SAR Interferometry with a Proliferated Daily Ground Track Microsatellite Constellation

Presented By:
Valentyn Tolpekin
valentyn.tolpekin@iceye.com

Team:
Valentyn Tolpekin
Qiaoping Zhang
Angel Johnsy
Michael Wollersheim

ICEYE

Outline

- Introduction & Motivation
  - Unique value of microsatellite InSAR
  - Challenges encountered
- Examples of InSAR Modalities
  - Coherent Change Detection
  - Differential InSAR
  - Persistent Scatterer Interferometry (PSI)
- Improved GTR orbit control
  - Examples
- Key Takeaways & Future Outlook

ICEYE

The ICEYE SAR Constellation

Unique Technology

AGILE SAR SATELLITE CAPABLE OF DIVERSE IMAGING MODES

Persistent Monitoring

ACTIVE SENSING
RESOLUTION RANGE 0.25-15 m

70 + Satellites Launched

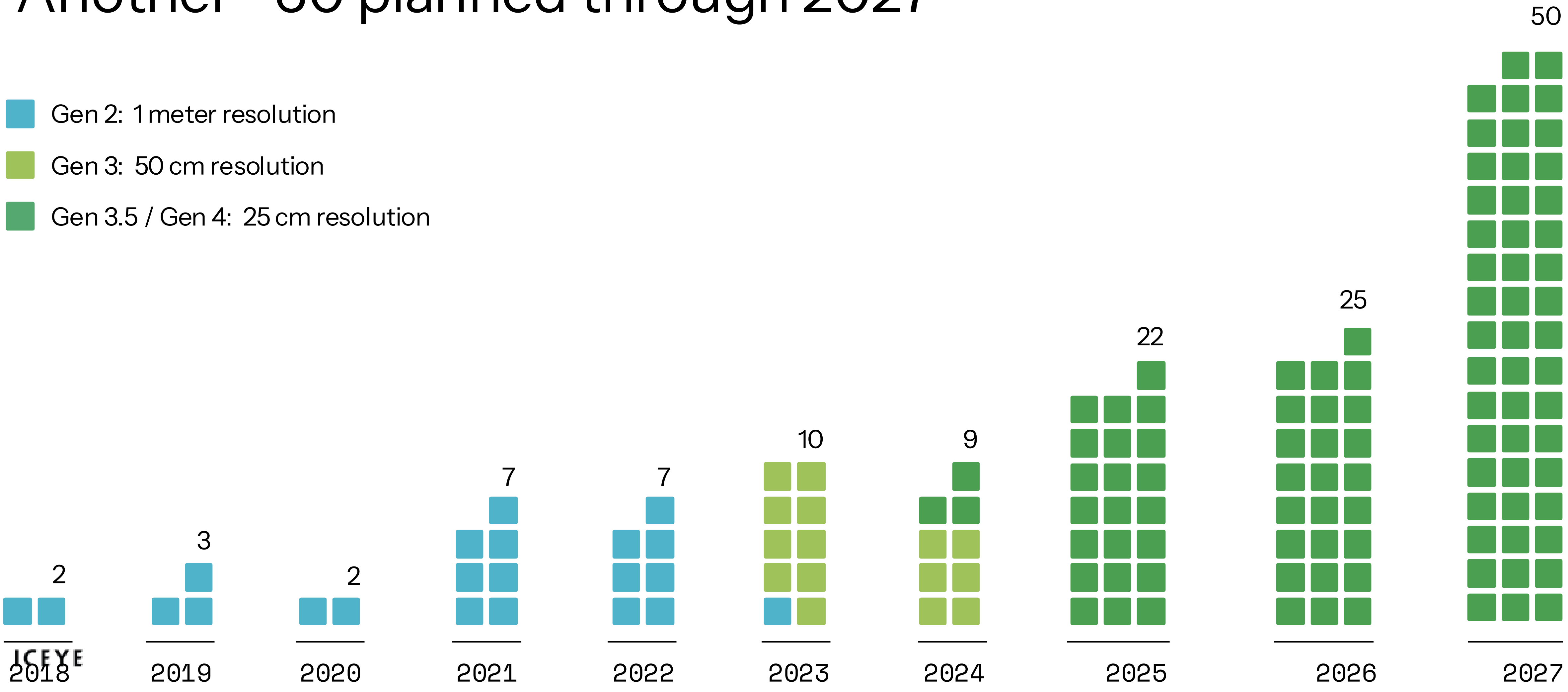
WORLD'S LARGEST SAR CONSTELLATION

Frequent Revisit

5 - 10X DAILY ANYWHERE ON EARTH

PROVEN LAUNCH EXPERTISE

72 satellites launched to date. Another ~60 planned through 2027



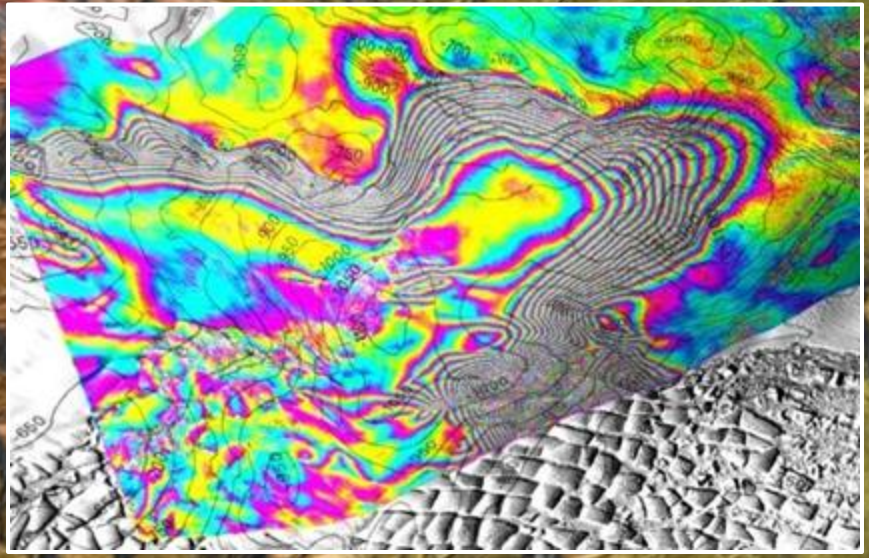
ICEYE

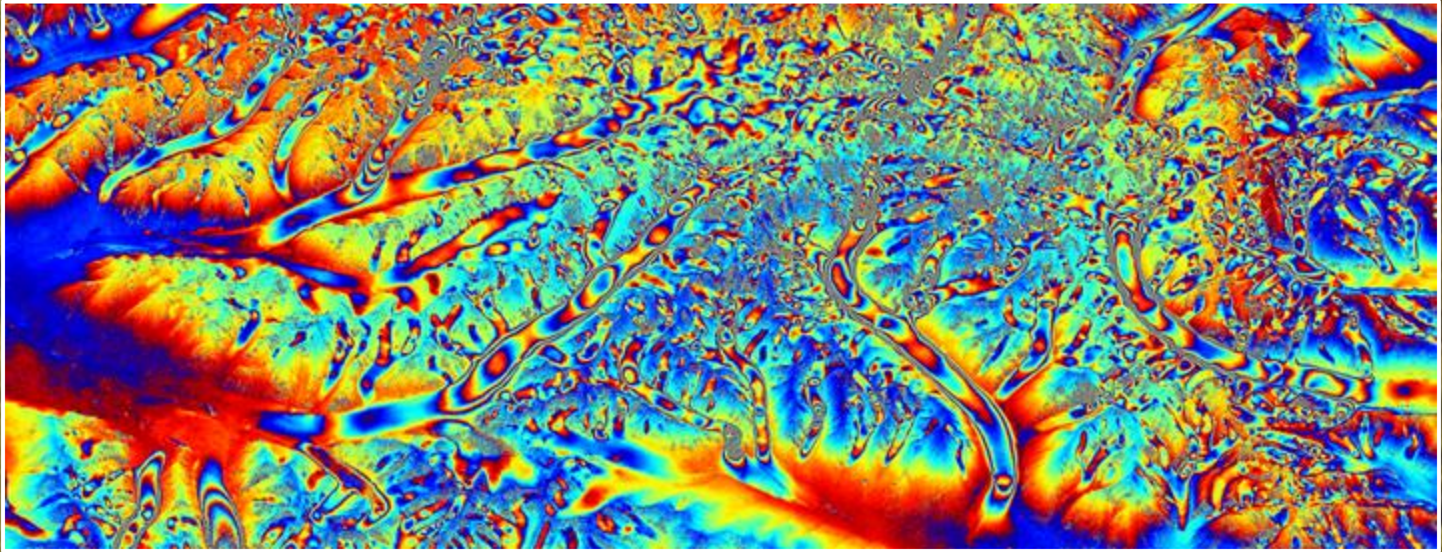
Unique Value of Microsatellite InSAR - Frequent Revisit

Crucial for Fast-Changing Environments

Example Use Cases:

- Grounding Lines: high-velocity or rapidly-melting glaciers lose coherence quickly
- Landslide & Slope Failure: More observations needed when deformation rate becomes critical
- Terrain Assessment: Immediately refreshed DEM following disaster (e.g. landslides, floods)





Unique Value of Microsatellite InSAR - Very High Spatial Resolution

When Detail Matters

Example Use Cases:

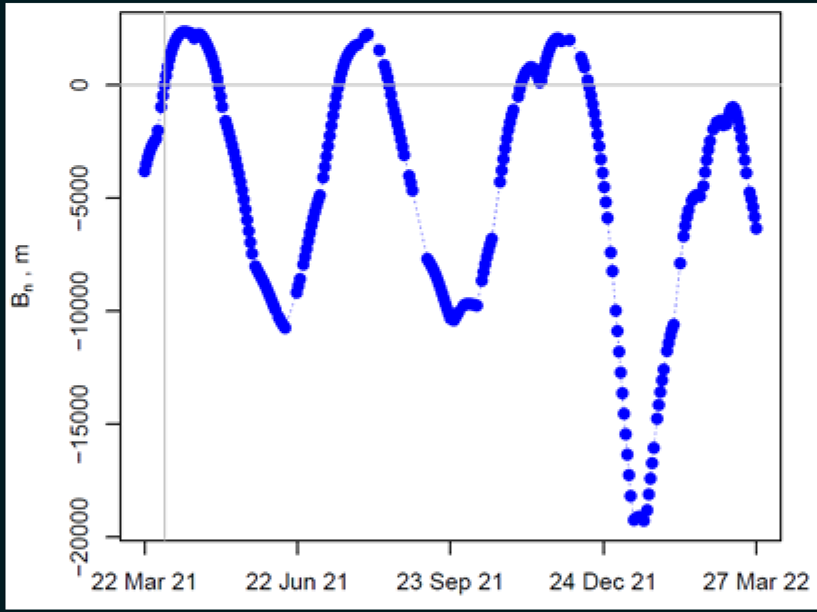
- Coherent Change Detection (CCD): Track vehicle movement or monitor agricultural activity
- Infrastructure monitoring: Detect fine-scale displacement on bridges, dams and utilities

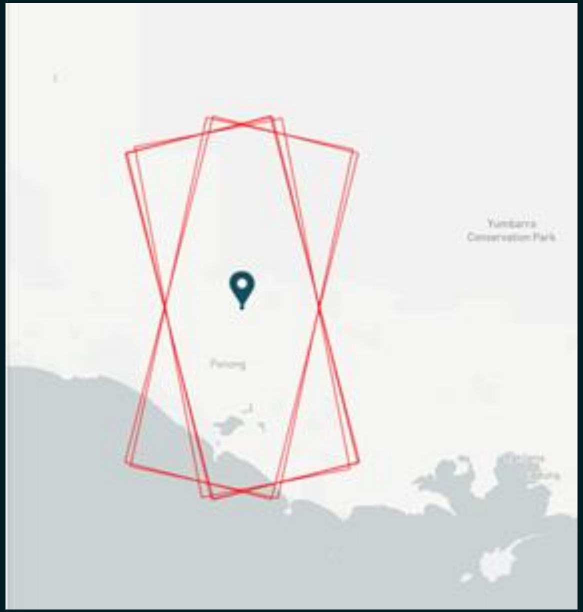
Challenges of Microsatellite InSAR

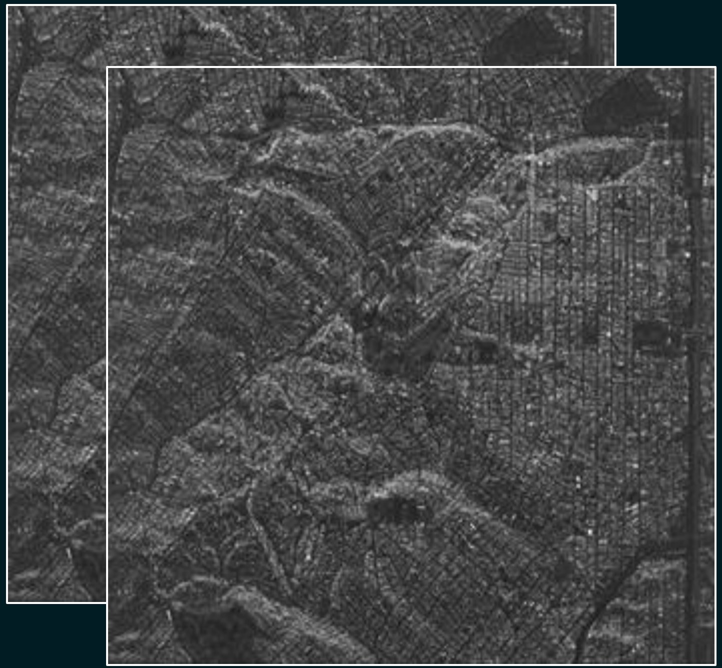
Orbit Stability and Baseline Control

Tasking Oriented: Not an 'always-on' Archive

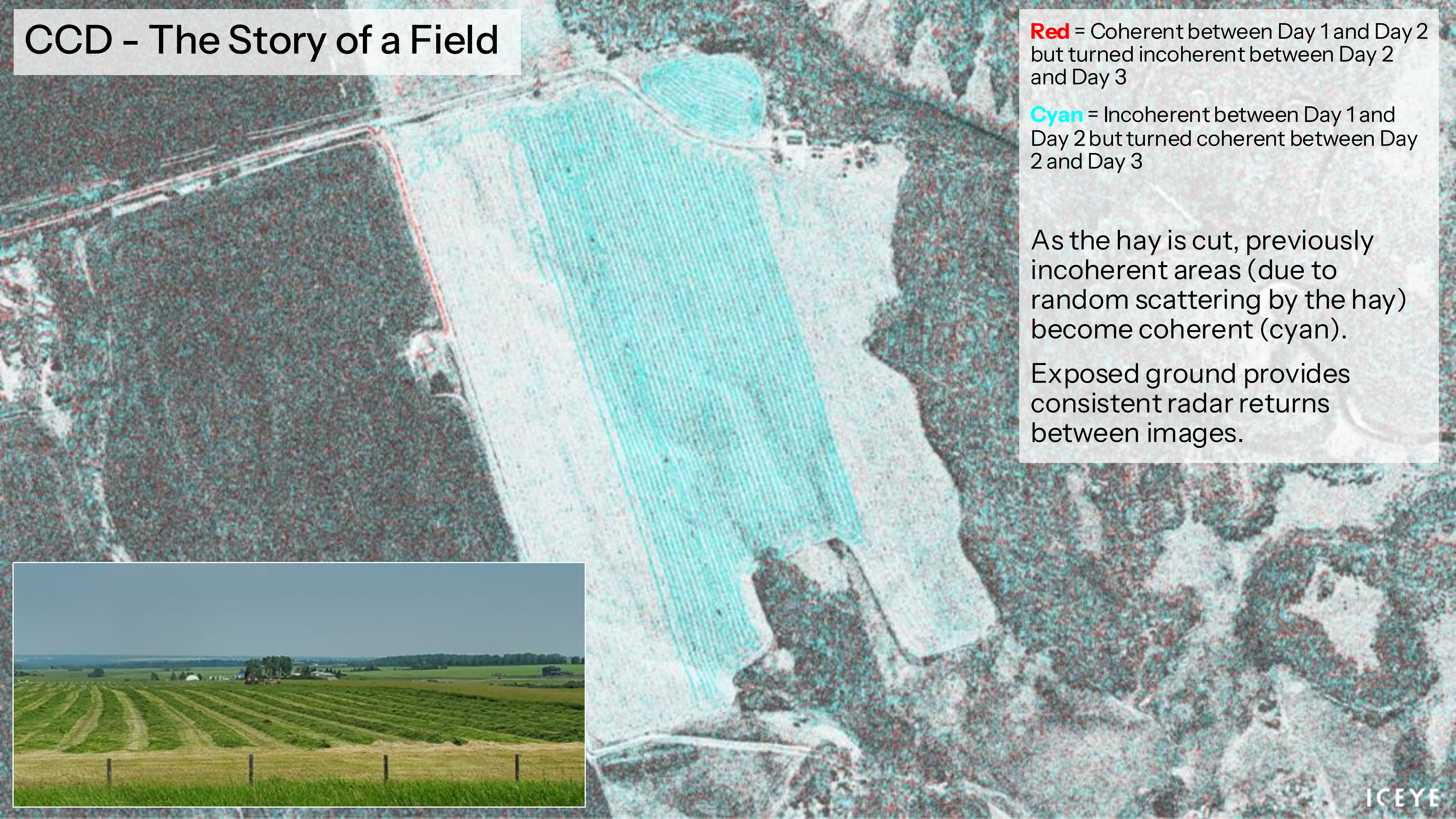
Co-registration complexity: High-res stacks need precise alignment despite imperfect satellite geolocation







CCD - The Story of a Field



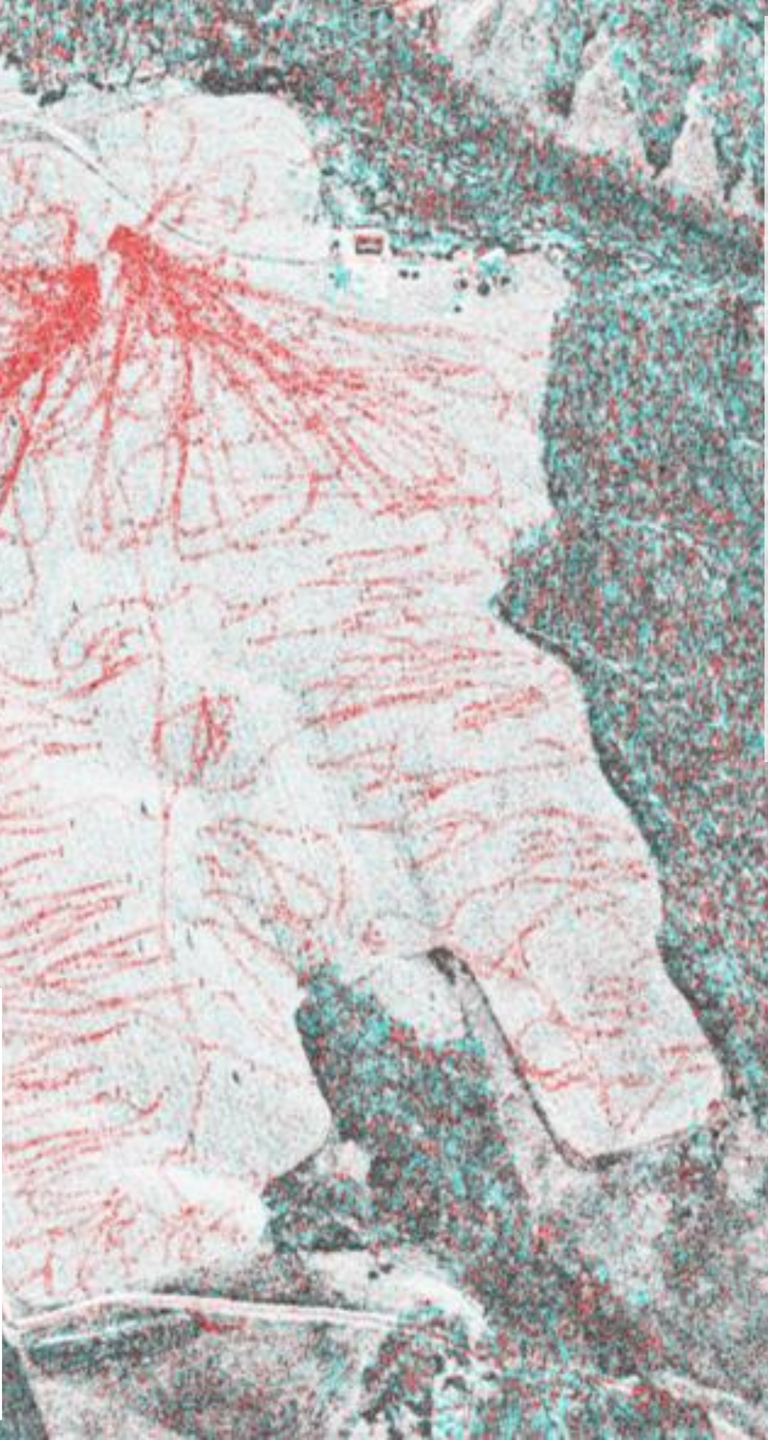
Red = Coherent between Day 1 and Day 2 but turned incoherent between Day 2 and Day 3

Cyan = Incoherent between Day 1 and Day 2 but turned coherent between Day 2 and Day 3

As the hay is cut, previously incoherent areas (due to random scattering by the hay) become coherent (cyan).

Exposed ground provides consistent radar returns between images.

CCD - The Story of a Field



Red = Coherent between Day 1 and Day 2 but turned incoherent between Day 2 and Day 3

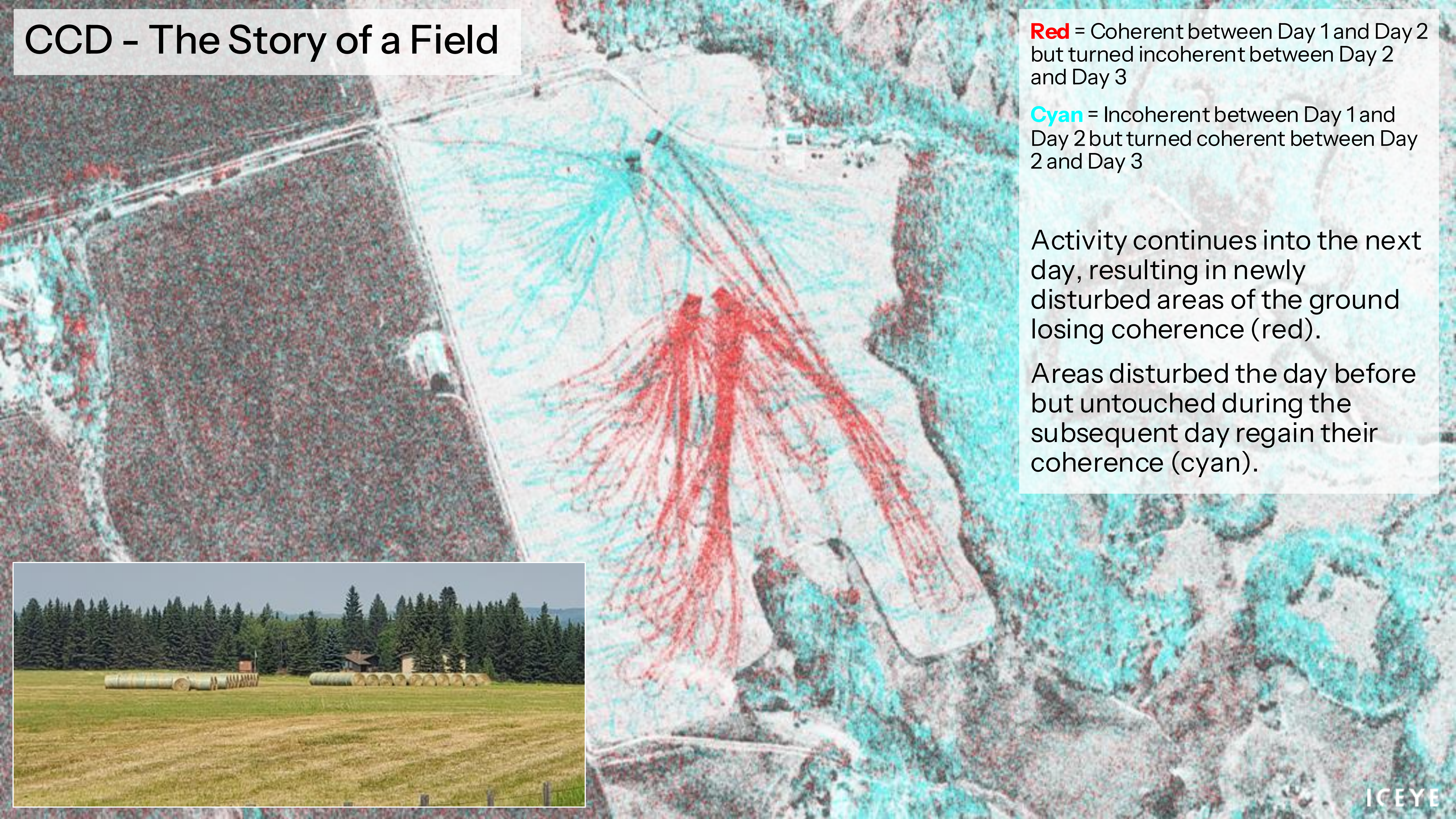
Cyan = Incoherent between Day 1 and Day 2 but turned coherent between Day 2 and Day 3

As hay is baled and gathered by a tractor, disturbed ground loses coherence between radar images.

Tractor movement is revealed by this coherence loss (red).

ICEYE

CCD - The Story of a Field



Red = Coherent between Day 1 and Day 2 but turned incoherent between Day 2 and Day 3

Cyan = Incoherent between Day 1 and Day 2 but turned coherent between Day 2 and Day 3

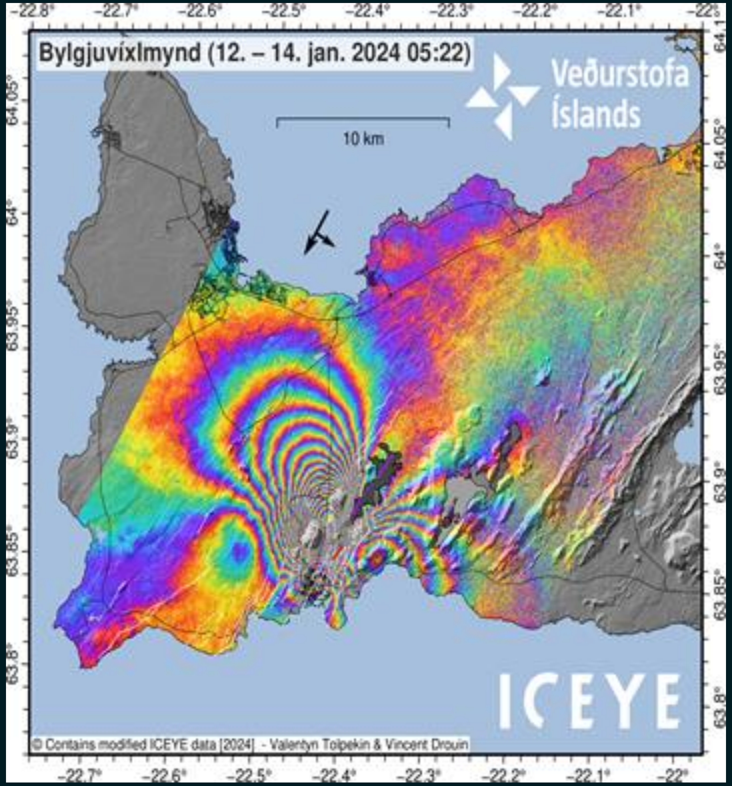
Activity continues into the next day, resulting in newly disturbed areas of the ground losing coherence (red).

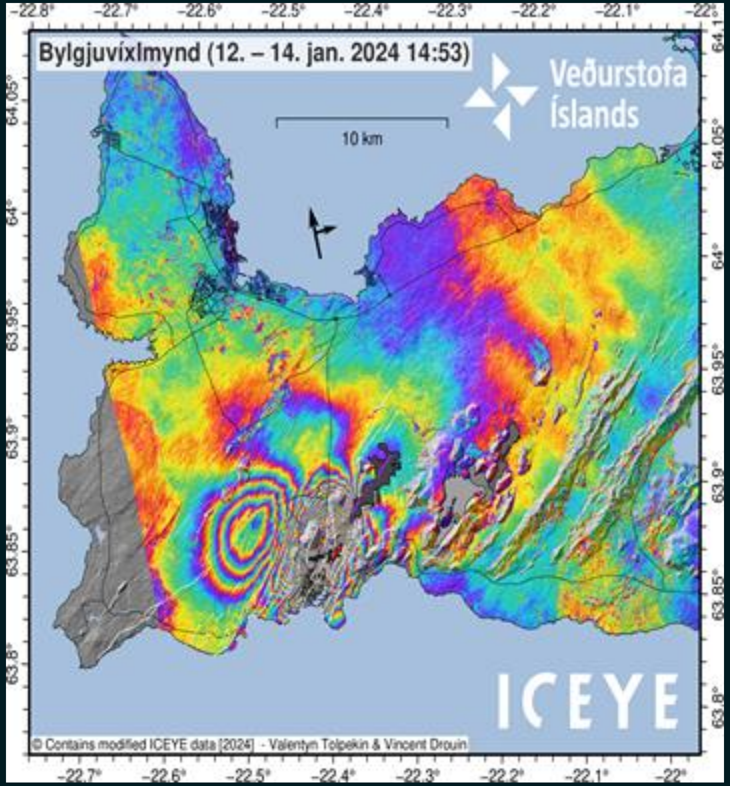
Areas disturbed the day before but untouched during the subsequent day regain their coherence (cyan).

ICEYE

Differential InSAR

- Leveraging daily revisit for quantifying deformation during time-critical monitoring of fast events
- Validated use cases: landslides, volcanic eruptions, earthquakes, and glacier monitoring





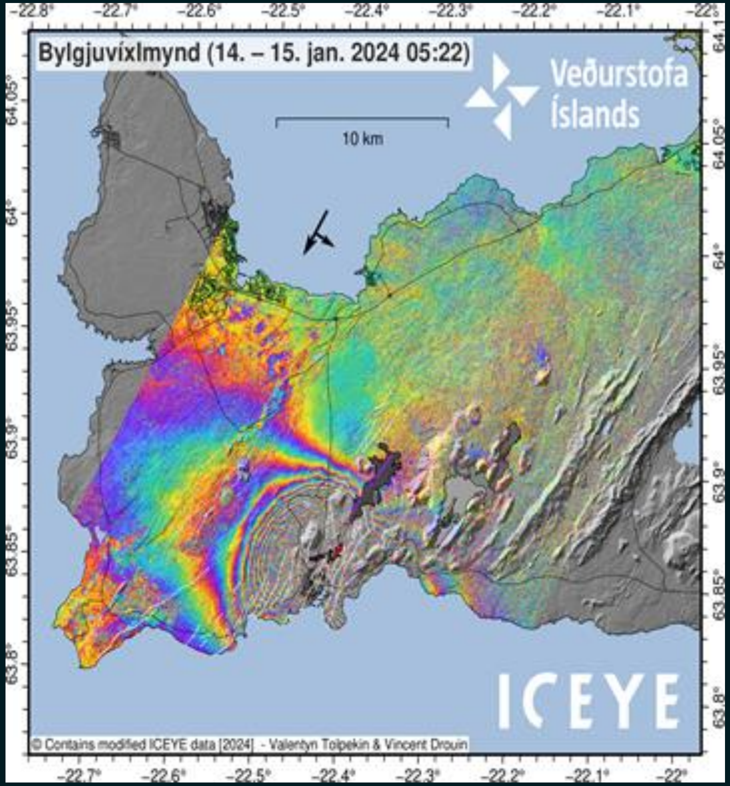


Image Credits: Icelandic Meteorological Office https://en.vedur.is/ Photos: Ragnar Heiðar Þrastarson, (used with permission)

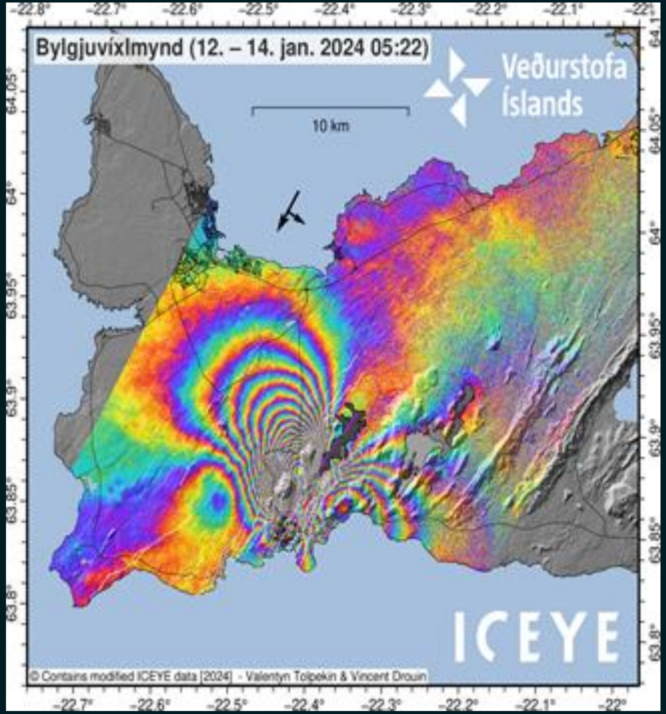
Differential InSAR

Icelandic Met Office

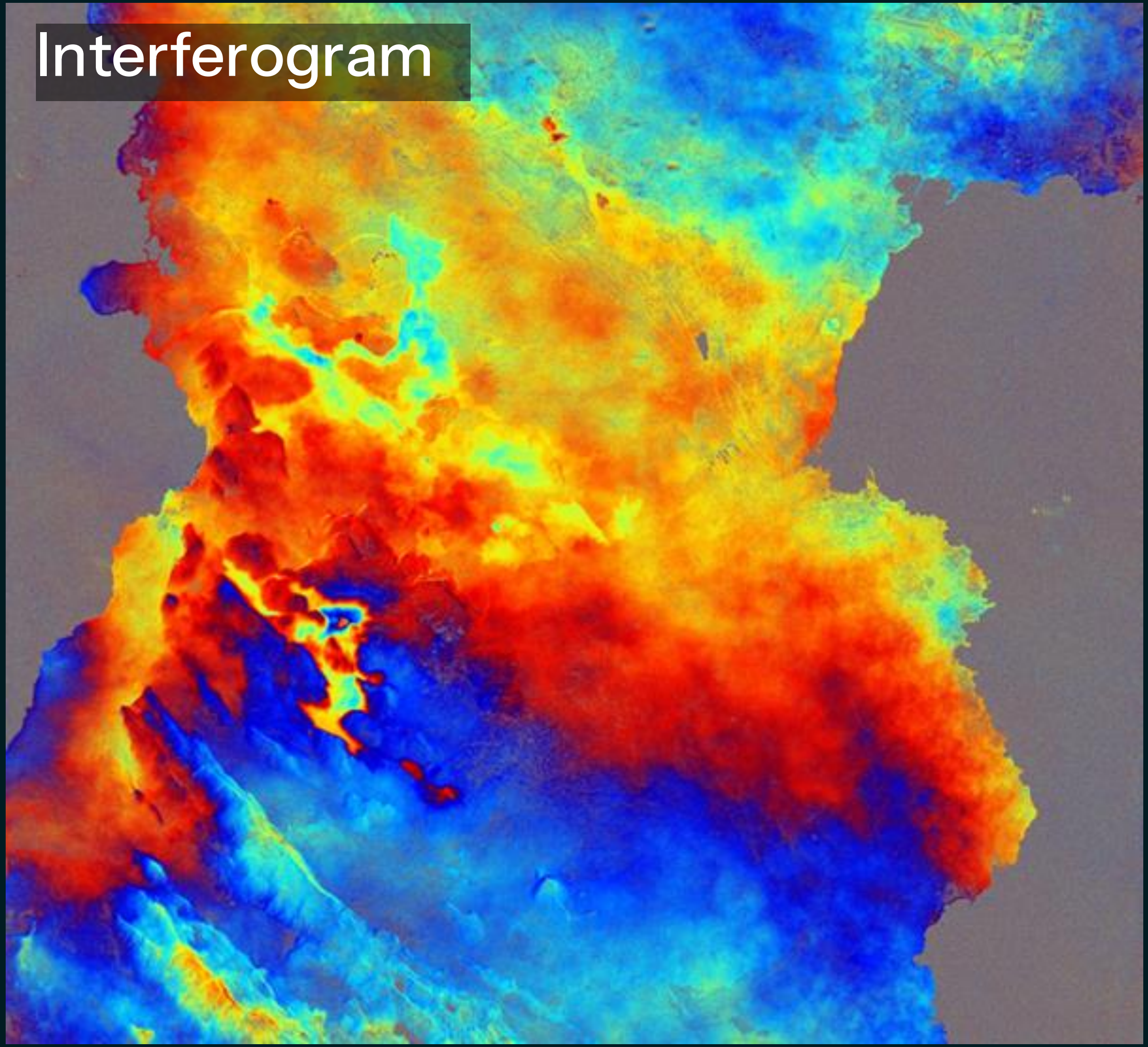
- Leveraging daily revisit to quantify deformation during time-critical monitoring of fast events
- Validated use cases: landslides, earthquakes, glacier monitoring and volcanic eruptions
- Frequent volcanic activity in the Reykjanes Peninsula since 2021, right to the present day
  - **The most recent eruption occurred on July 16, 2025**
- ICEYE works closely with Icelandic Met Office, providing InSAR & CCD to prepare and respond

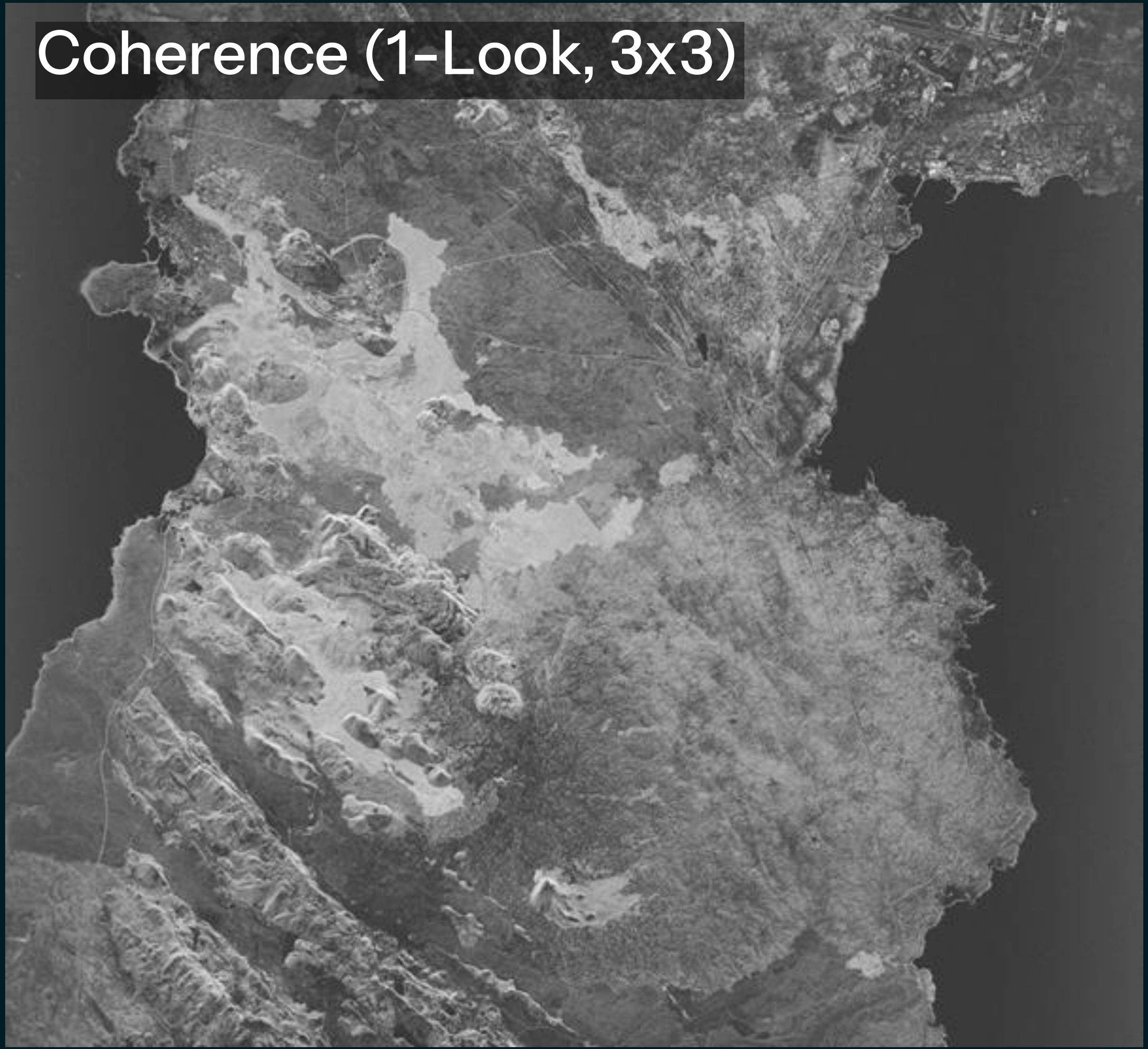

Lava emerging from a fissure near Grindavik


Fissure eruption near Svartsengi power plant

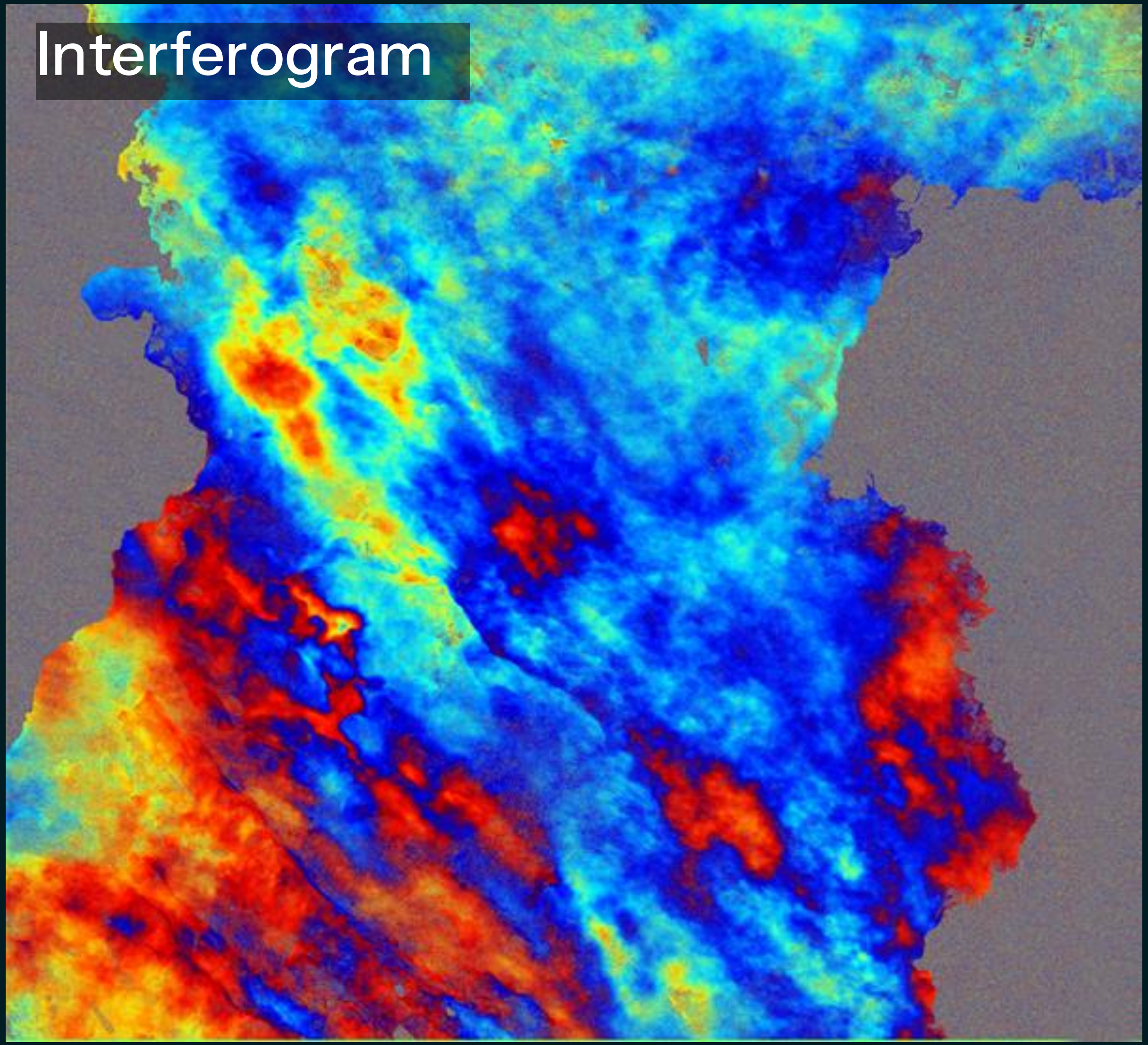


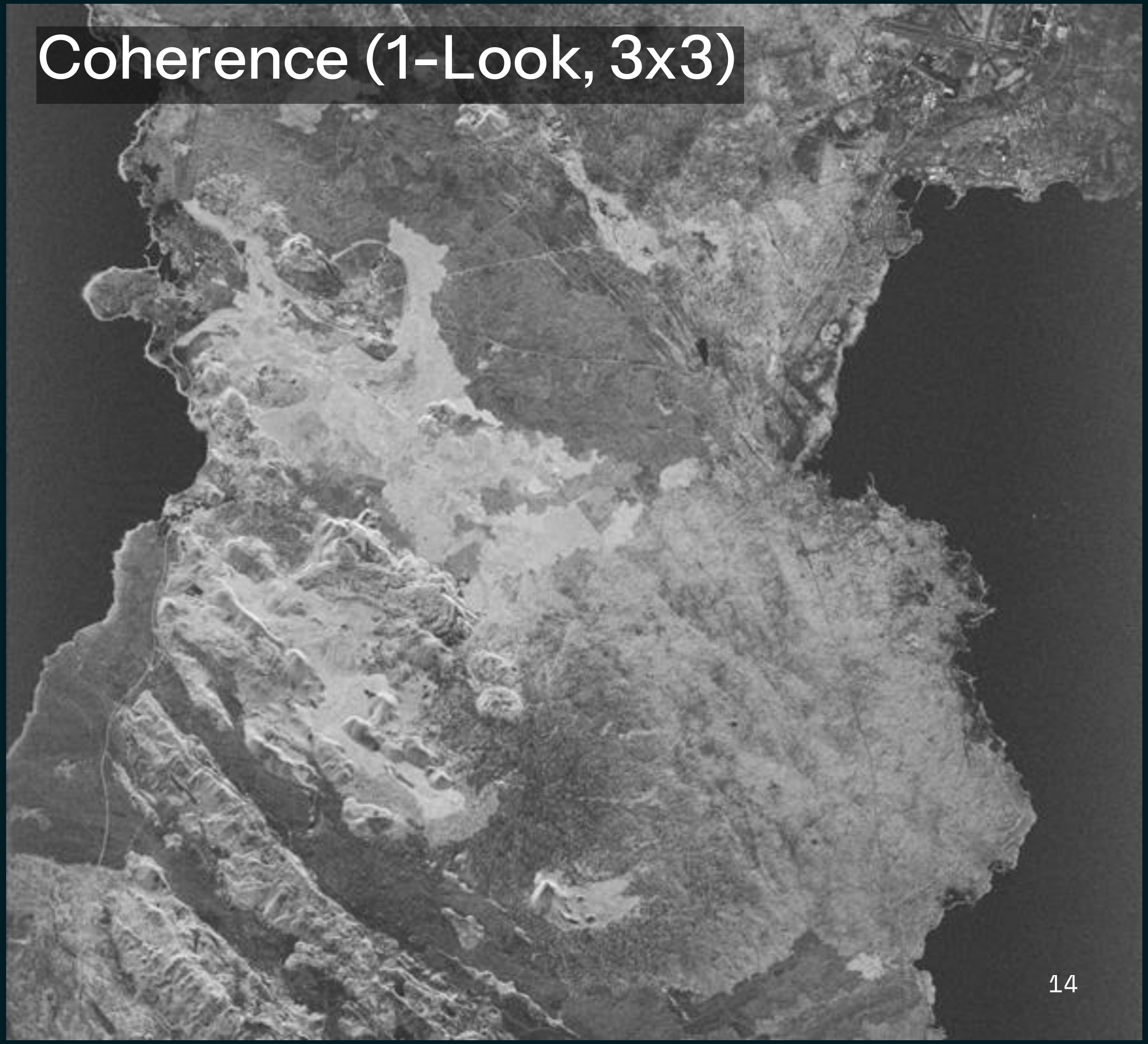
June 6 - 7 (Month before eruption)



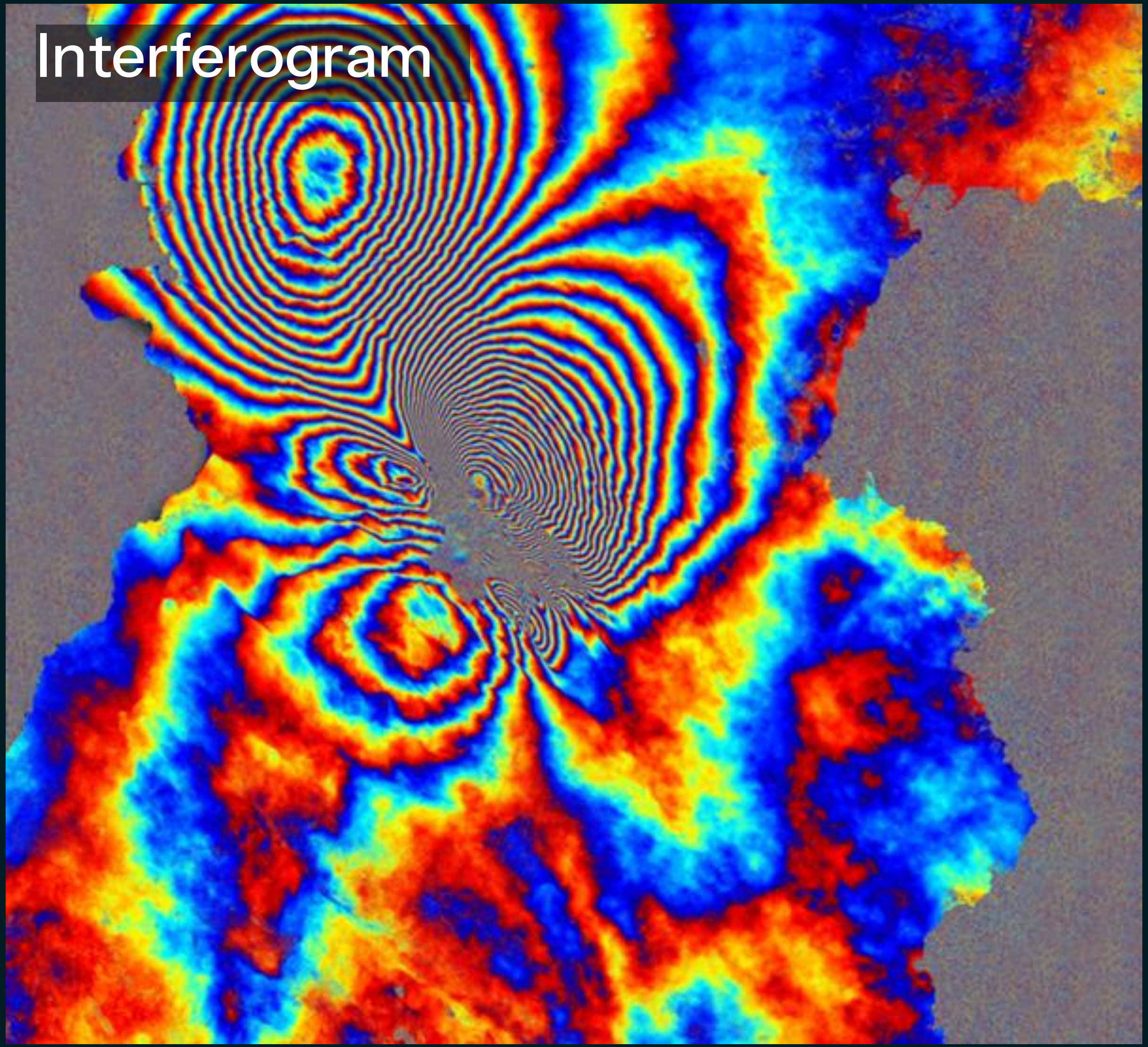


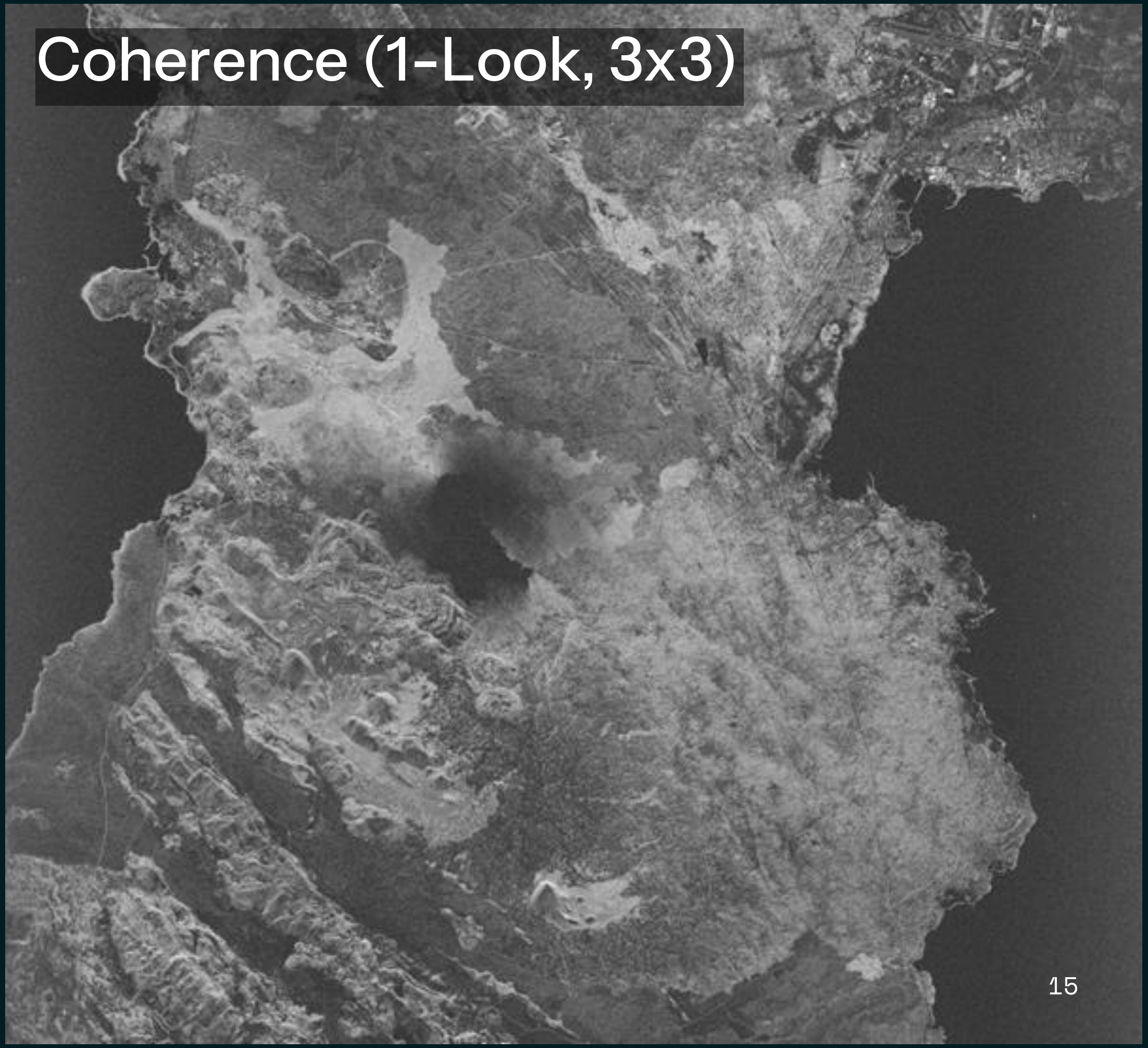
July 14 - 15 (Day before eruption)



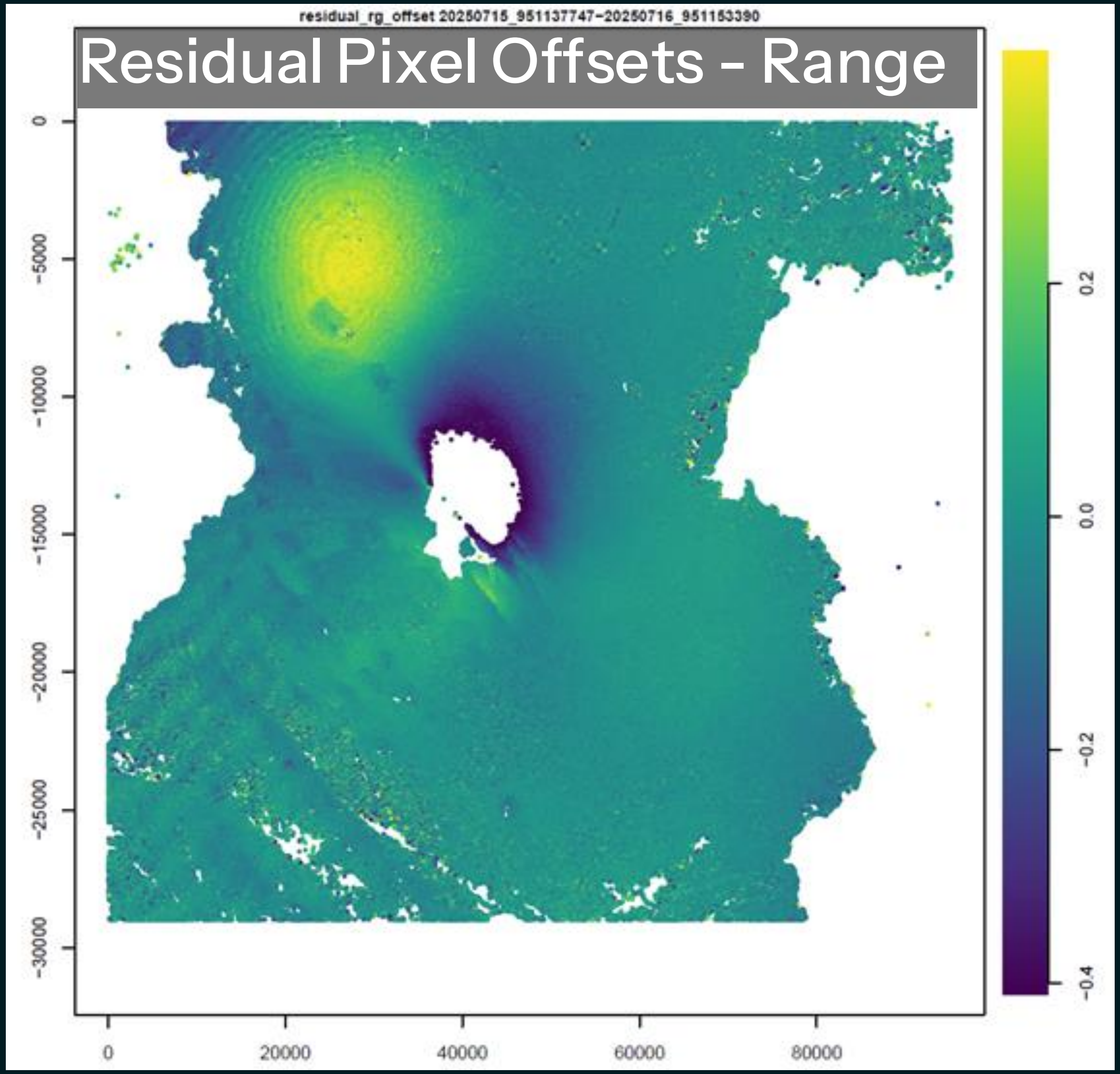


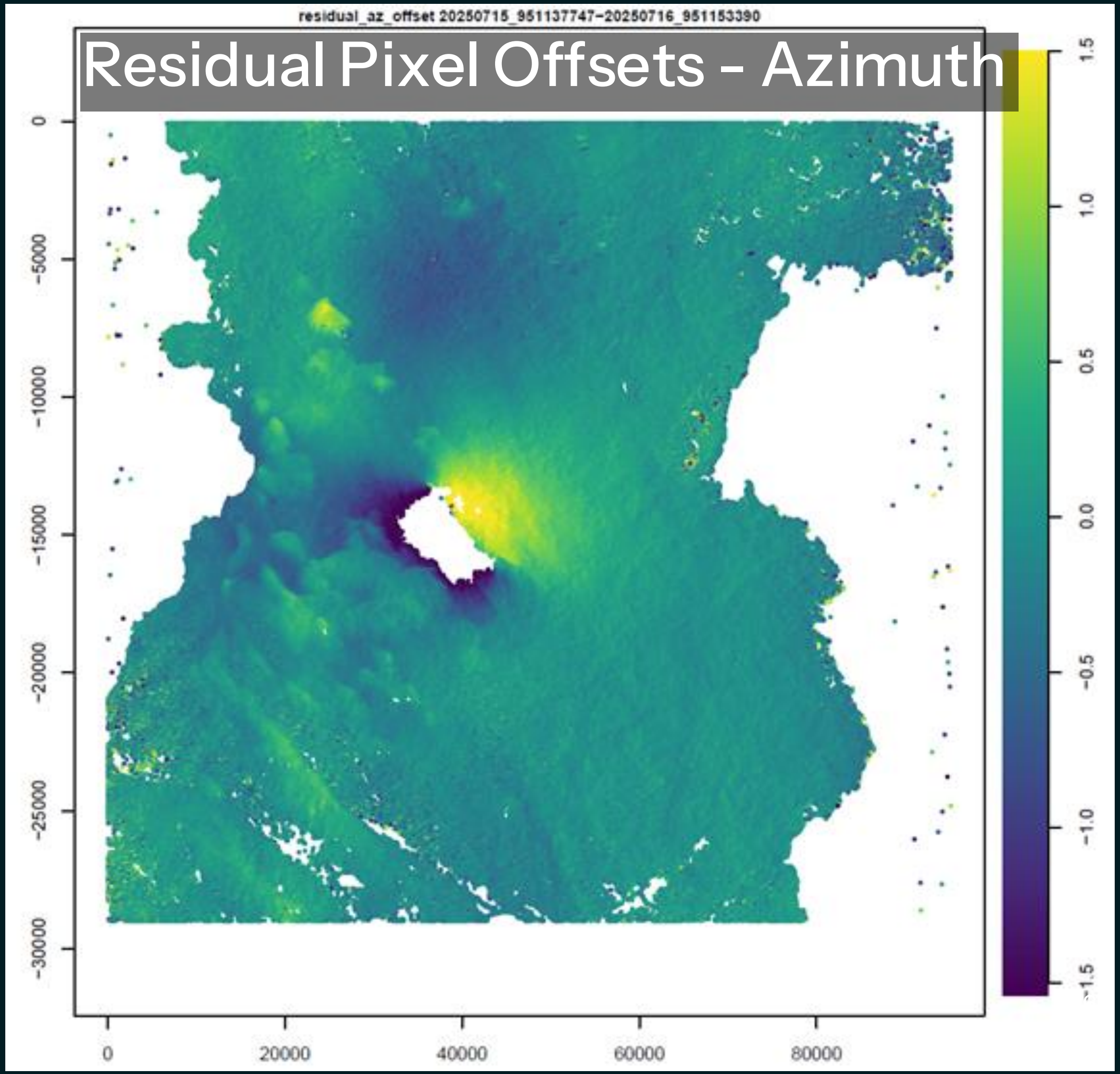
July 15 - 16 (Moments before eruption)



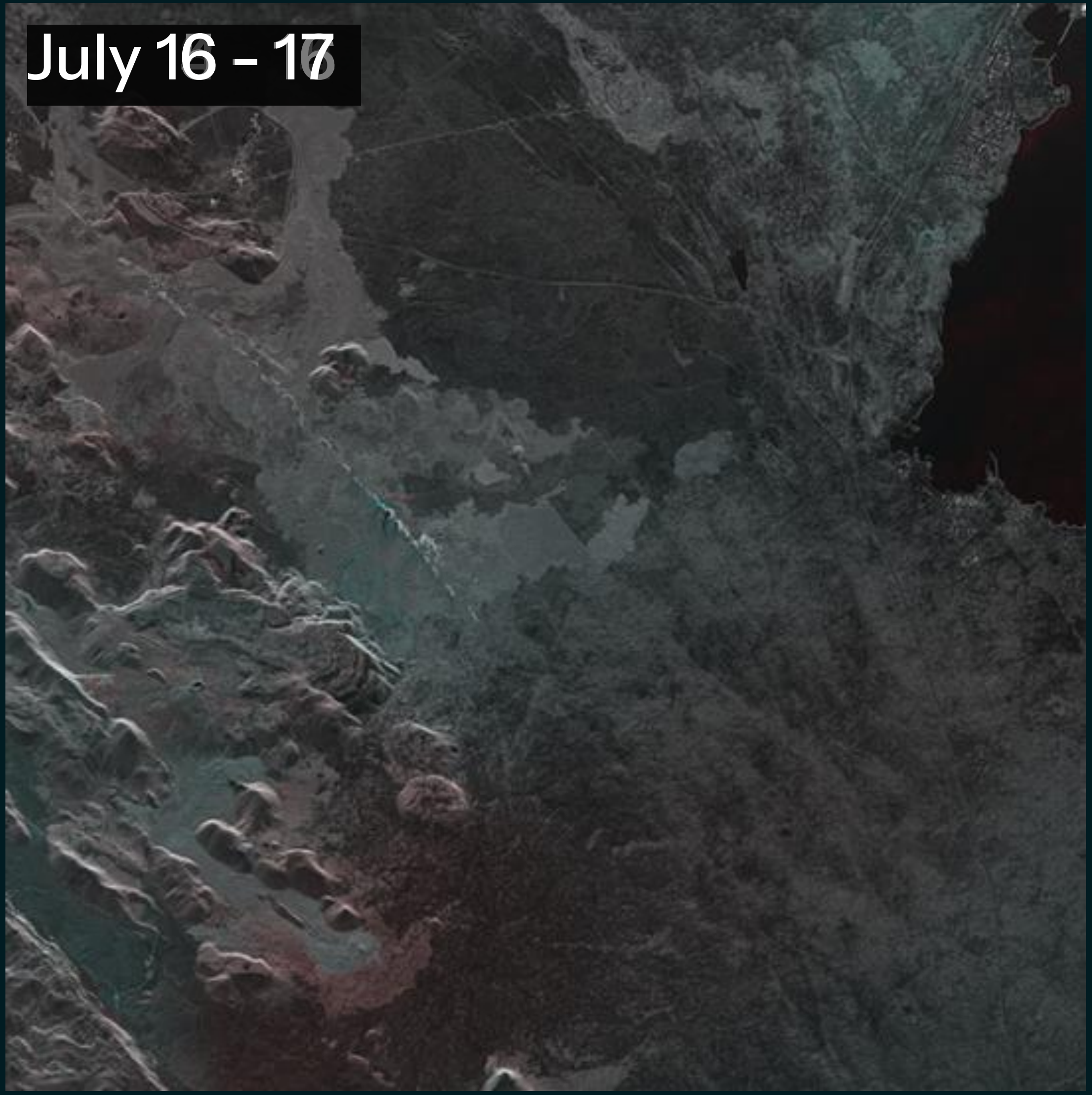


Co-registration Residual Pixel Offsets - July 15 - 16





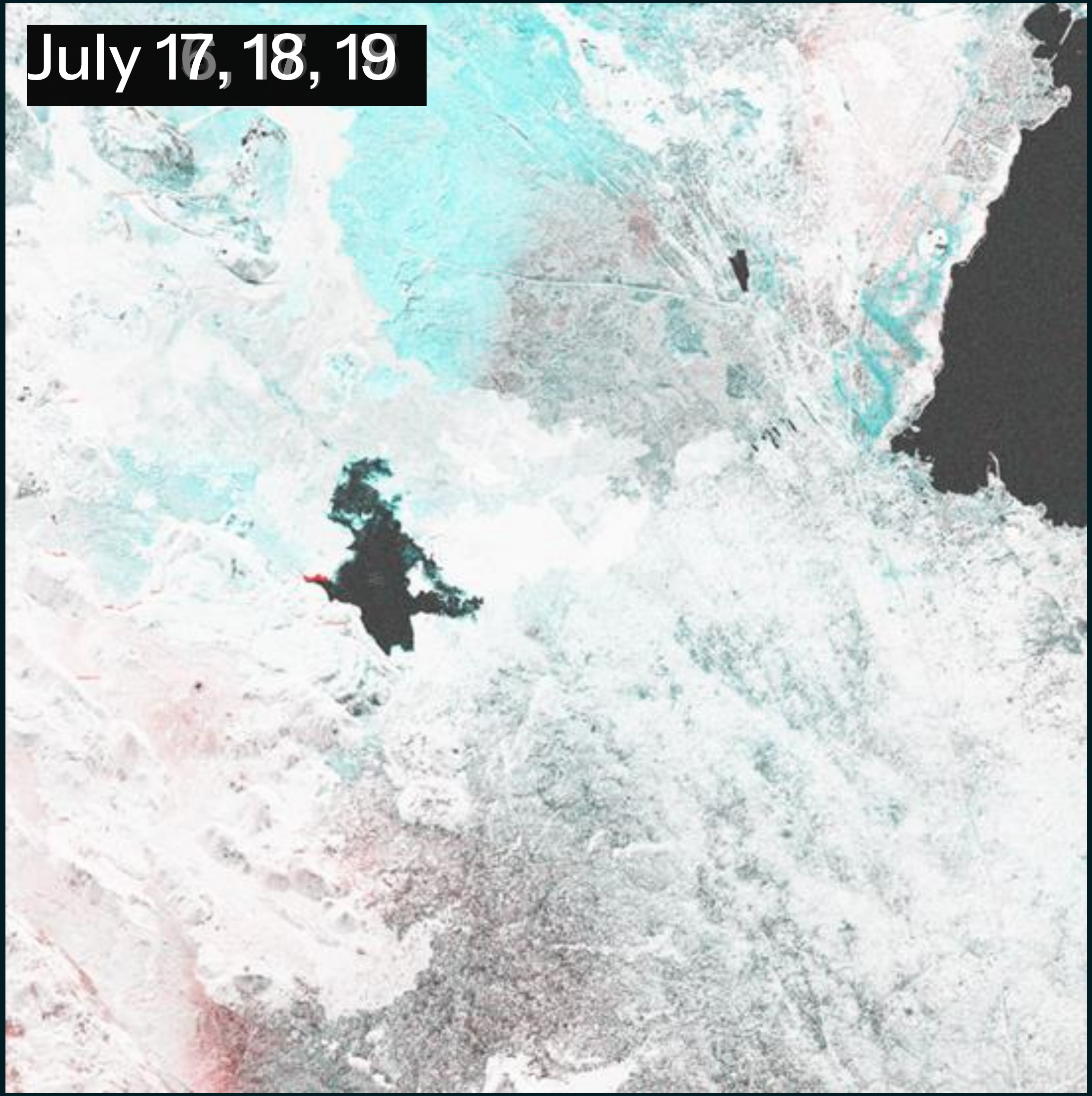
Lava Monitoring - Amplitude Change Detection



Amplitude Change Detection shows a disturbance along the fissure once the eruption starts on July 16, however the full extent of lava is not clearly shown

Icelandic Met Office

Lava Monitoring - Coherent Change Detection



Coherent Change Detection shows clearly the fresh lava areas (black / not coherent).

Areas covered by new lava become red as the coherence is lost.

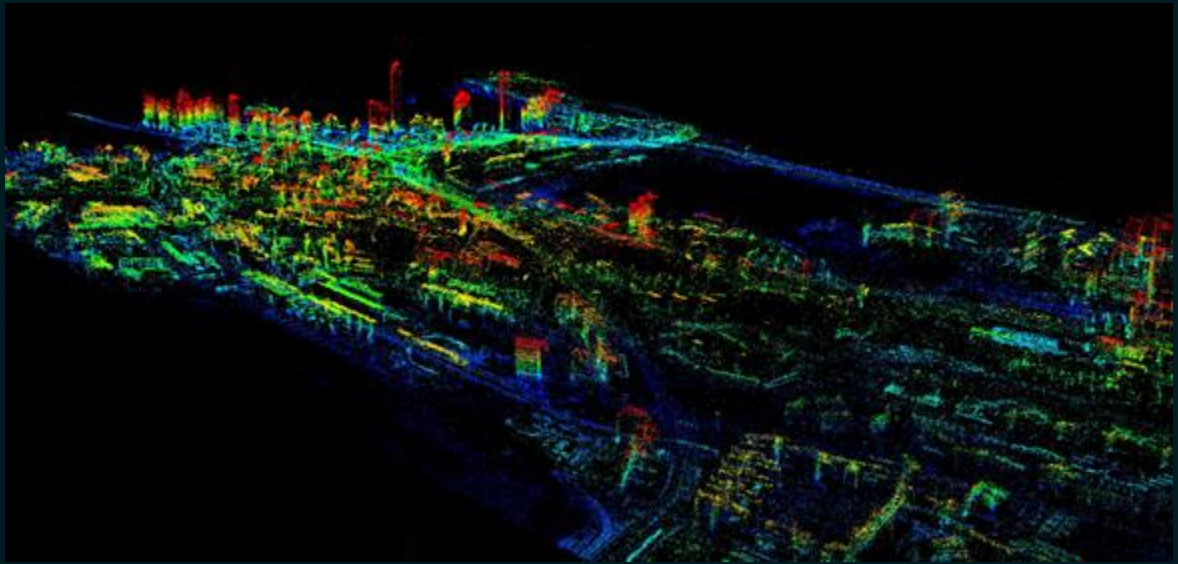
Areas where the lava hardens become blue as the coherence returns to these areas.

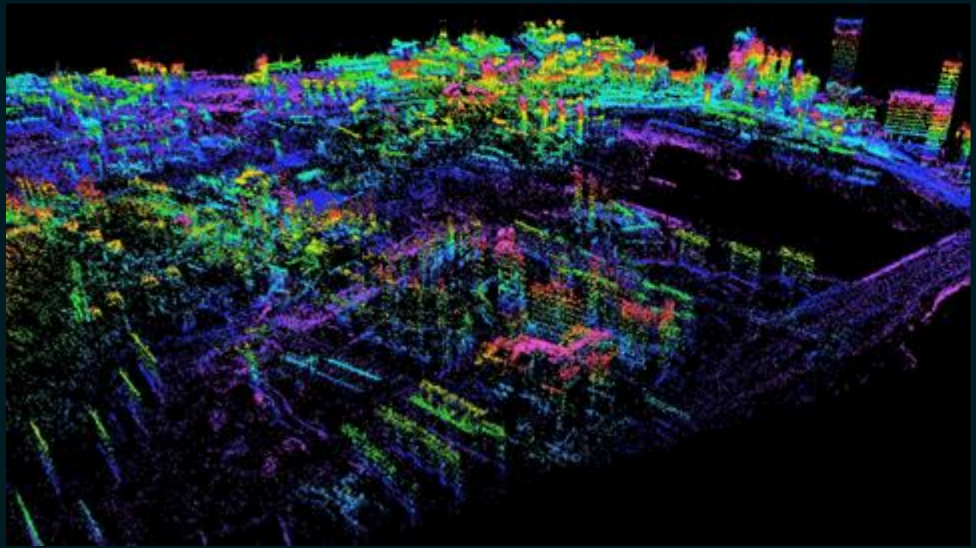
Interferograms multi-looked 3x9
Coherence Window size is 3x3

Persistent Scatterer Interferometry (PSI)

- **Demonstrations of PSI capability are emerging among microsatellite SAR**

- **PSI Requires:**
  - *Stable orbits, deep stacks, phase precision*
  - These are possible to achieve with small satellites



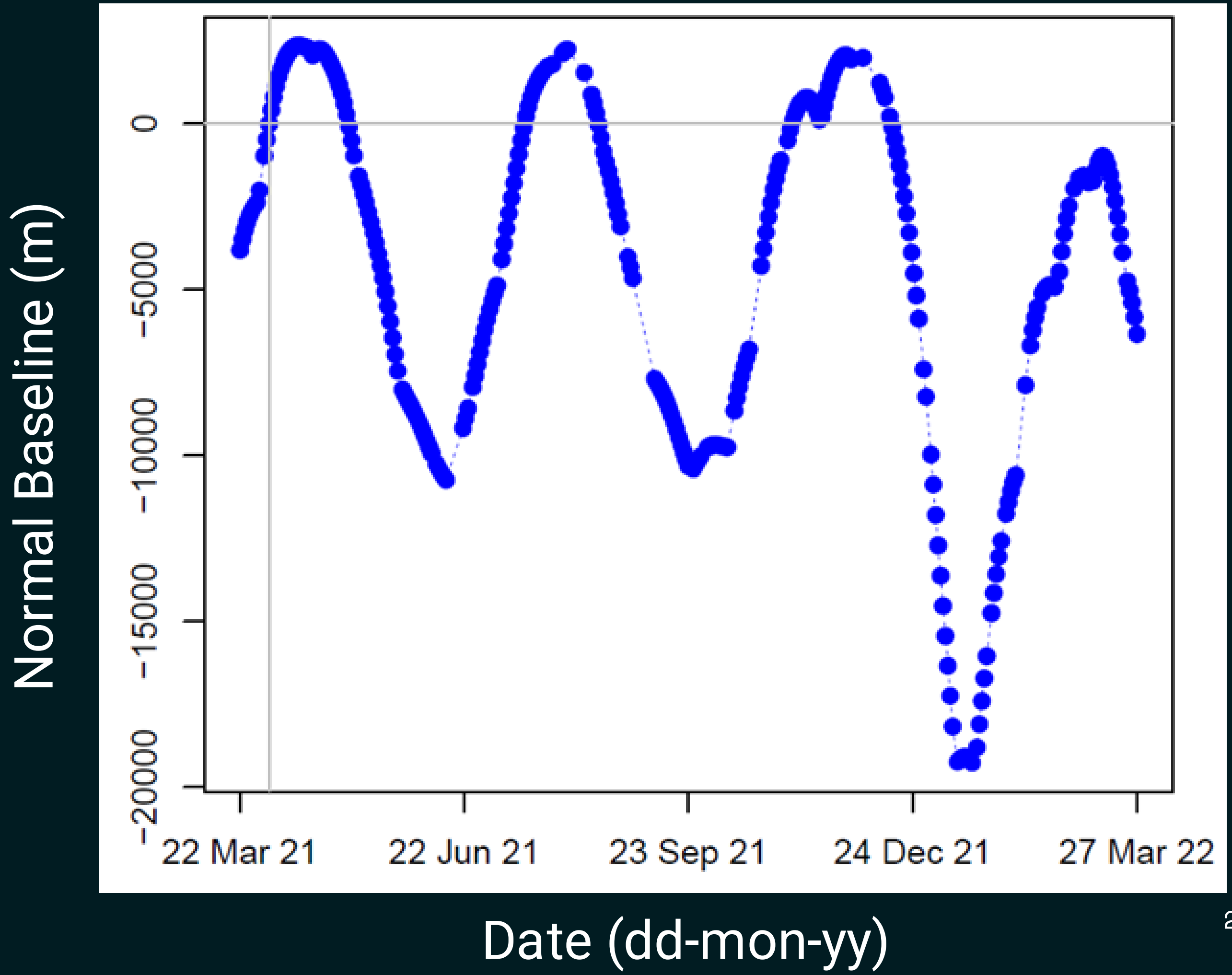


Orbit Stability and Baseline Control: Generation 1 GTR

Achieving stable baselines has been a work in progress since our first attempts in 2021.

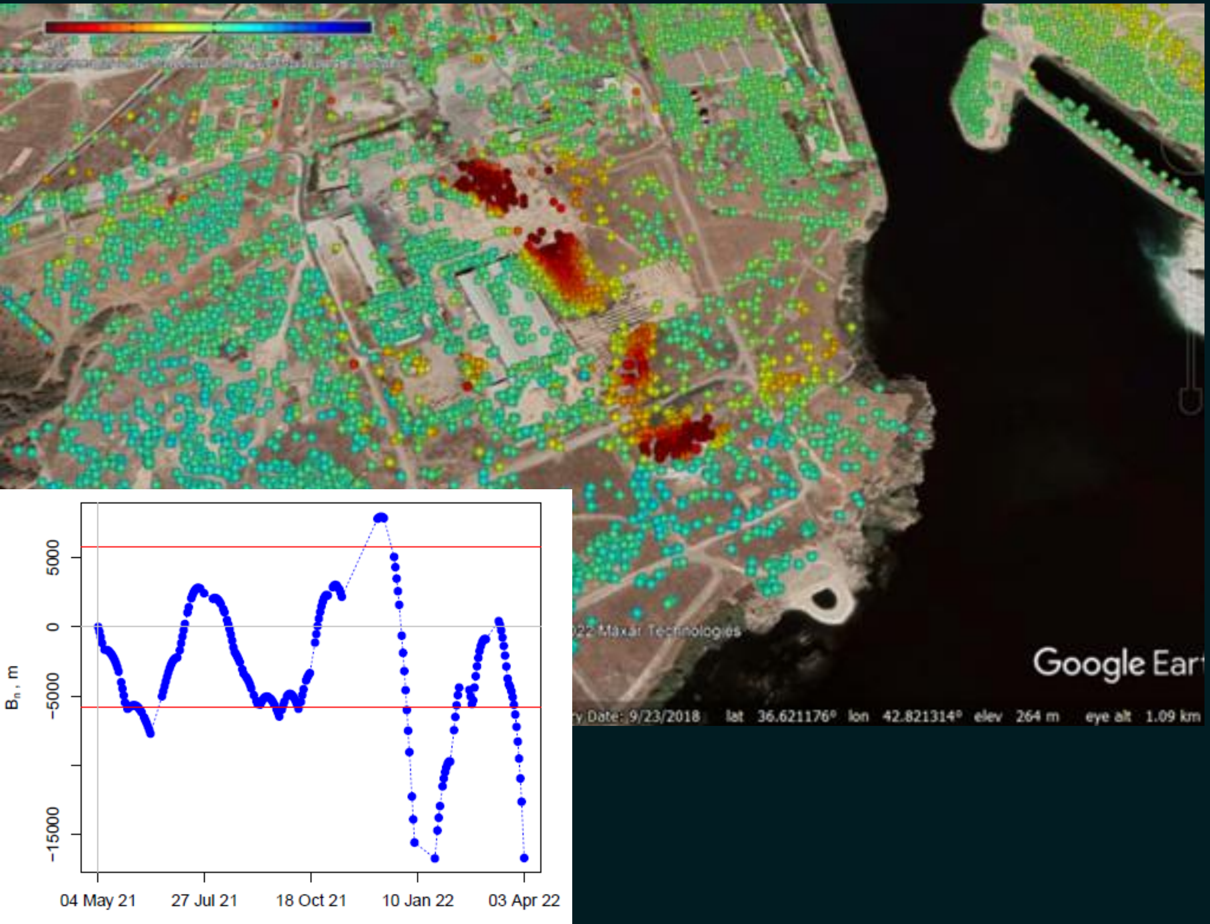
Day-to-day baselines would be short, but orbital tube was wide (~15km).

Orbit control improved significantly, and we are closer to the possibility of frozen orbits

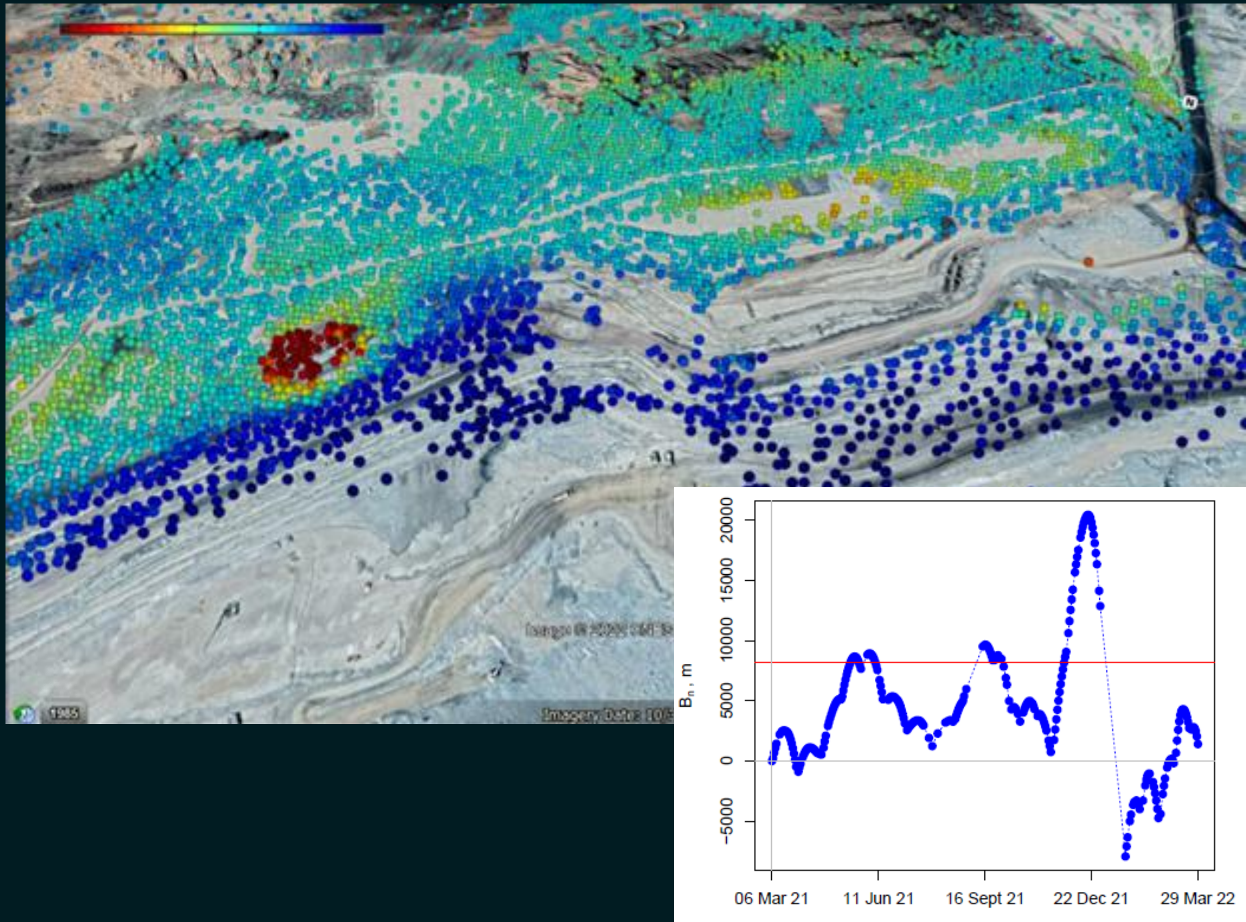


Use-Case Highlights: Subsidence Monitoring Generation 1 GTR long stacks (>1 year)

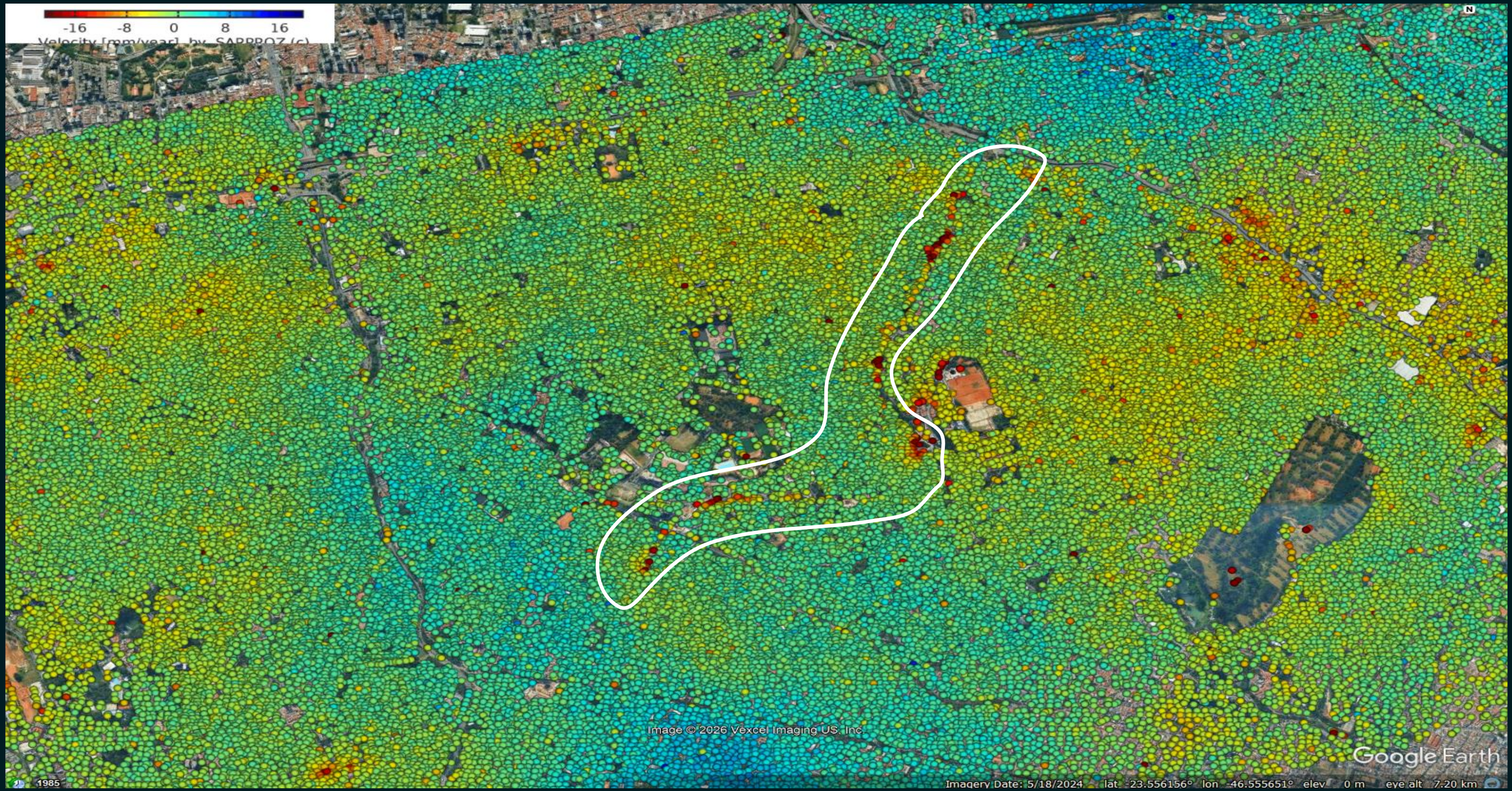
Subsidence in Mosul Dam, Iraq



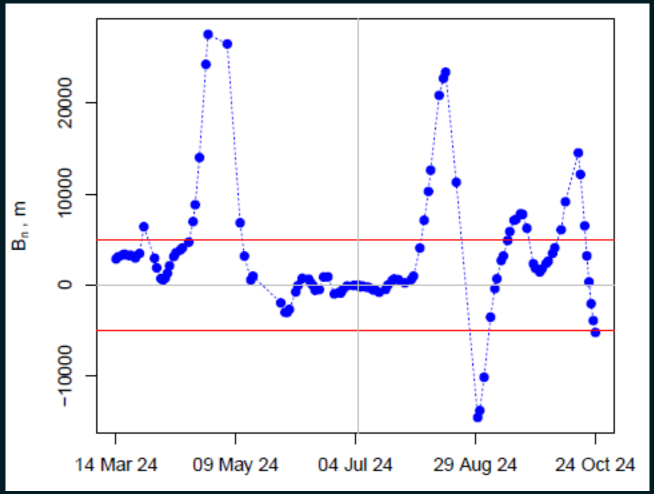
Unstable Slope, Open Pit Mine, Namibia



Subsidence Monitoring with Generation 1 GTR

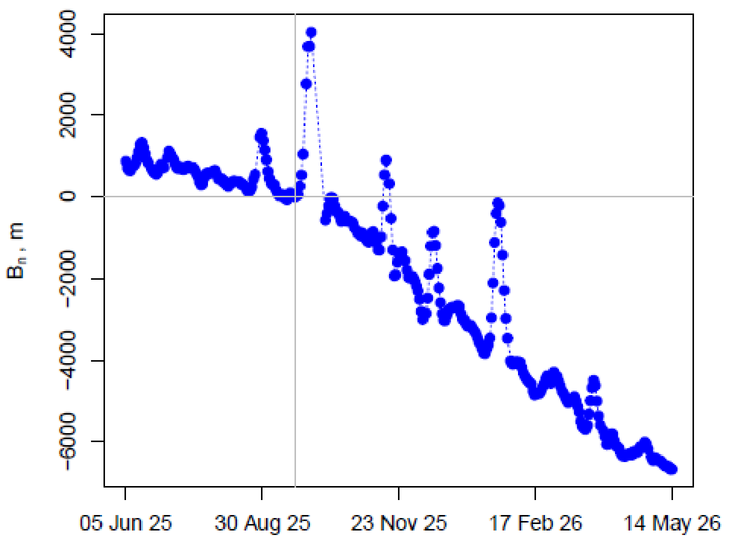


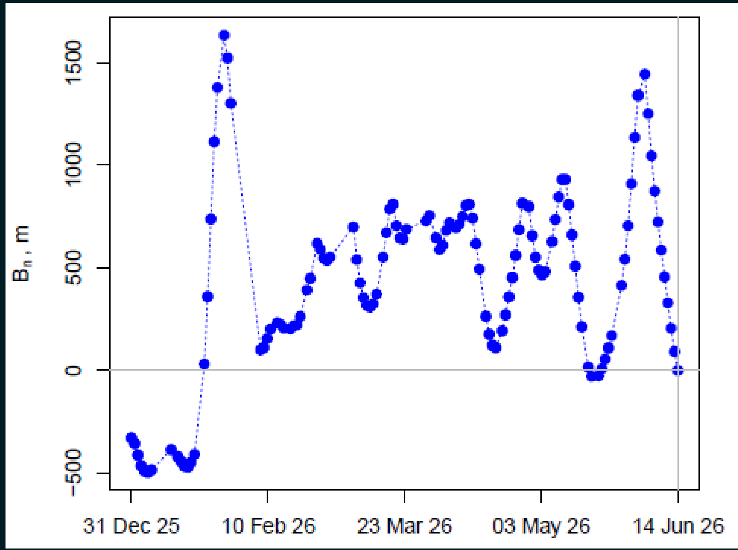
Subsidence caused by underground tunneling while expanding the Sao Paulo Metro Line

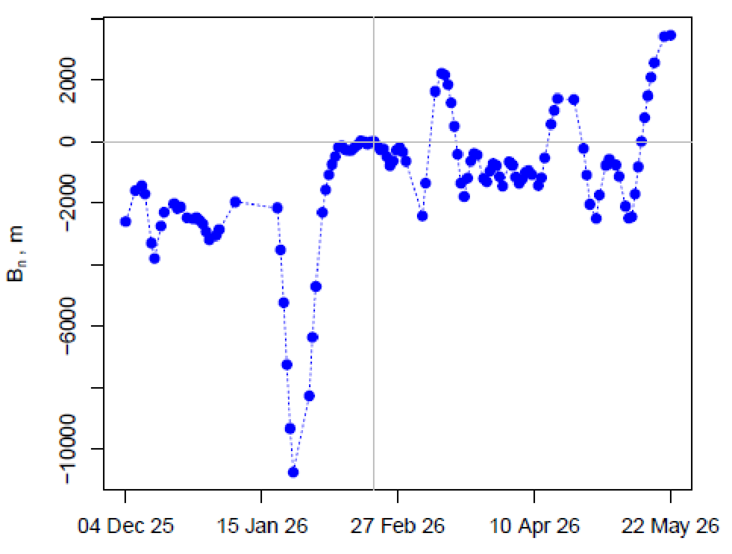


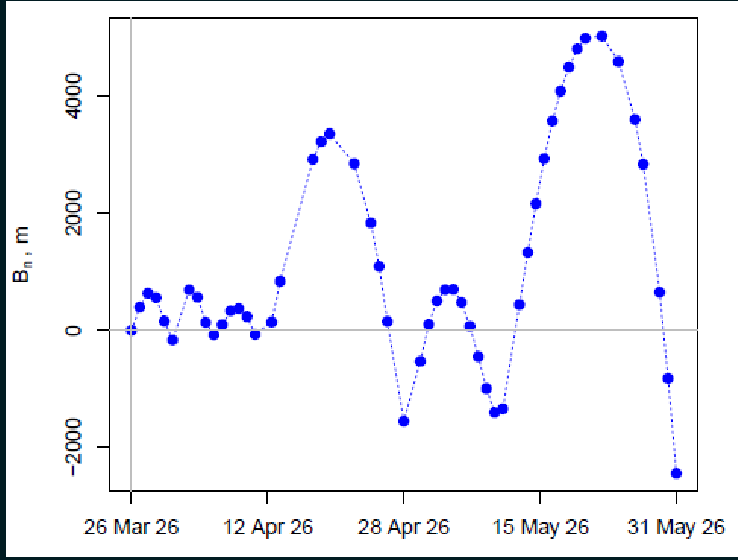
Orbit Stability and Baseline Control: Generation 2 GTR

- First satellite in 2025
- Currently 6 satellites in Daily GTR (DGTR) orbit
- More satellites are on their way to DGTR this year
- 1 satellite in 12 day GTR
- Anomalies are still present: work in progress

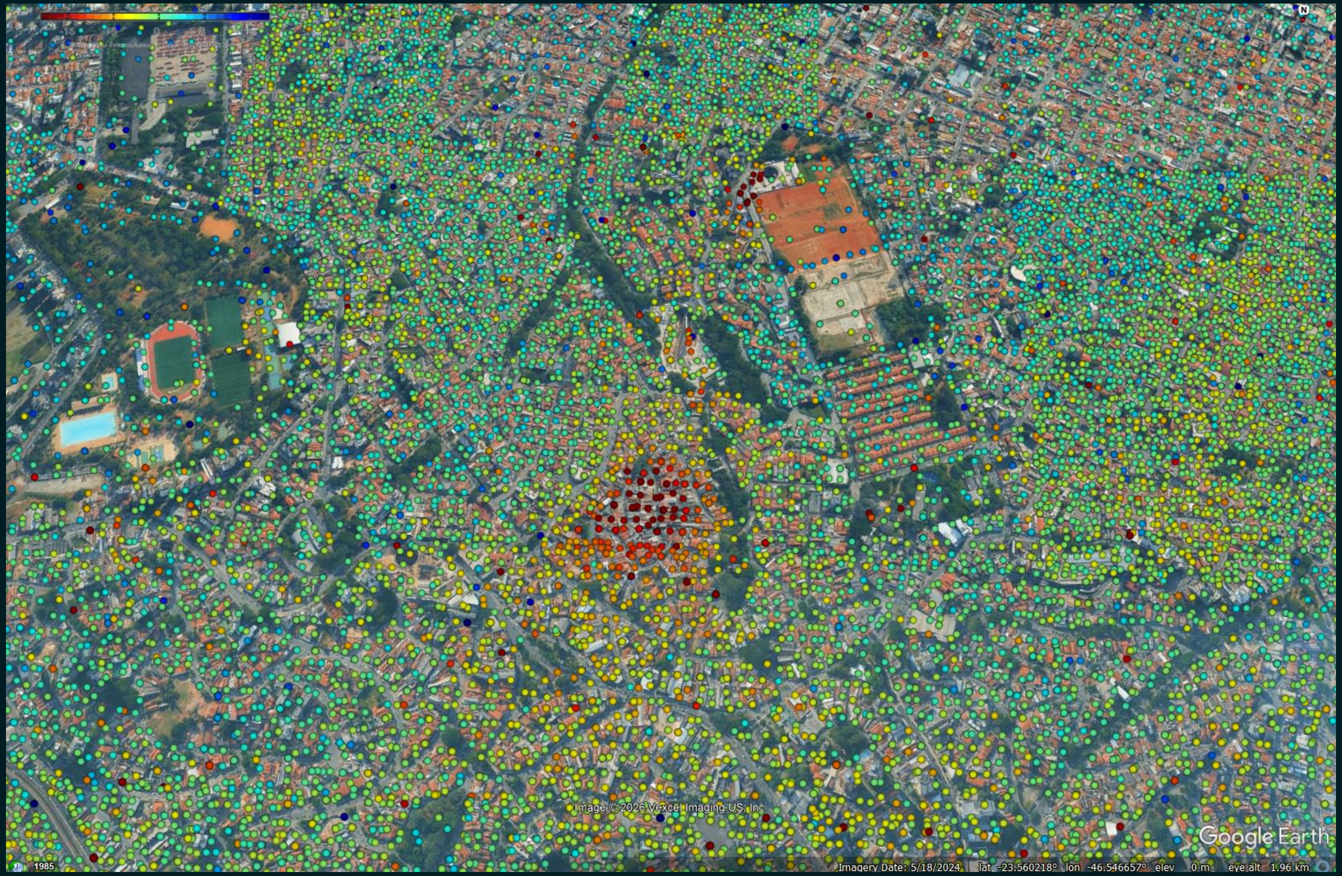




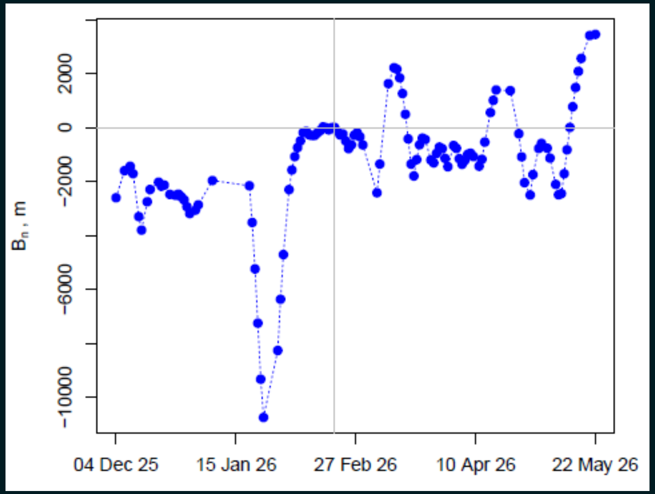




Subsidence Monitoring with Generation 2 GTR: Sao Paolo

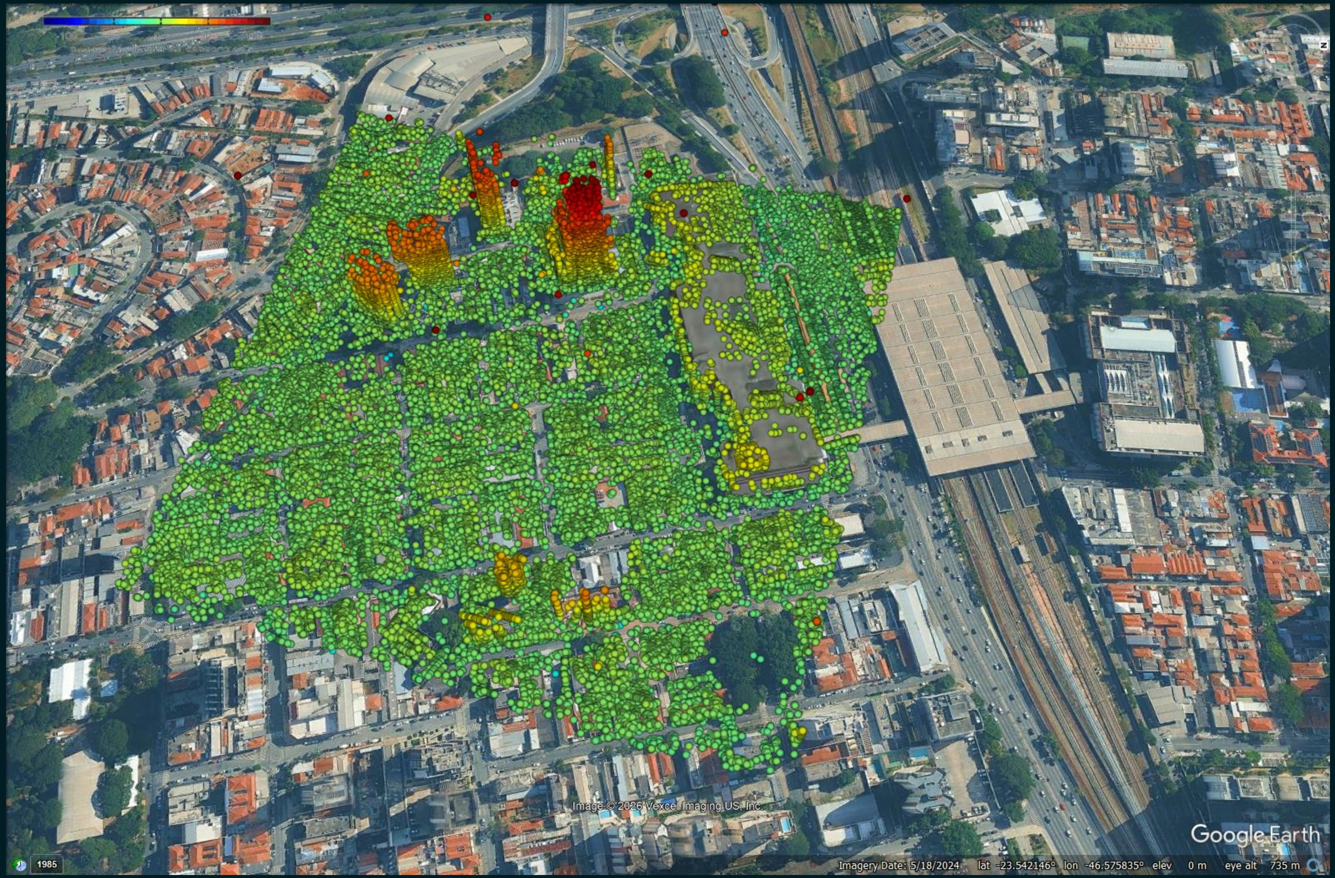


- Tunnelling activity stopped in June 2025
- Residual ground settlement observed
- Relatively shorter stack duration: insufficient deformation development, subject to noise
- Higher amplitude stability than Generation 1 GTR
- More stable PSI results with shorter stacks compared to Generation 1



ICEYE

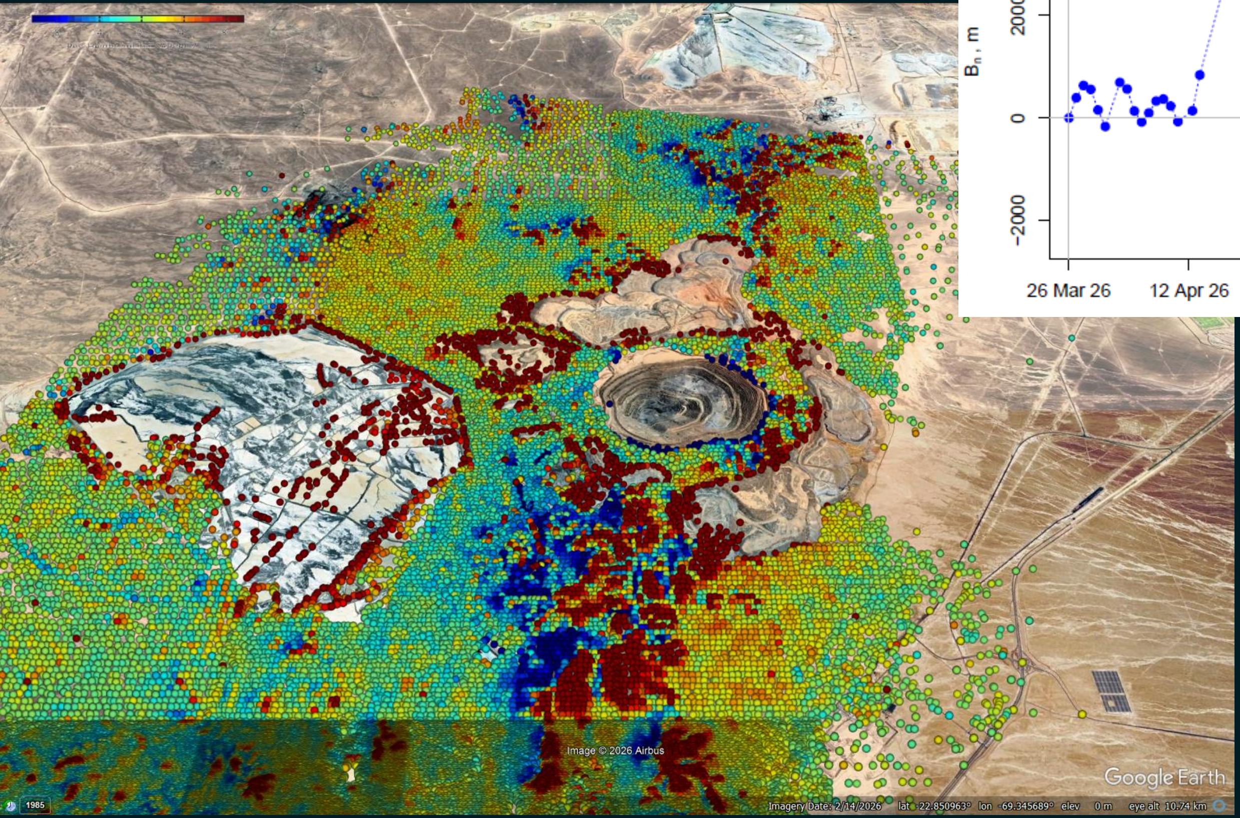
Residual height with Generation 2 GTR

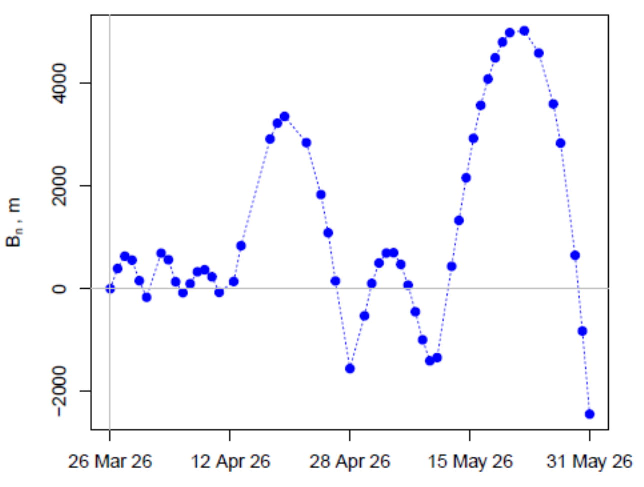


- Higher amplitude stability also on high rise buildings compared to Generation 1 GTR
- Dense point clouds possible
- Missing top of a 150 m building:
  - **The top of the building points can be recovered by relaxing thresholds, at the expense of added noise**
  - **The effect is attributed to SAR image focusing affected by the large elevation difference**
  - **Working on the fix in SAR processor**

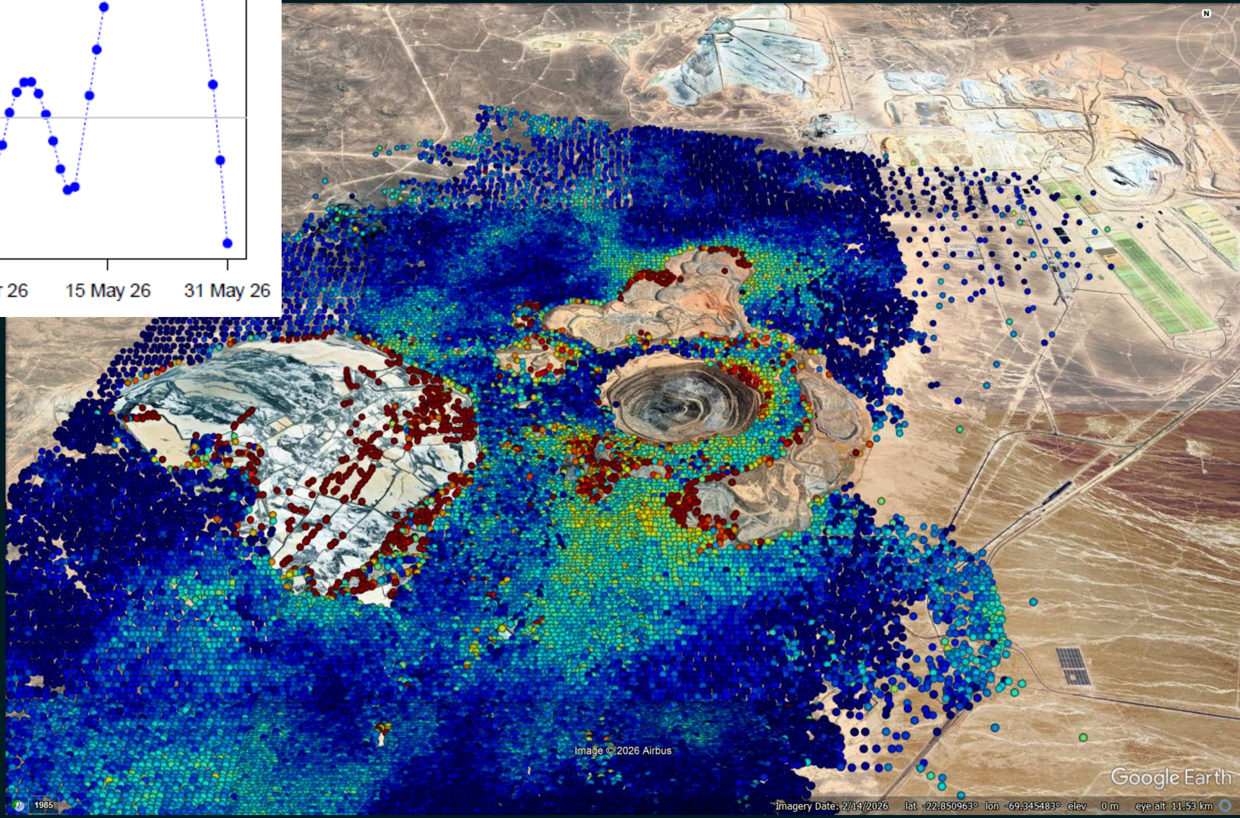
Mining area monitoring with Generation 2 GTR

Residual height





Deformation rate



Key Takeaways & Next Steps

ICEYE

- Microsatellites can already deliver high-quality InSAR products in multiple modes
- Daily revisit enables time-sensitive monitoring for fast-changing environments
- Confirmed improvement of GTR orbit control leads to improved PSI results
- Stability of baselines continues to improve over time
- ICEYE Open data

Thank you!

Valentyn Tolpekin
valentyn.tolpekin@iceye.com

ICEYE OPEN DATA