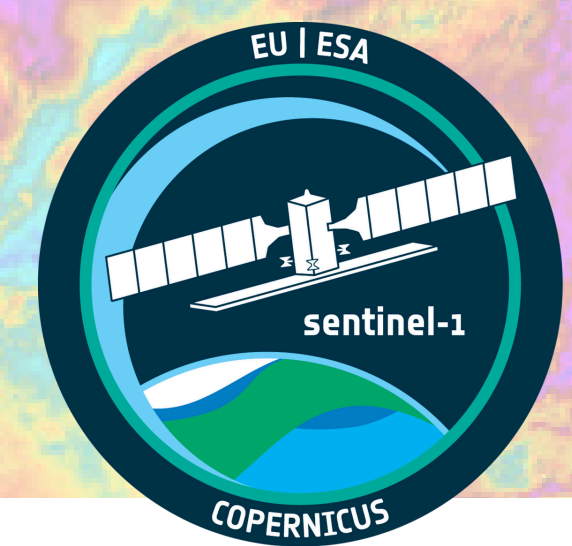


# Measuring Earth's Subtle Movements: Land Deformation Monitoring with Sentinel-1 SAR



## Sentinel-1 Copernicus Mission

Sentinel-1 is part of the European Copernicus Programme launched in April 2014 and a two satellite constellation equipped with Synthetic Aperture Radar (SAR). The radar actively emits microwaves and records the backscatter, allowing observations independent of daylight and cloud cover [1][2]. By having moving satellites, the aperture can synthetically be increased which simulates a bigger antenna and therefore increases the spatial resolution. Sentinel-1 uses a C-band SAR instrument with multiple operational modes [3]. One of its most important modes is the 'Interferometric Wide Swath (IW) Mode' which uses Interferometric Synthetic Aperture Radar (InSAR). By comparing the phase information of radar signals acquired at different times, InSAR can detect millimeter scale surface deformations (see Fig. 2) [3]. This technique allows the mapping of land subsidence, uplift and tectonic movements, making Sentinel-1 a key resource for land deformation monitoring. Other modes include Strip Map Mode (SM), Extra Wide Swath Mode (EW) and Wave Mode (WV), each having different resolutions and nominal swath widths (see table below) [3][13]. Three satellites (A to C) have been launched into orbit over the last 10 years, and Sentinel-1D is set to launch in the second half of 2025. Following a power issue on Sentinel-1B in December 2021, it has been out of action. Since then, Sentinel-1C has taken over, and together with Sentinel-1A, it has been scanning the Earth's surface [3].

<b>Owner</b>	ESA	<b>Spatial Resolution [m]</b>	5 (SM, WV), 20 (IW), 40 (EW)
<b>Satellites</b>	Sentinel-1A, Sentinel-1B, Sentinel-1C, Sentinel-1D	<b>Spatial Resolution [m]</b>	20 (WV), 80 (SM), 250 (IW), 400 (EW)
<b>Sensor</b>	InSAR	<b>Spatial Resolution [m]</b>	12
<b>Band</b>	C-band (3.75 to 7.5 cm)	<b>Spatial Resolution [m]</b>	100.7

## Application

The C-band radar waves used for the InSAR operate at frequencies between 4 - 8 GHz and are capable of penetrating most weather clouds. As information is an active remote sensing technique, measurements do not rely on solar illumination. This independence is an important advantage during extreme events involving surface deformation alongside with a dimming of the atmosphere such as volcanic eruptions [10].

The active sensing technique of InSAR allows millimeter scale precision in the detection of surface deformations, offering a much higher resolution than passive satellite imaging techniques. This precision can be reached due to the detection of phase changes in the backscattered electromagnetic waves between two radar images taken at different times. Interferograms show the vertical displacement of the Earth's surface as a function of phase change with respect to a reference surface using coloration. Repeated colours indicate the completion of a phase, which is equivalent to a displacement of half the radar wavelength ( $\lambda/2$ ). The number of completed phases must be added to the locally measured phase change in order to obtain the total vertical displacement [10].

Sentinel-1A and Sentinel-1C orbit earth 180° apart at an altitude of 693 km. Due to the high accuracy and the stability of the identical radar instruments on each Satellite, measurements of Sentinel-1A and Sentinel-1C can be combined for cross-satellite interferometric analysis, offering the possibility of interferograms using images taken only one day apart instead of the 12-day orbital repeat interval of a single satellite [12].

## Surface Deformation

Deformation of the Earth's surface spans multiple spatial scales - from magma chamber dynamics [5] to the movement of entire tectonic plates [6] - and multiple temporal scales, from the minutes-scale shakes of an earthquake [7] to the billion-years evolution of the planet's surface [6].

The Svartsengi volcanic system in Iceland, for example, has shown heightened activity since 2020, with a surge in seismic events and three eruptions to date [8]. Located near the town of Grindavík, which requires frequent evacuation [9], it is closely monitored by the Icelandic Meteorological Office [5]. One key indicator is ground uplift, caused by magma injection into the chamber, detected using GPS and InSAR data [5] [8]. Yet, forecasting eruptions remains highly uncertain—sometimes offering as little as 30 minutes' warning [5]. Improving how surface observations are linked to subsurface processes is therefore crucial.

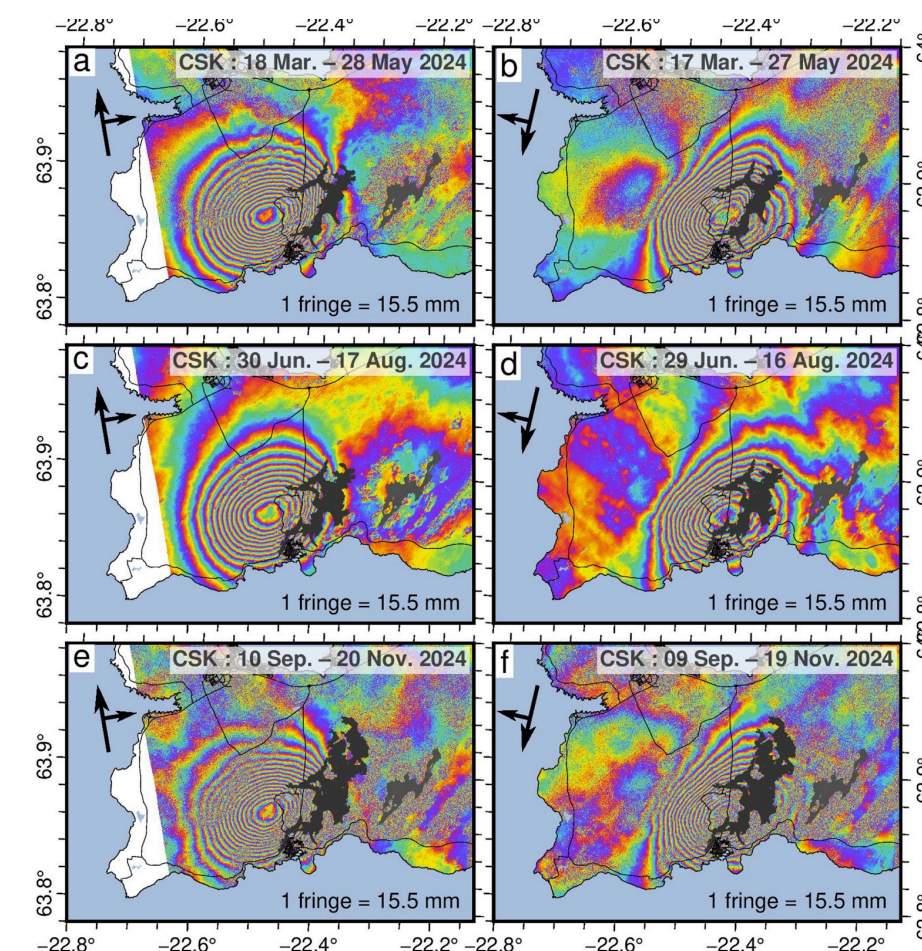


Fig. 1: Spatial pattern of deformation during inflation episodes as revealed by InSAR [9]

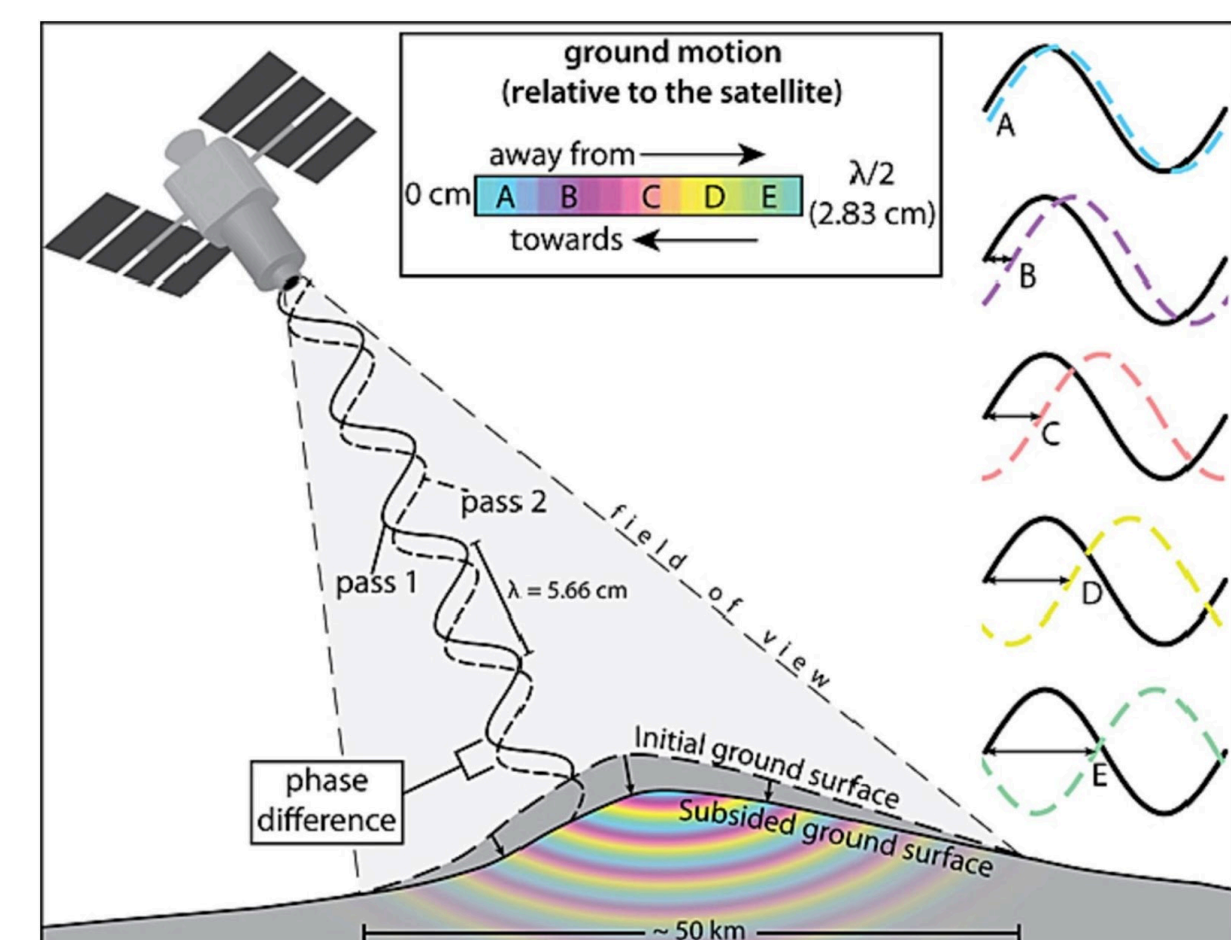


Fig. 2: Diagram of principle of InSAR technology attributing colors to phase difference [4]

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