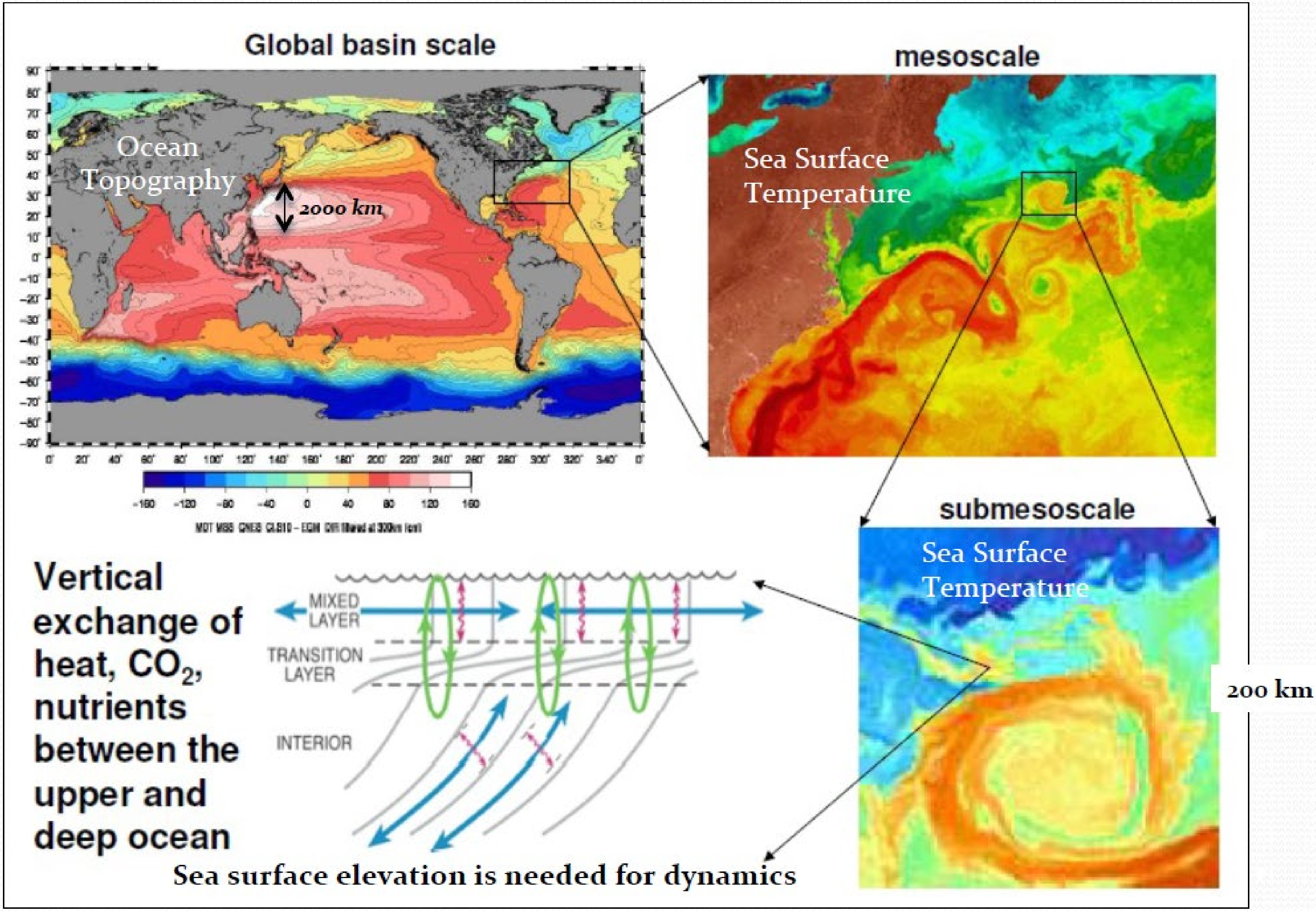
➢ Ideal for ocean studies of rapidly evolving small mesoscales and submesoscales



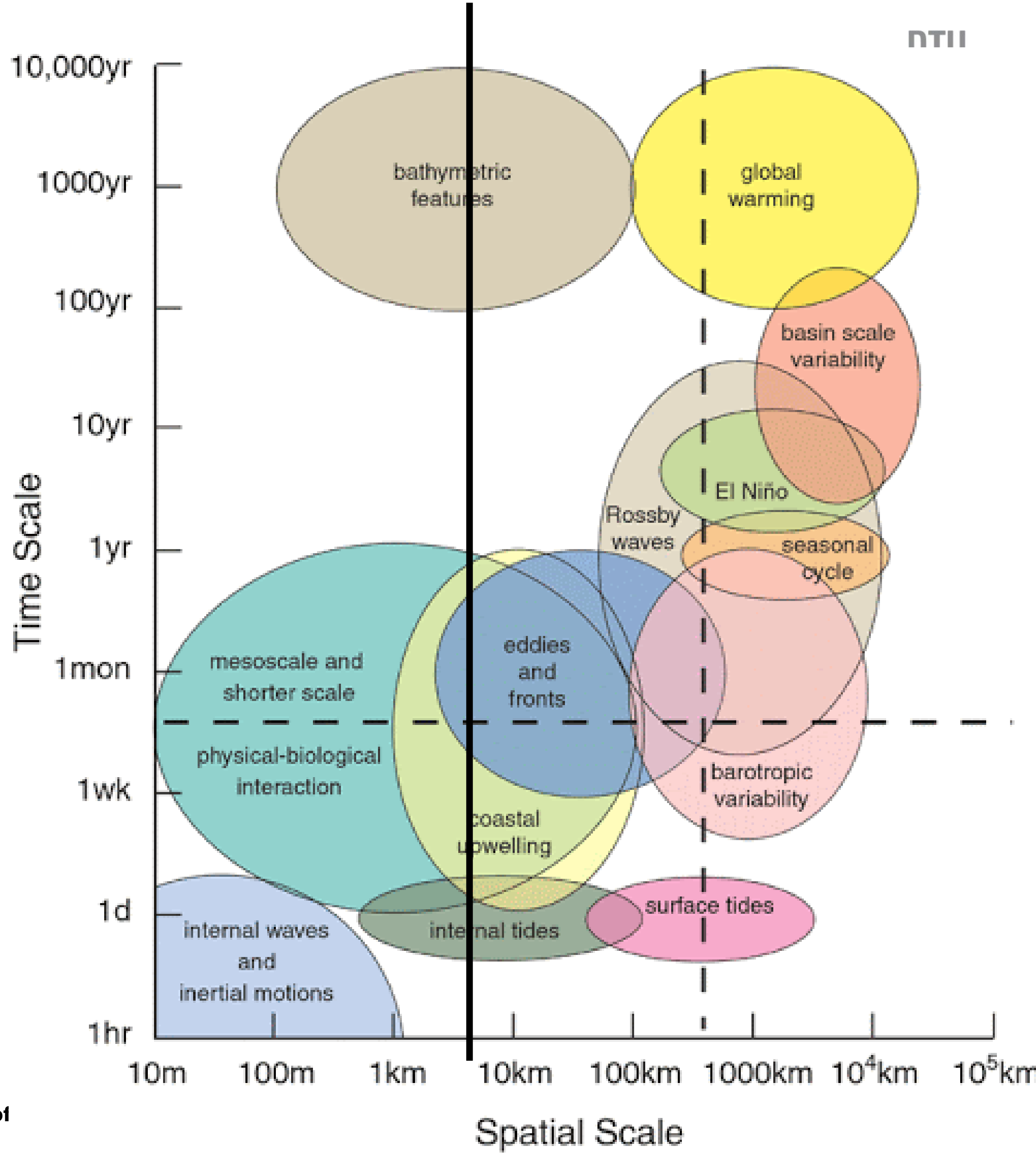
3-year 21-day repeat orbit
Nominally : Mar 2022 to Mar 2025
Full global coverage
1-day and 10-day sub-cycles for
better mesoscale coverage



Targeting the smaller scales of ocean dynamics



Scales in the Ocean drive SWOT accuracy



Resolution is around
5 x 5 meters.
However need to
average ocean cells
to have phase
robustness (50x50m)

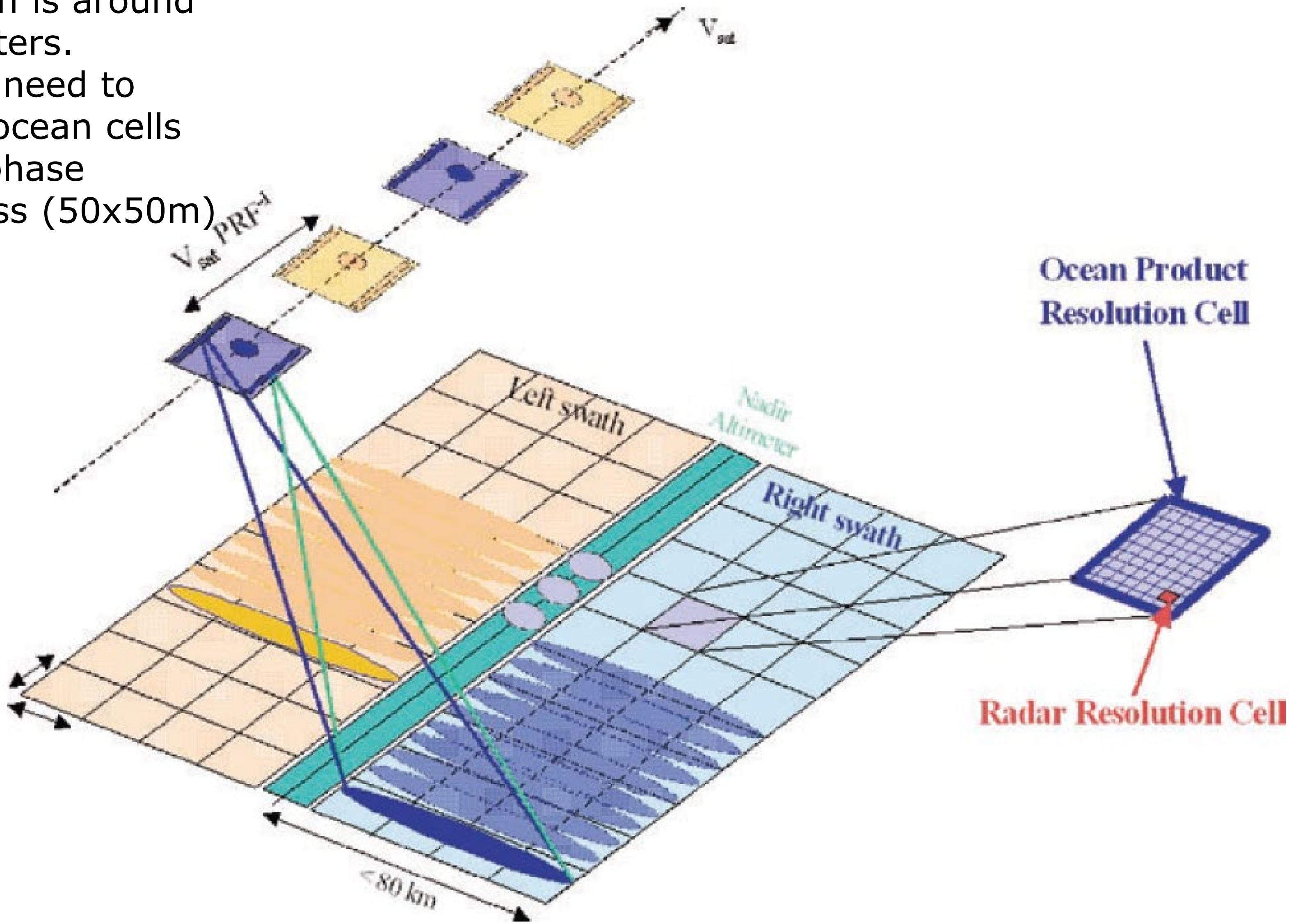
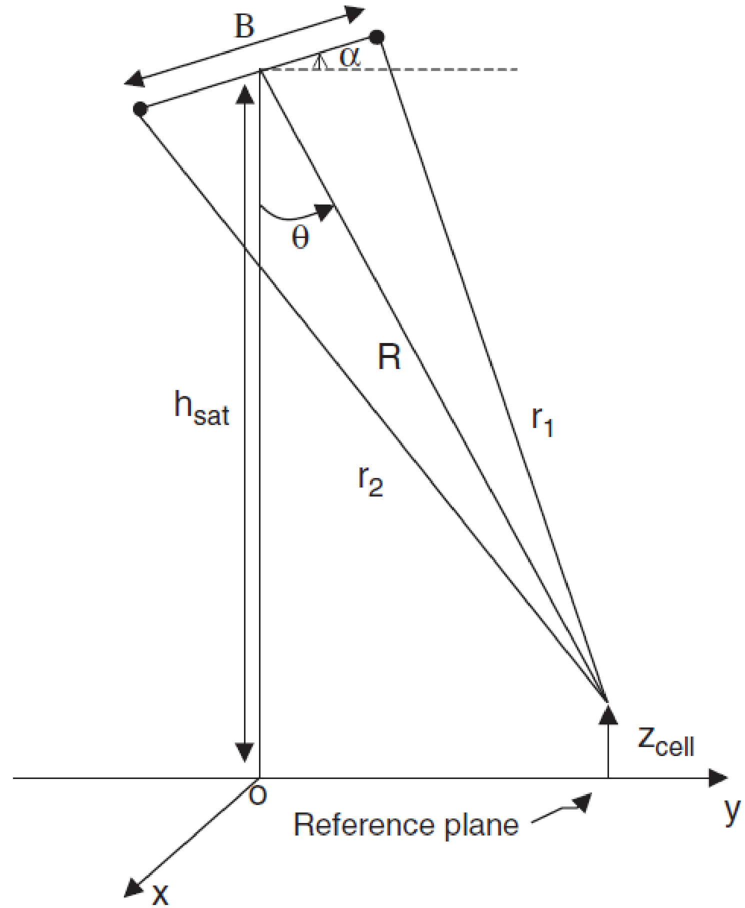


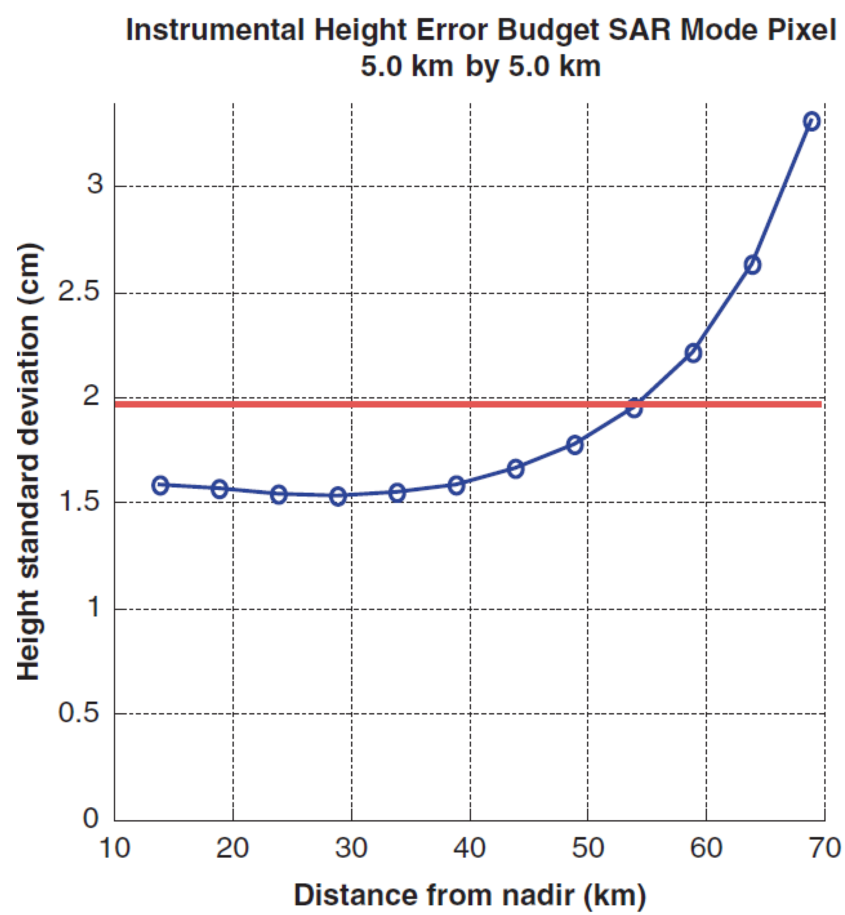
Fig. 20.3 Geometry and resolution cells for a swath altimeter

SWOT height precision

Uncertainty of baseline roll (instrument)
And Distance y away from nadir.

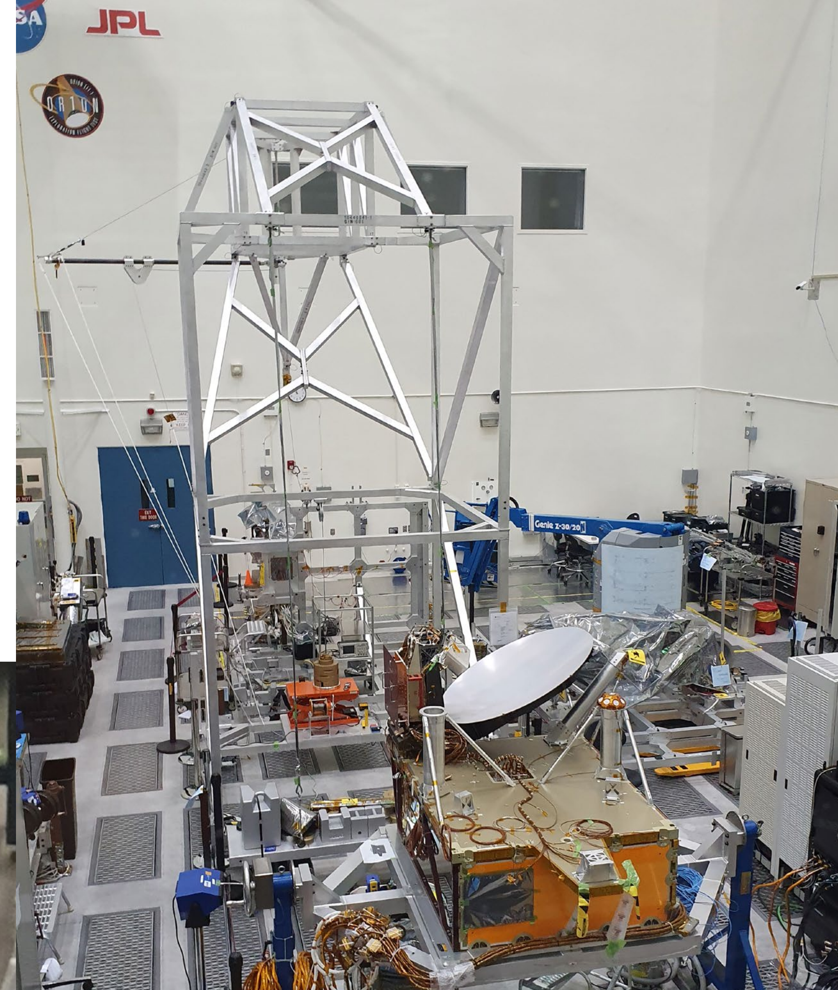
$$\delta z \approx R\theta\, \delta\alpha = y\delta\alpha$$

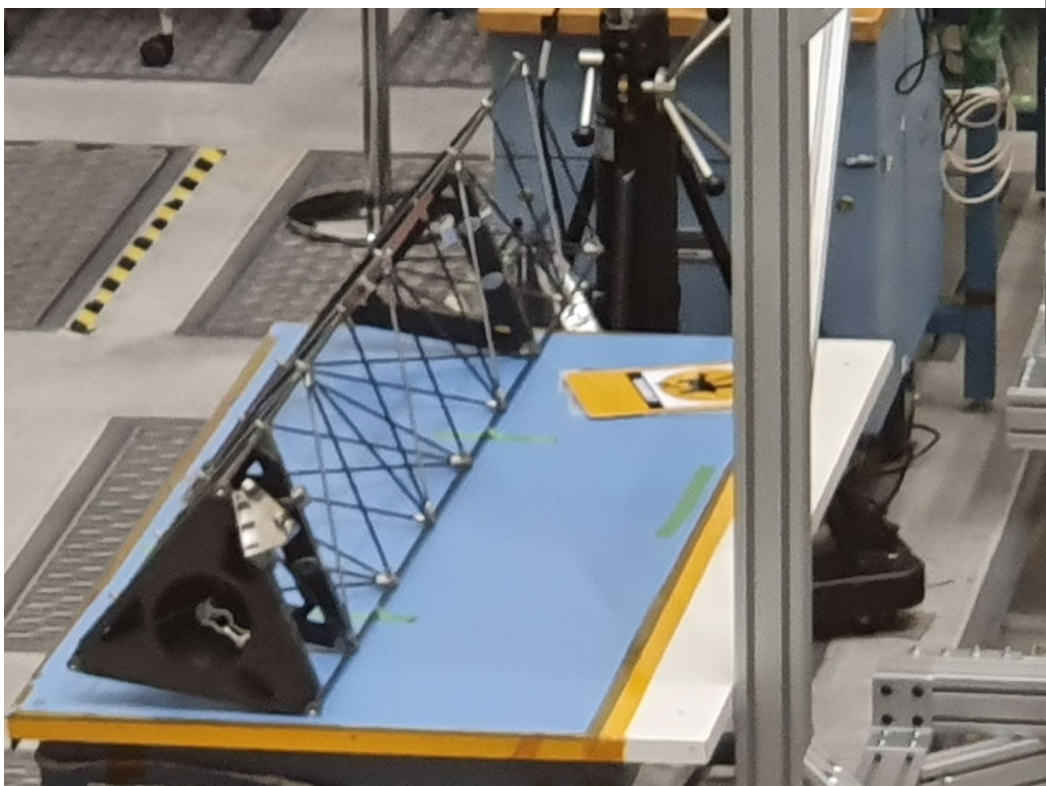




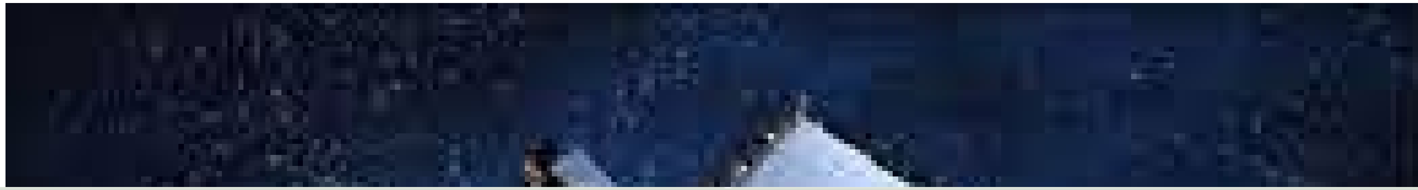
Status on SWOT

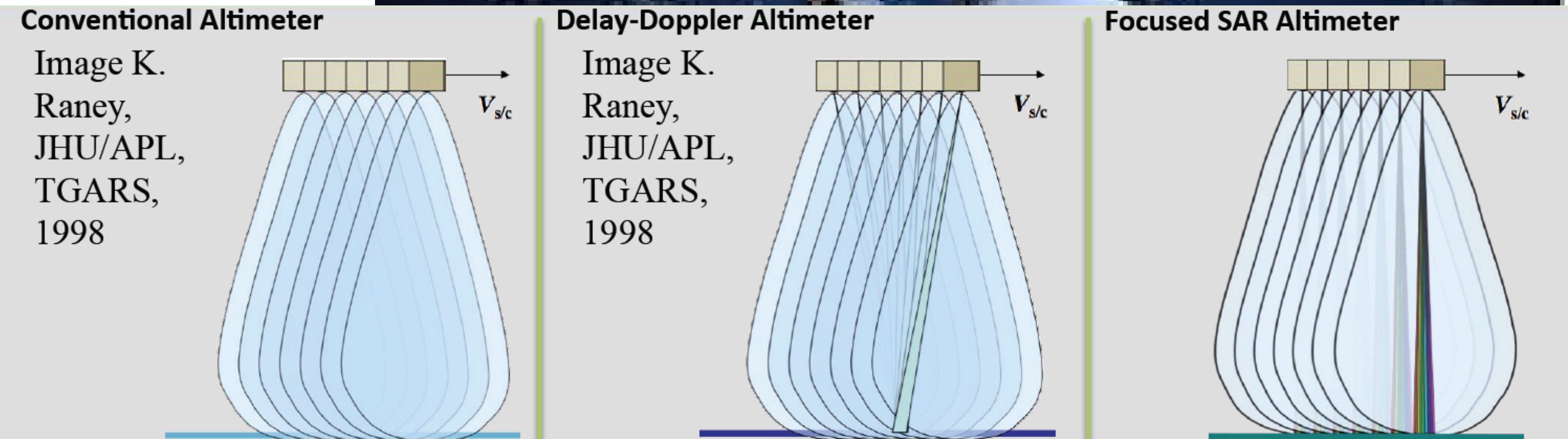
We participate in SWOT Science team.
I Visited JPL facility in January 2020
Launch delayed from Sep 2021
to Feb 2022 (due to covid)





Until then – we can use FF SAR of C2.





Conventional Altimeter

- Low Resolution Mode
- Pulse limited footprint (circular)
- 1.5 / 5 km res. depending on SWH
- Open burst operation
- PRF ~ 2 kHz

Delay-Doppler Altimeter

- Unfocused SAR processing
- ~300 m resolution Along-Track
- Pulse limited across-track
- Closed Burst
- PRF ~ 18 KHz

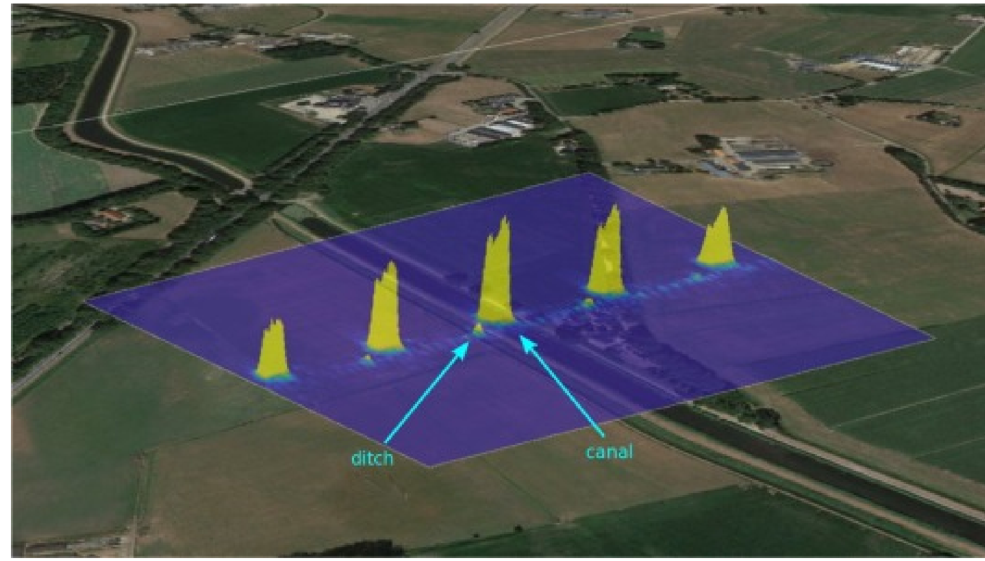
Focused SAR Altimeter

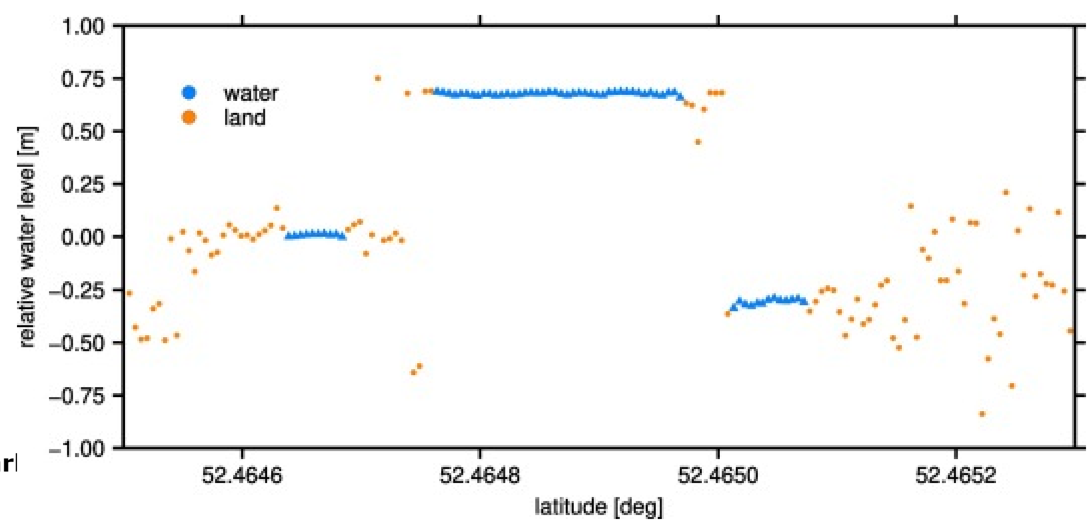
- Fully Focused SAR processing
  Coherent processing for ~2 seconds
- Resolution Along-Track ~ 0.5 m
- Pulse limited across-track
- Closed Burst
- PRF ~ 18 KHz

The main beam is 8 km in Radius, but if you use information from the side lobes the "total beam" can be considered to be much 3 x wider.

Taking SAR to the limit. Fully Focused SAR-

- Target must be stable over 2 sec
- Ocean is NOT……..
- Inland water is…..





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- Synthetic Aperture Radar.
    - Measurements
    - Theory

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Topography

Deformation.

Differential INSAR (DINSAR)

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