INSAR MONITORING IN AREAS WITH RAPIDLY CHANGING ELEVATION

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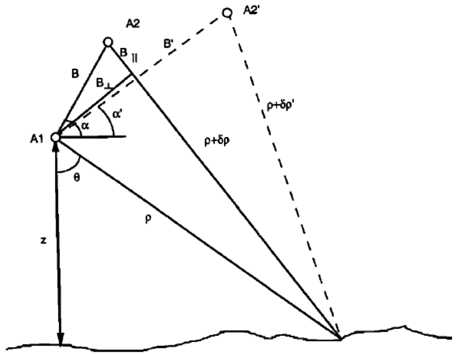
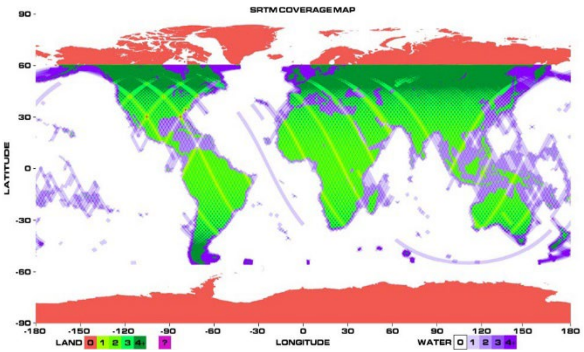
Height errors in InSAR

- Early days of InSAR: three-pass interferometry used to remove topographic signal
- SRTM era – availability of 'global' DEM data
- Residual errors – stack processing allows regression for height

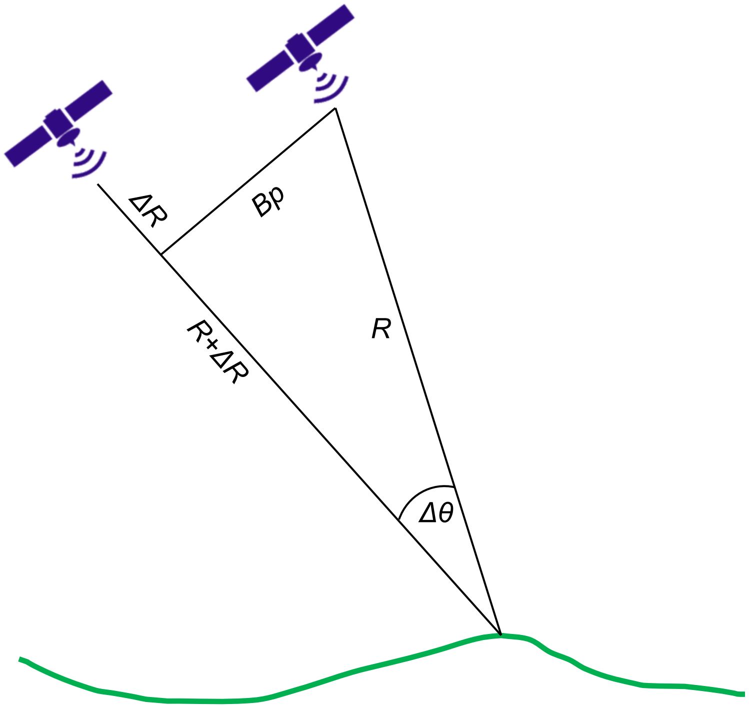
➢ *Problem solved…?*



Zebker et al, 1994.



Sensitivity to height



- Height sensitivity:

$$\frac{\partial\varphi}{\partial z} \approx \frac{4\pi}{\lambda}\frac{B_p}{R\sin\theta}$$

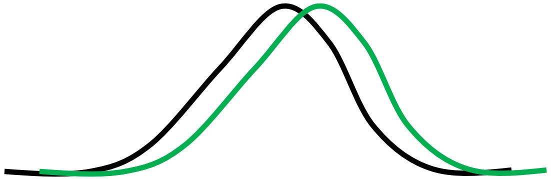
- Altitude of ambiguity:

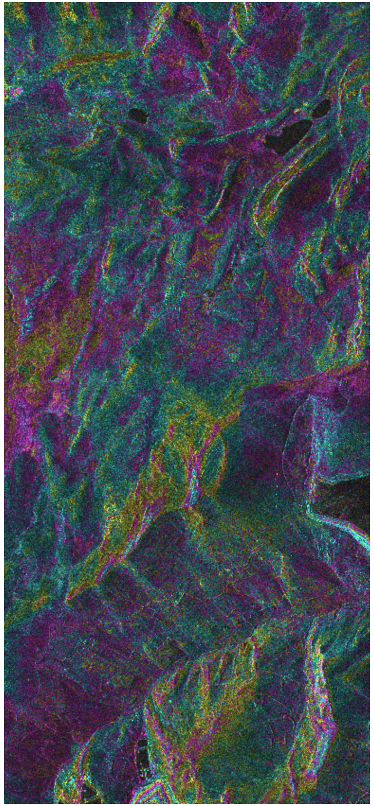
$$AoA = \frac{\lambda}{2}\frac{R\sin\theta}{B_p}$$

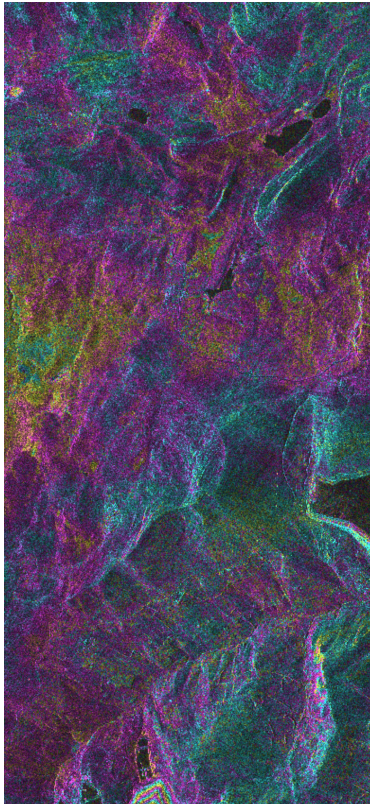
- Height sensitivity increases with:
  - – Larger baselines (Bp)
  - – Steeper incidence angles (θ)
  - – Shorter wavelengths (λ)

DEM residuals – common issues

- **Poor alignment**
- Low res DEM compared to SAR
- Out of date – topography has changed







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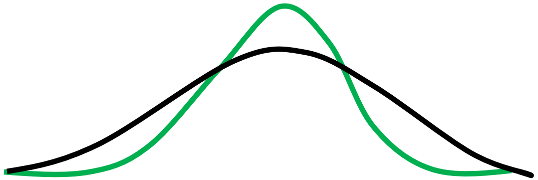

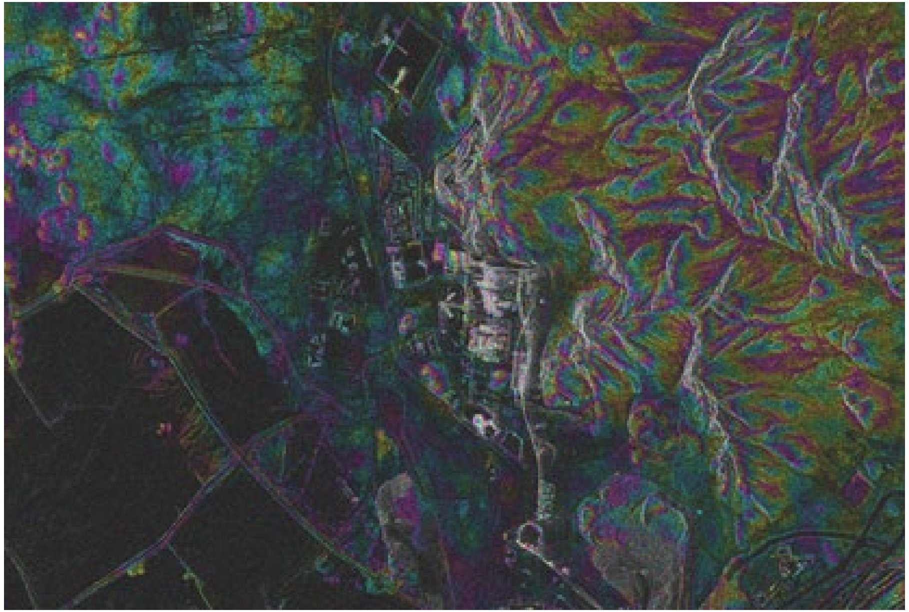

Kompsat-5 3m SAR, 350 m baseline, SRTM 90 m DEM

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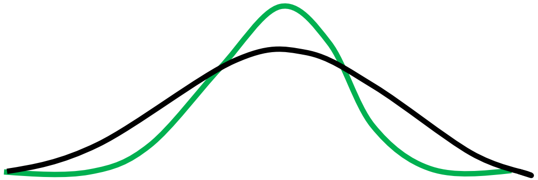

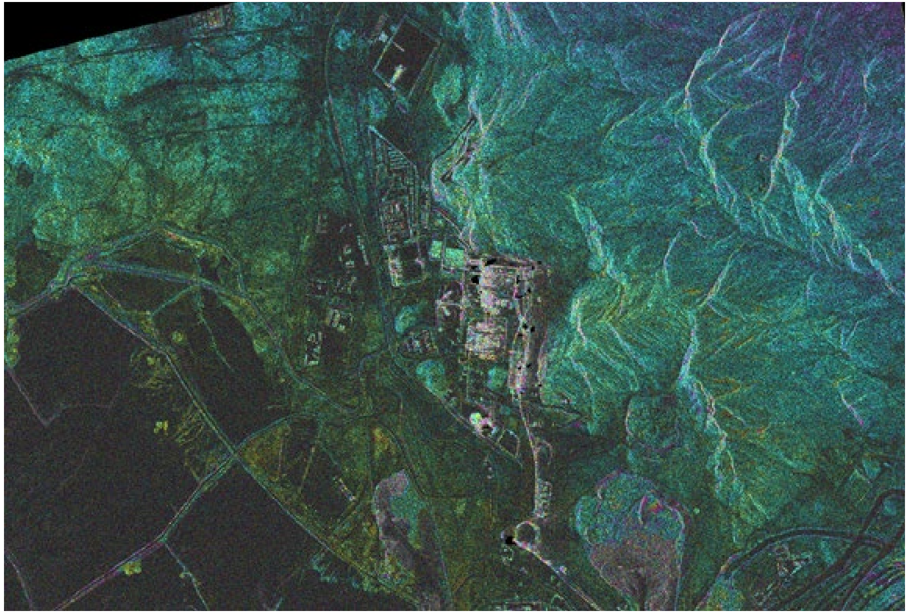

Kompsat-5 3m SAR, 350 m baseline, proprietary 10 m DEM

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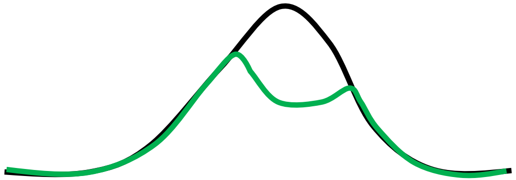

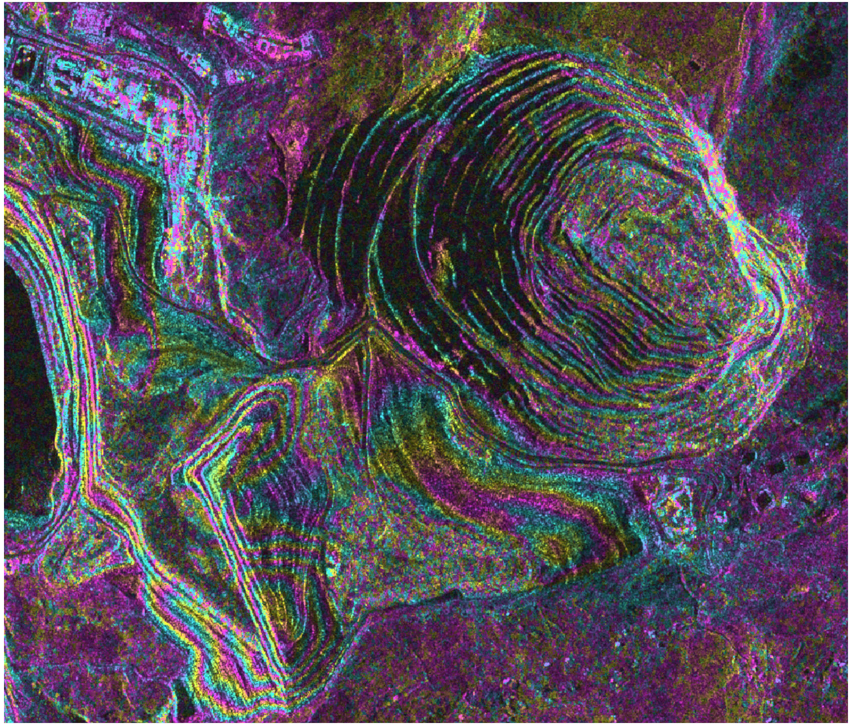

Copernicus GLO-30 DEM 2011-2015

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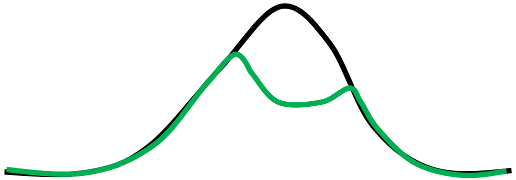
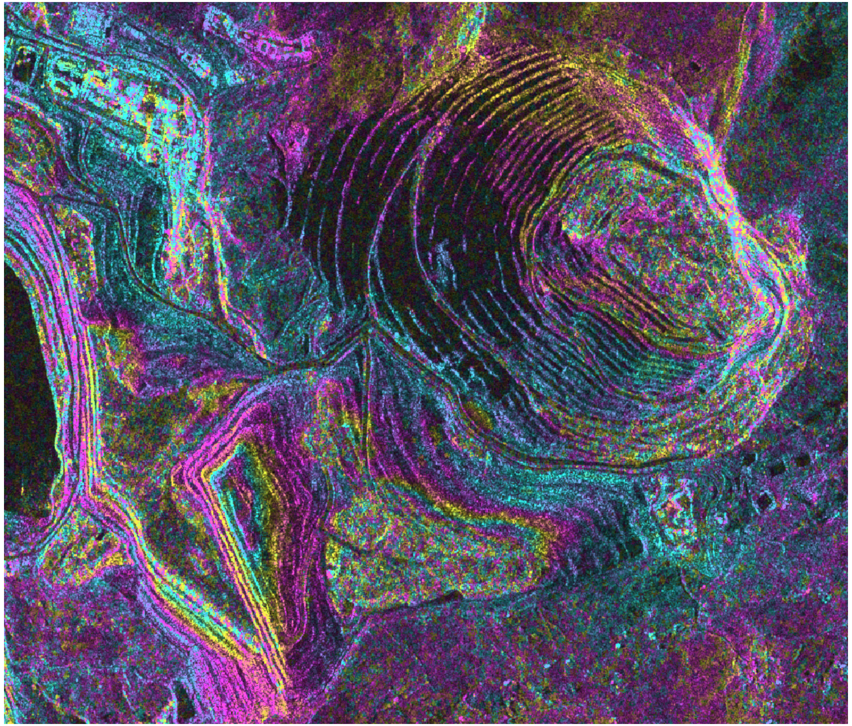


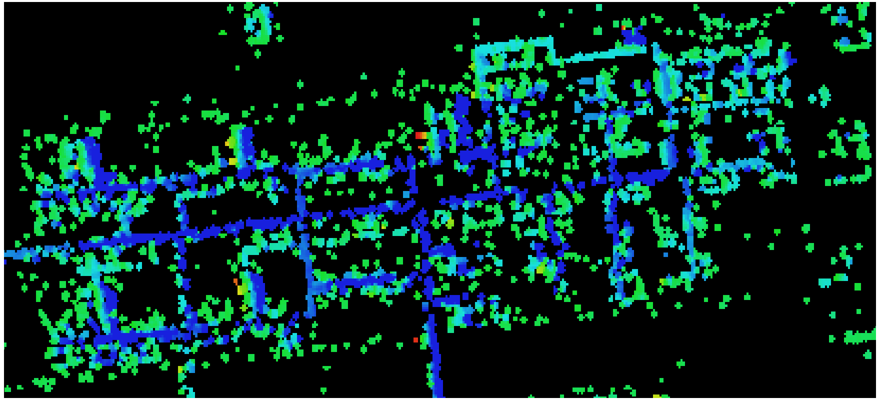


LIDAR DEM 2023

Time series processing – regression for height correction

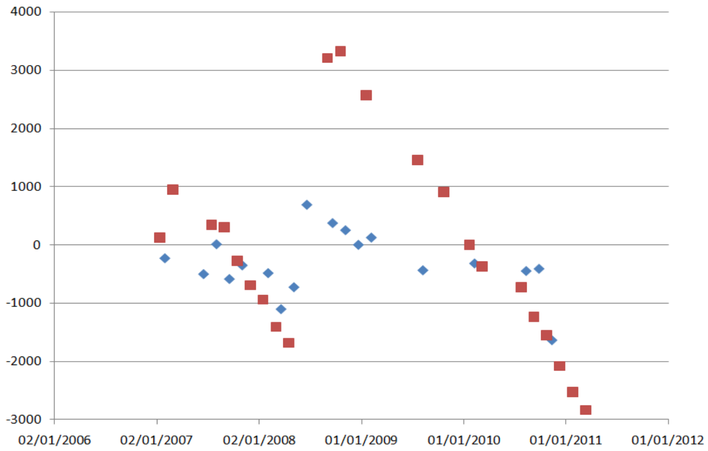
- Large stack of SAR data allows height correction
- Linear regression – phase residual proportional to baseline
- Can invert for height correction separately, or typically with deformation

$$\begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1m} & \frac{4\pi}{\lambda}\frac{Bp_1}{R_1 \sin\theta_1} \\ t_{21} & t_{22} & \cdots & t_{2m} & \frac{4\pi}{\lambda}\frac{Bp_2}{R_2 \sin\theta_2} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ t_{n1} & t_{n2} & \cdots & t_{nm} & \frac{4\pi}{\lambda}\frac{Bp_m}{R_m \sin\theta_m} \end{bmatrix} \begin{bmatrix} z_1 \\ z_2 \\ \vdots \\ z_n \\ h \end{bmatrix} = \begin{bmatrix} \varphi_1 \\ \varphi_2 \\ \vdots \\ \varphi_n \end{bmatrix} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_n \end{bmatrix}$$



Stack regressions - limitations

- Not enough SAR images in stack
- Low coherence areas – surface change, or large height error
- Correlated baselines
- Rapidly changing topography
- Small baselines
  - Not a problem for deformation, but limits ability to model topography!
- Applications where that matters:
  - Volcanoes
  - New infrastructure
  - Mines

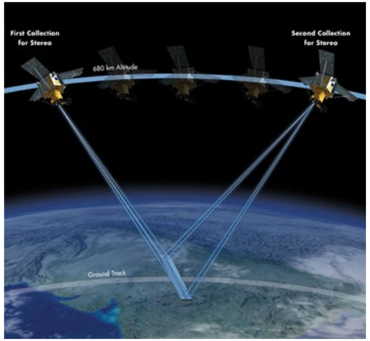


Mine sites – frequent and ongoing changes

- Continuing change affecting different areas at different times
  - Pit excavation
  - Waste/stock piles
  - TSF raises
  - Post-failure topography
- Co-occurring deformation
  - Settlement of dumped material
  - Triggered instability
- Intermittent coherence
  - Frequent surface disturbance
- Non-linear break-points in deformation regime
- Timely results crucial

Using alternative DEMs

- Up to date high resolution DEMs can improve results
- Source – depending on requirements
  - Satellite/airborne/drone stereo optical images (e.g. Worldview, Pleiades)
  - Satellite bistatic radar (e.g. TanDEM-X WorldDEM)
  - Airborne/drone LIDAR



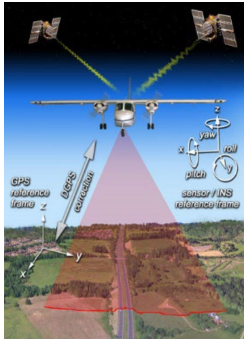


Image: © CGG, 2023. Optical imagery and elevation data © 2017 Maxar Technologies

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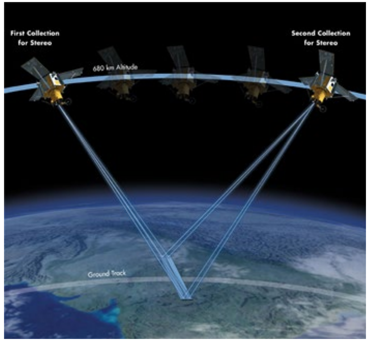
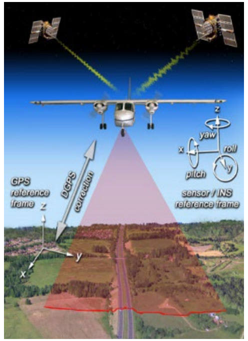
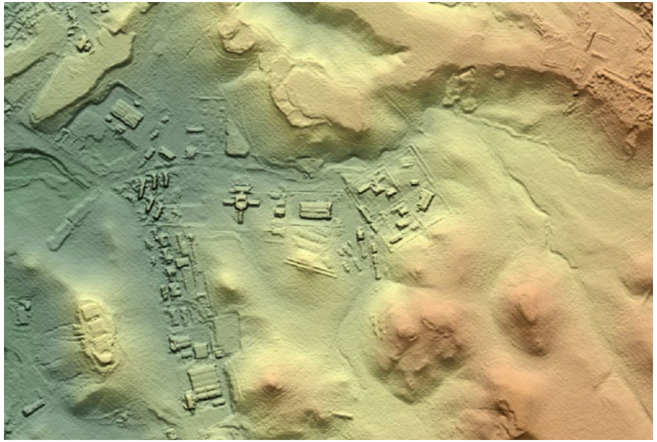
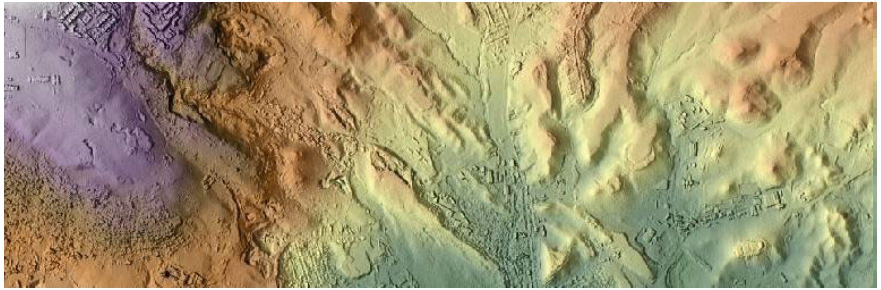


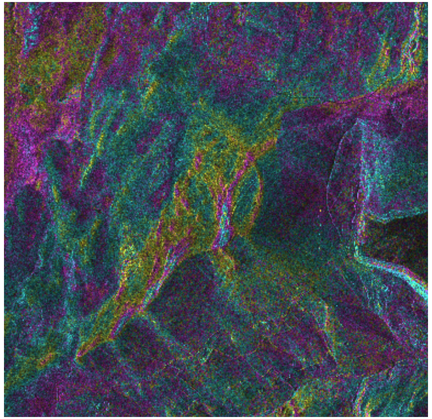


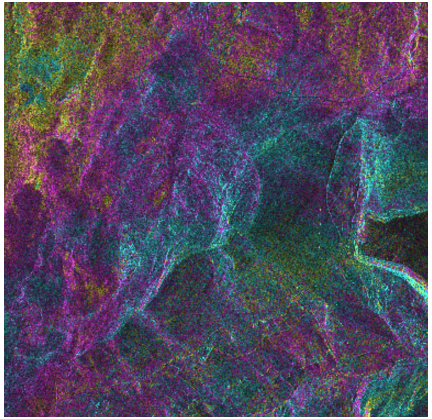


Using alternative DEMs - limitations

- Cost – dependant on specifications
- Availability – cloud cover, flight restrictions, site logistics, archive coverage
- Small areas and discontinuous coverage – mosaicking, georeference issues
- Timeliness – lead time after sudden changes







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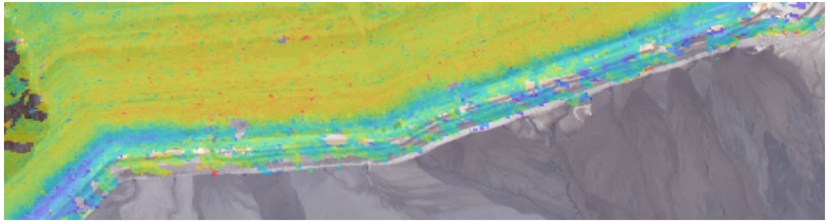
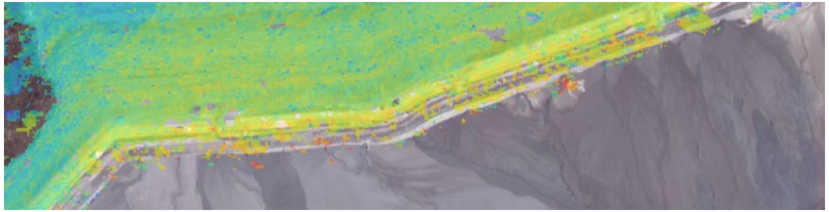


Apparent uplift signal after recent TSF dam raise



Height error removed after using updated high-resolution DEM

Using alternative DEMs - limitations

- Cost – dependant on specifications
- Availability – cloud cover, flight restrictions, site logistics, archive coverage
- Small areas and discontinuous coverage – mosaicking, georeference issues
- Timeliness – lead time after sudden changes
  - ➢ Improving capabilities: e.g. **SkySat**:
    - – 1m DSM, typically 0.5m vertical accuracy
    - – Acquisitions often within days

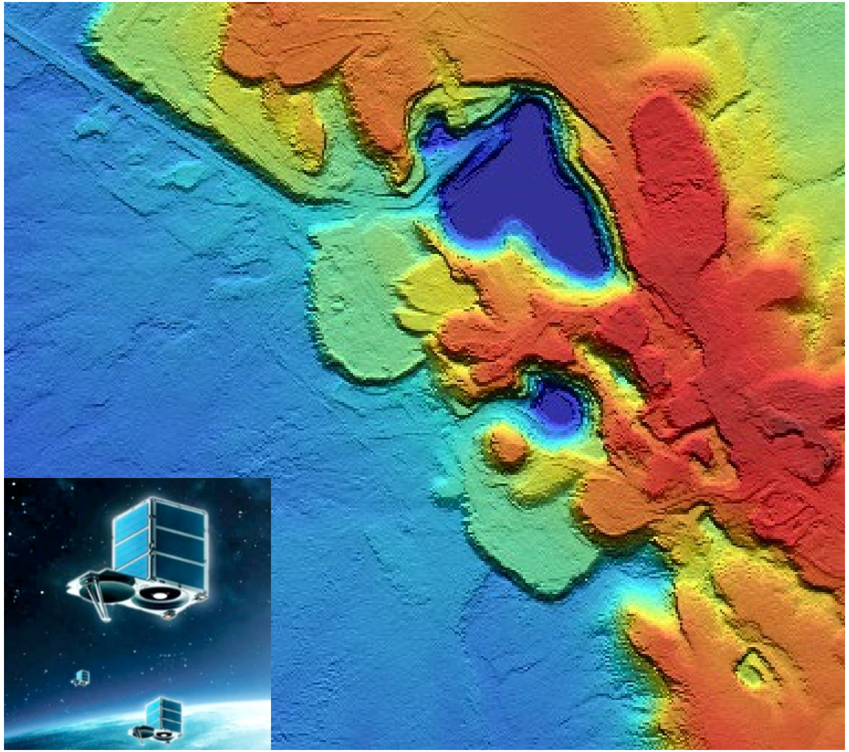
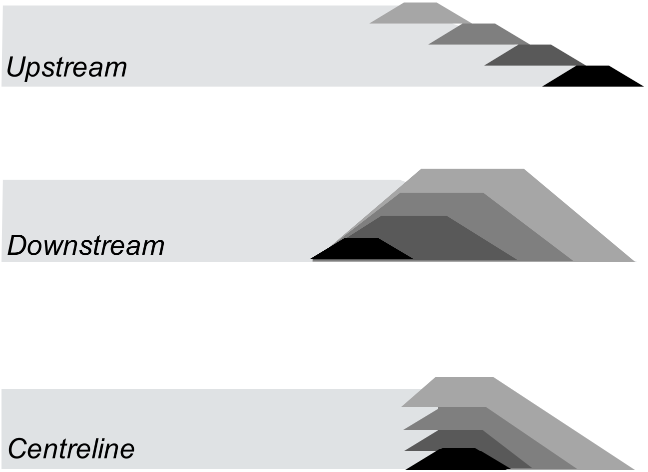


Image: © CGG, 2023. Source data : Planet Labs

Retrospective studies –TSFs

- Past stability history is of great interest
  - Many TSFs have limited info on older structures
  - Historical InSAR enabled by 30 year SAR archive
- Past topography is harder to find:
  - Up to date DEM is exactly what you don't need!
  - Want DEM data closest in time to each time period, or even each interferogram



Tailings dam construction methods – older phases (black) can be buried under newer material

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- Past topography is harder to find:
  - Up to date DEM is exactly what you don't need!
  - Want DEM data closest in time to each time period, or even each interferogram
- Potential sources
  - Site operators
  - Open access local or global datasets
  - Archive satellite optical stereo pairs
  - Process periods between dam raises
  - Other sources of frequent historical DEMs in development

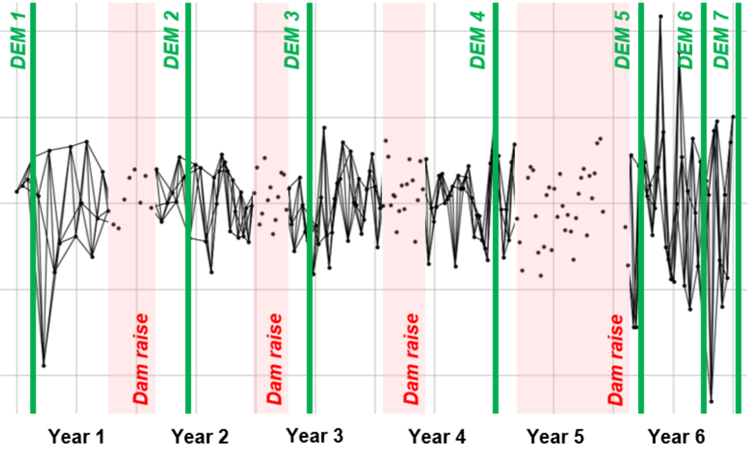
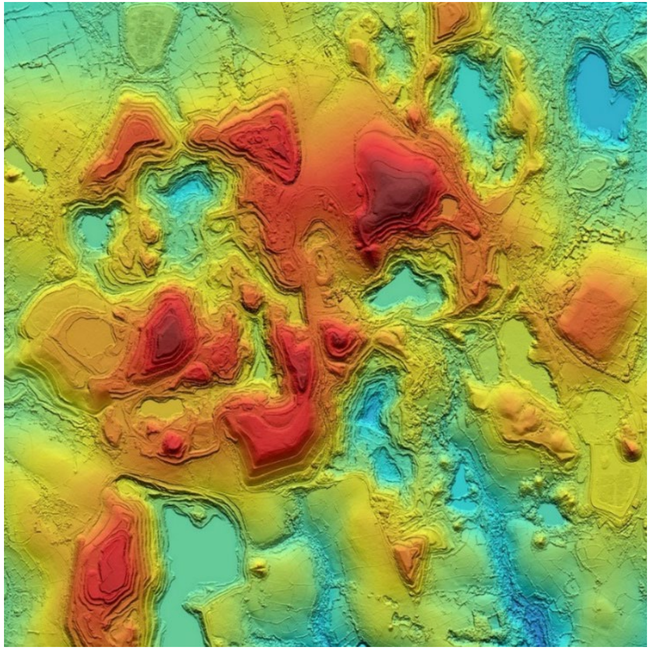


Image: © CGG, 2023. **Source data : Gold Fields, or Confidential Client?**

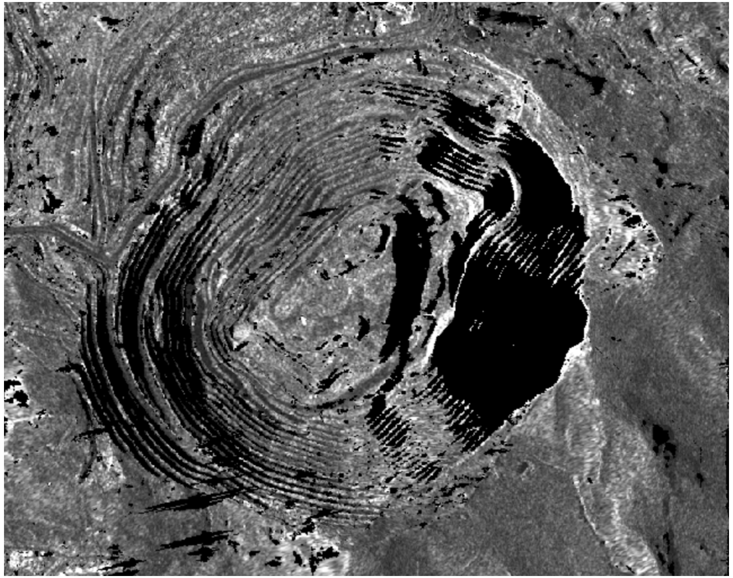
Conclusions

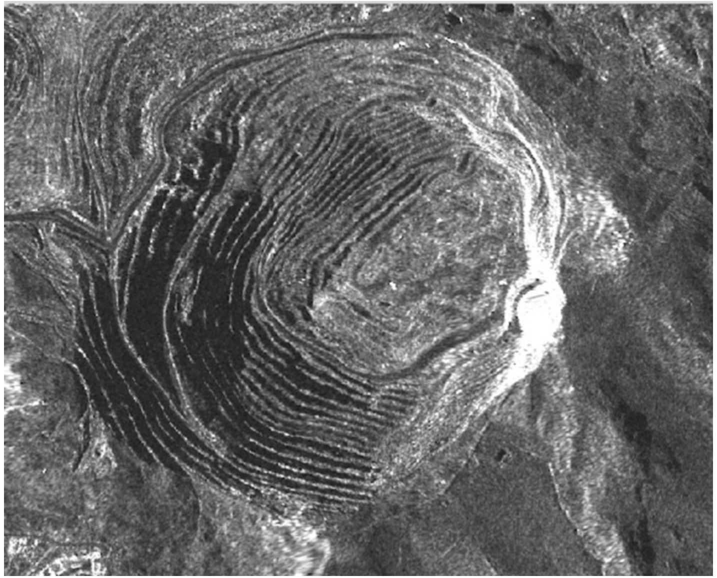
- ‘Standard’ InSAR approaches with global DEMs and stack-based regressions not well suited to frequently changing sites like mines and TSFs
- Both spatial and temporal resolution of DEM data crucial for accurate and actionable results
- Frequency and timeliness of DEM datasets improving for ongoing monitoring work (and additional elevation analysis products)
- Historical InSAR valuable if challenge of contemporary DEMs can be overcome



Final thought – georeferenced SLCs

- Discussion on Monday about distributing pre-georeferenced SLCs…
- Very quick test based on GLO-30 versus recent high-res DEM





Thank you

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