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GIS-based workflows for SAR/InSAR Science Data Systems

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Overview

- Sentinel-1 in a GIS-based framework
  - Standard SAR/InSAR applications in GIS
  - Multi-sensor, multi-modal analytics
- Preparing for upcoming global SAR missions
- Preparing for sub-meter resolution data from small sats
- What can the SAR world learn from other EO datasets?
  - Geocoded SLCs as a standardized Level-2 product

Overview of Global scale S1 Products @ Descartes Labs

	SAR backscatter	InSAR	RTC factor
Spatial scope	All Global IW (VV + VH)	Global IW (VV, Over land)	Global IW. Static dataset.
Temporal scope	Full mission	Full mission	Full mission
Posting	10m UTM	20m UTM	10m UTM
Resolution	15m Az x 5m Rg	~50 m	From 30m DEM
Bands	VV, VH $sigma_{0,E}$ (-40 to 30 dB)	Coherence, Wrapped phase (<= 24 days)	Shadow-Layover mask, RTC factor, Local incidence angle

All products are burst-based and generated from geocoded SLC bursts
Similar product suite will likely be generated from other missions as well

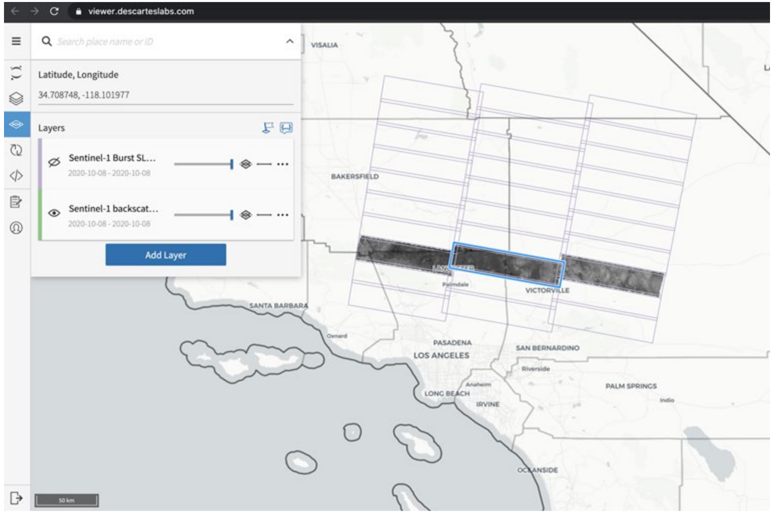
Geocoded Bursts: Bringing S-1 SAR data into GIS frameworks

Burst in along-track/ slant-range coordinates → Thermal noise calibration → Geocoding + Phase correction using a DEM → Geocoded Burst on a map

10m N x 2.5m E

Resampling accounts for azimuth carrier

Similar to Zebker (2017)



Agram et al. (2022), "An efficient global scale Sentinel-1 radar backscatter and interferometric processing system", Remote Sensing.

K[.] represents spatial filtering operations. Backscatter, interferogram and coherence can be consistently derived on the fly using band math and filtering:

$$\sigma_0\left(B_1\right) = \mathrm{K}\left[\|B_{g,1}\|^2\right]$$

$$\mathrm{ifg}\left(B_1, B_2\right) = \mathrm{K}\left[B_{g,1} \cdot B_{g,2}^*\right]$$

$$\rho\left(B_1, B_2\right) = \frac{\mathrm{K}\left[B_{g,1} \cdot B_{g,2}^*\right]}{\sqrt{\mathrm{K}\left[\|B_{g,1}\|^2\right] \cdot \mathrm{K}\left[\|B_{g,2}\|^2\right]}}$$

Radiometric Terrain Correction as band math

$$\frac{\gamma_{0,T}}{\sigma_{0,E}}(\text{in dB}) \approx \frac{\gamma_{0,T}^{ref}}{\sigma_{0,E}^{ref}}(\text{in dB}) + \mathcal{C} \cdot B_{\perp}^{ref} + \mathcal{D} \cdot B_{v}^{ref}$$

- InSAR and RTC in a common framework - Agram et al. (2023), “Radiometric terrain flattening of geocoded stacks of SAR imagery”, Remote Sensing.
- Baseline tube for Sentinel-1, NISAR, ALOS-2 really narrow and baseline terms can be dropped
- Can be applied to geocoded SLCs / backscatter products
- Enables consistency across different products derived from source data
- Framework is applicable for any InSAR-capable mission, even for large baselines like ALOS-1
- Within GIS frameworks, can be easily implemented using the same band math operations as NDVI / NDWI/ EVI computation
- **Note:** RTC factor will be recomputed with the release of new SNAP version

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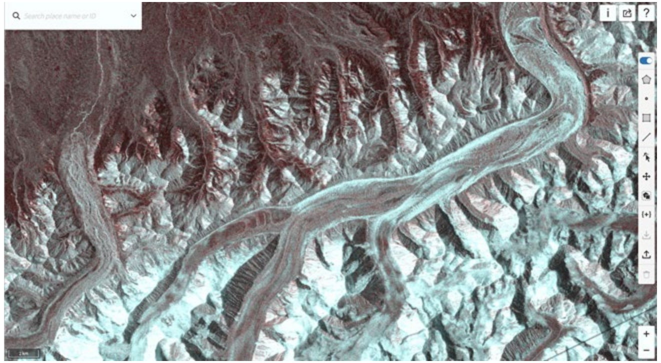
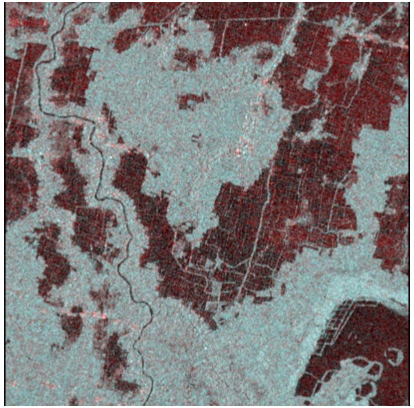
Common SAR/InSAR applications with Sentinel-1

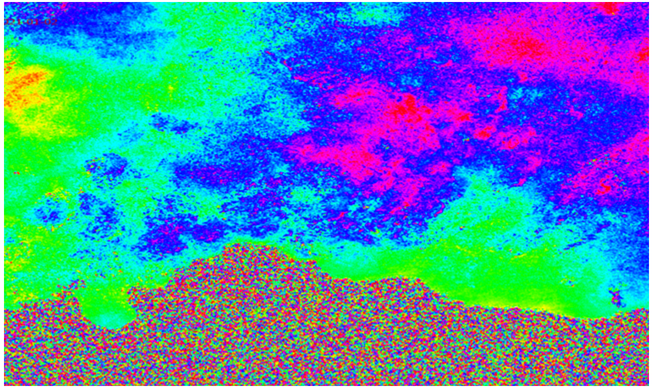
12-day coherence, California



$\sigma_{0,E}$, Mudrow Glacier



$\sigma_{0,E}$, Sulawesi, Indonesia



6-day InSAR phase, Iceland

- Access to Sentinel-1 backscatter / coherence is same as access to Sentinel-2 / Landsat/ MODIS etc
- SAR/InSAR analytics use same GIS-based framework as optical data analytics

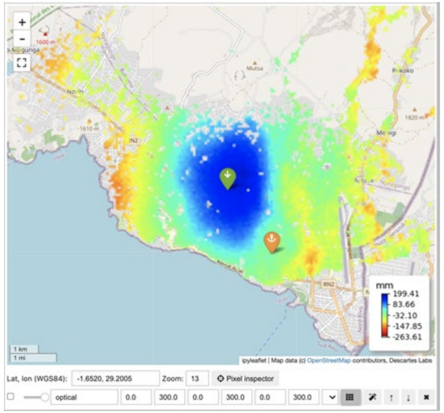
Example: Quicklook velocity / time-series

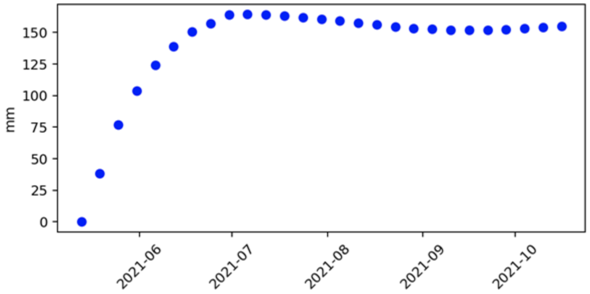
```
name = "Volcan Wolf"
center_lat = 0.017087
center_lon = -91.341172
lon_delta_km = 1
lat_delta_km = 1
start_time = datetime(2021, 1, 1)
end_time = datetime(2022, 3, 1)

quicklook_gdf =\
    ql.quicklook_data_from_lat_lon(
        name, center_lat, center_lon,
        lon_delta_km, lat_delta_km,
        start_time, end_time
    )
```

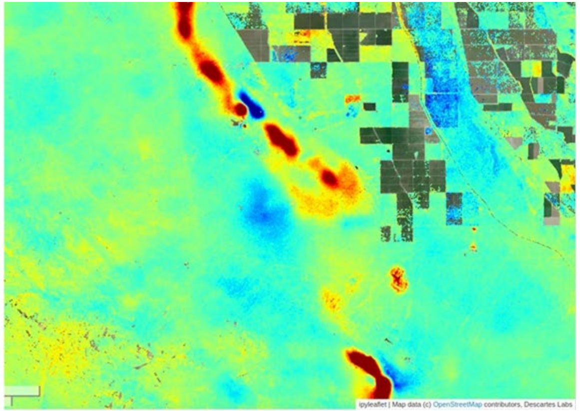
Fast hotspot detection anywhere in the world with IW-V acquisitions

Goma, DRC

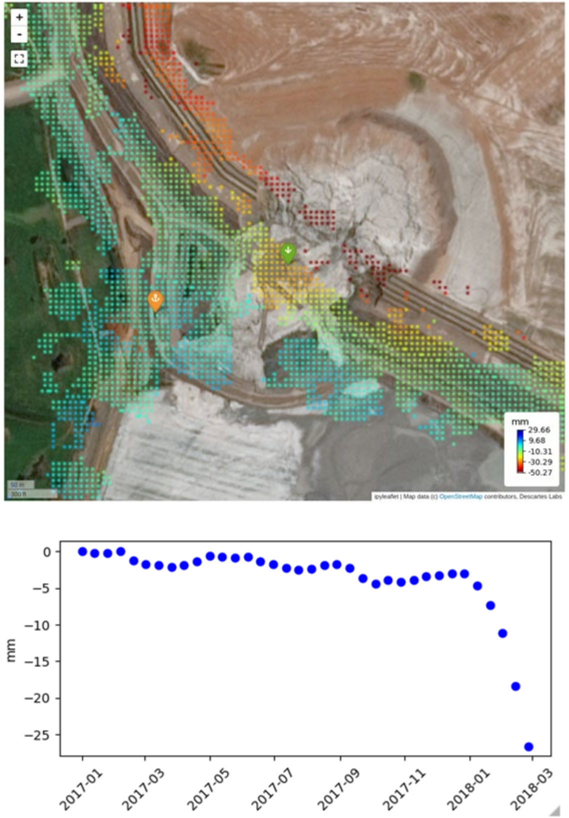




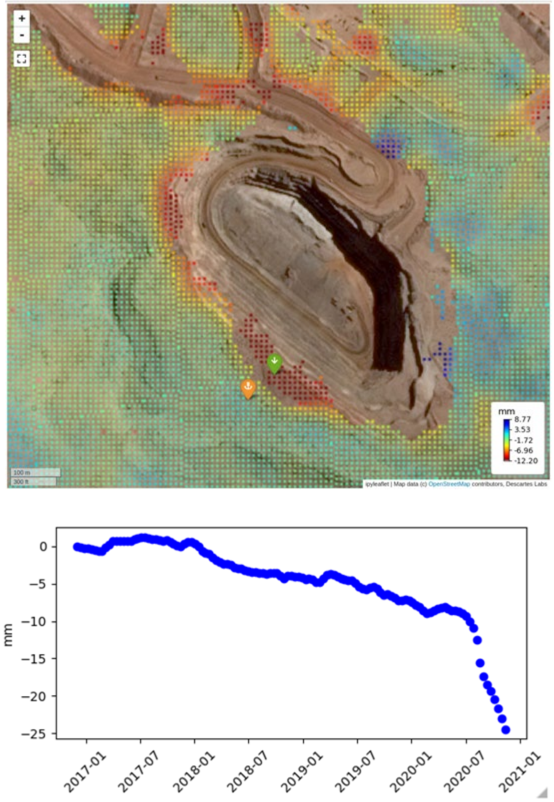
Missouri Triangle, CA



Example: Infrastructure monitoring



Cadia dam collapse



Gamsberg mine wall collapse

- GSLC data accessed like any other dataset on DL platform
- Suite of time-series algorithms developed to work on GSLCs
- Analytics suite also tested with GSLC data from TSX / CSK
- S1 stacks automatically updated with incoming imagery

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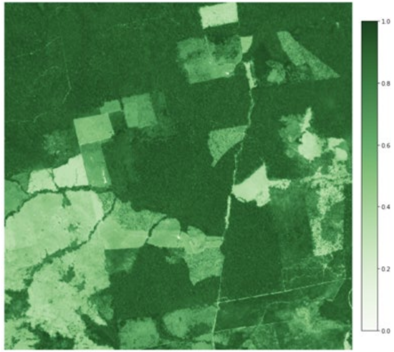
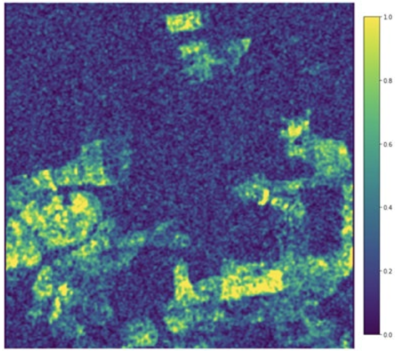
Example: Multi-modal analytics to detect deforestation

a) Optical (Airbus SPOT)

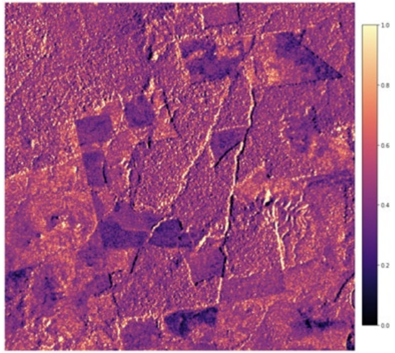
b) Sentinel-2 NDVI

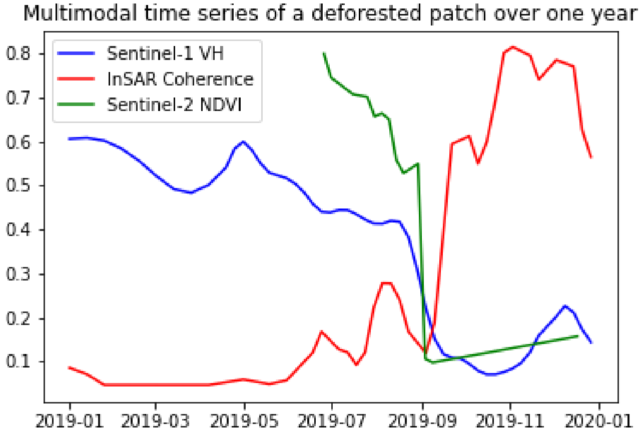


c) Sentinel-1 InSAR coherence

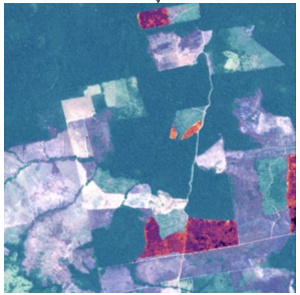


d) Sentinel-1 VH



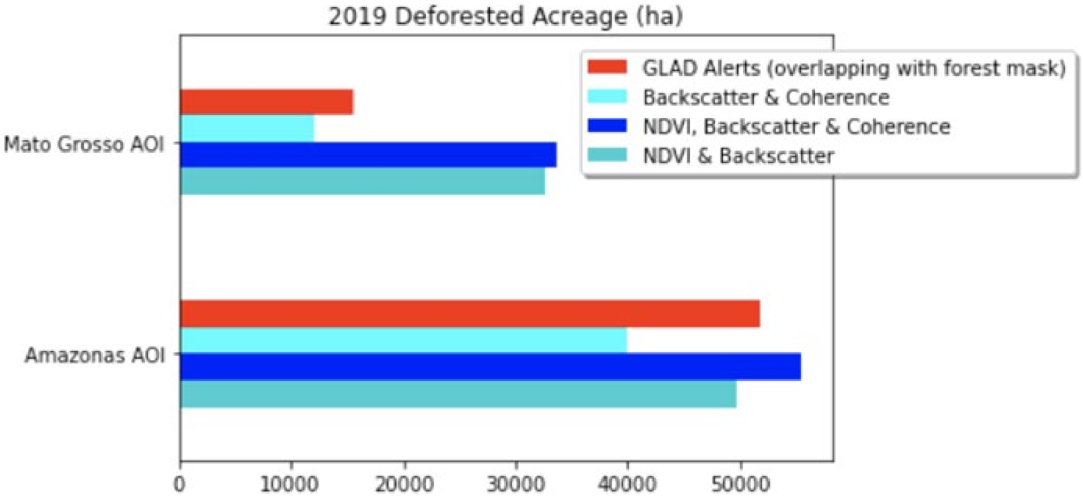


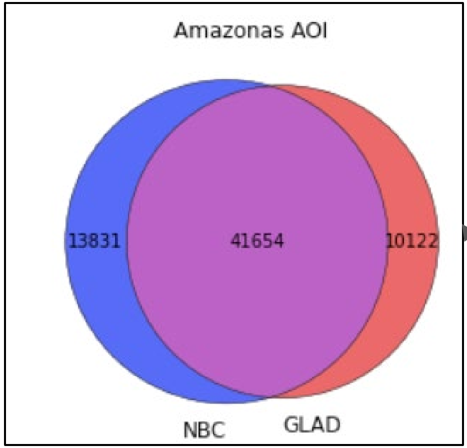
Probabilistic Bayesian approach

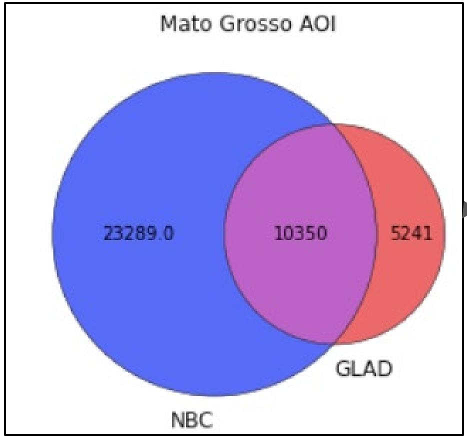


Reference: Reiche, J.; De Bruin, S.; Hoekman, D.; Verbesselt, J.; Herold, M. A Bayesian Approach to Combine Landsat and ALOS PALSAR Time Series for Near Real-Time Deforestation Detection. *Remote Sens.* **2015**, *7*, 4973-4996.

NDVI, Backscatter and Coherence model detects the most acreage



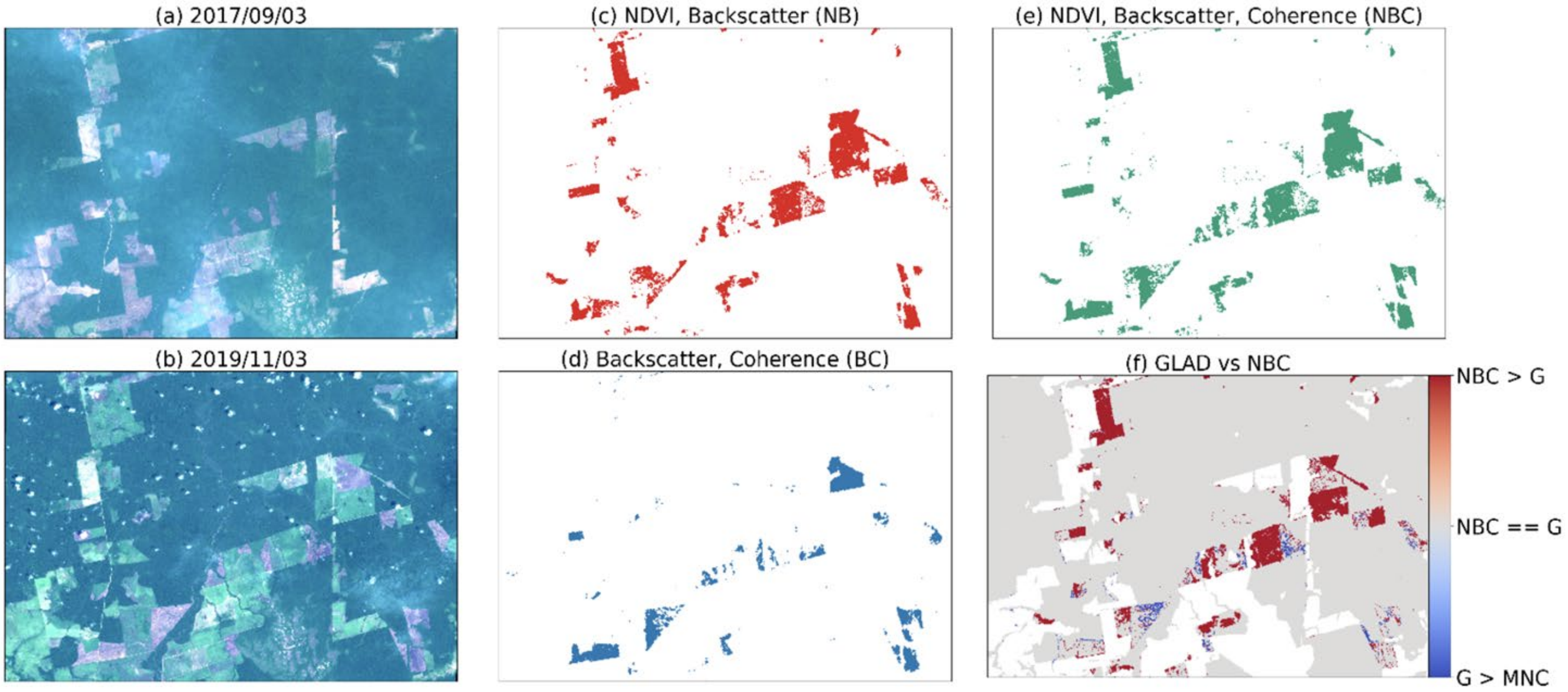




Reference AOIS:

- Amazonas AOI: 7,157,074 ha
- MG AOI: 4,463,677 ha

NDVI & Coherence supplement S1 backscatter to improve detections



Preparing for upcoming global missions

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- Sentinel-1, NISAR, ALOS and ROSE-L missions have been designed to support persistent InSAR analysis
  - Backscatter is only one component of usable data
  - Coherent change detection has a lot to offer for sustainability / agriculture sectors
  - Phase measurement for deformation analysis is another useful component
- Minimum requirement: access to calibrated high quality Level-1 SLCs
  - Quality of both - imagery and metadata
  - Supports both backscatter and interferometric applications
  - Sentinel-1 has raised the bar for what is acceptable, in terms of automation
  - Burst-based systems should support burst-based data organization and access
  - Using a clearly defined track-frame system enables automation
- Analytics: Coherence and backscatter at C-band / L-band complementary
  - Sentinel-1 + NISAR will be a reality 12-18 months from now

Preparing for sub-meter resolution SAR data

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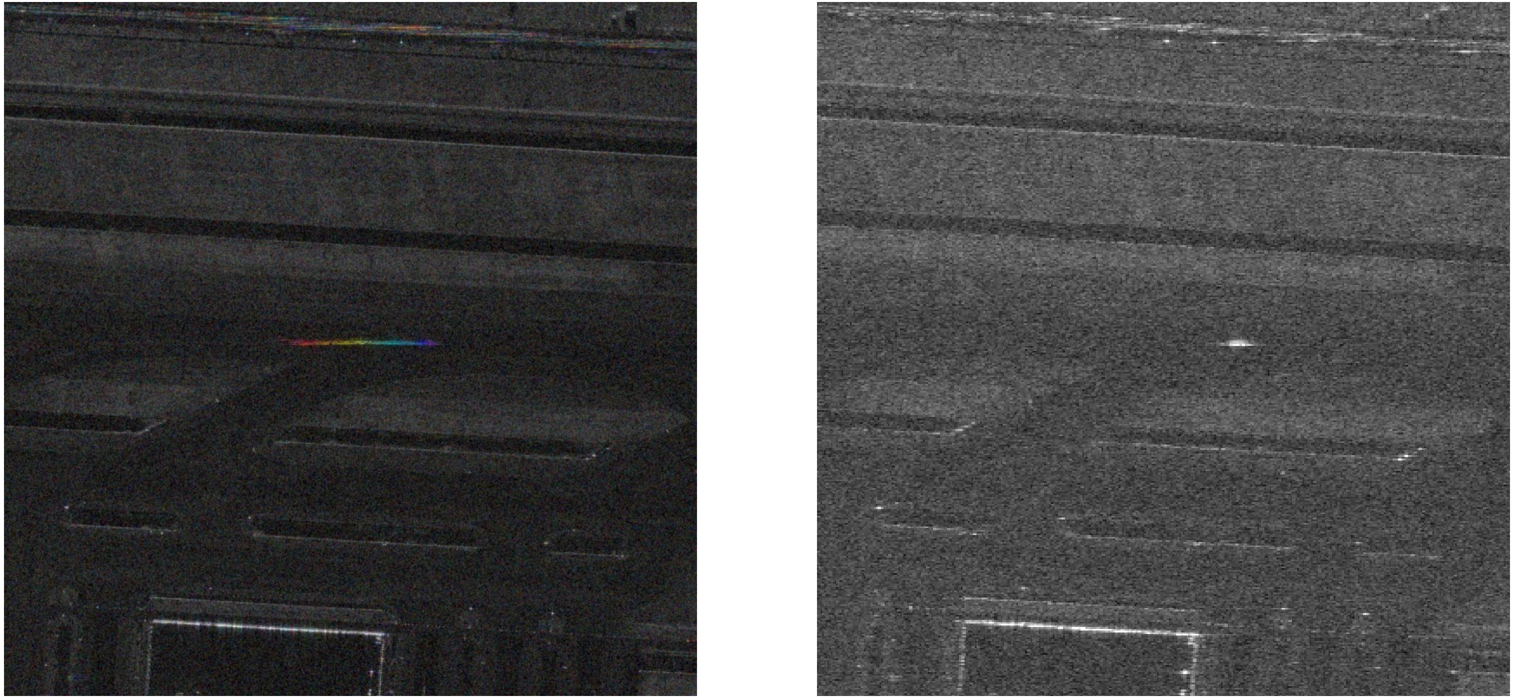
- Need for improved DEMs at global scale
  - Current day DEMs are good for medium SAR resolution data (~5-10m).
  - Higher resolution SAR data will need DEMs with improved spatial resolution (3-5m) for a Level-2 standardized product to be viable at global scale.
  - Currently possible over small AOIs using LIDAR-based DEMs.

- Challenge: Handling diversity in imaging geometry and modes
  - Small sats have a much wider orbital tube
  - Change detection: Due to change in physical properties vs change in imaging geometry
  - Currently, often requires manual intervention/ interpretation

Example: Sub-aperture based applications in GIS frameworks



Sub-apertures as bands, motion detection using Umbra SLC data

What can we learn from rest of Earth Observation (EO)?

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- SAR is a big part of the EO solution - not the only solution
  - Interoperability with other EO datasets is very important
  - Bring SAR data into GIS-based frameworks for broader adoption
  - Our Sentinel-1 product grids are compatible with Sentinel-2
- De-emphasize need for specialized tools for handing SAR data
  - For all practical purposes, SAR processing == custom projection system + custom interpolators
  - EO community familiar with custom projection systems - GOES, MODIS, SMAP etc
- Improve accessibility, coalesce around a broadly usable Level-2 product
  - For EO datasets, number of users Level-2/3 products >> Level-1 products
  - SAR experts can always use Level-1 products if needed, just like other EO data
  - A large majority of SAR users today use black box software to generate L-2 products with default settings themselves

Geocoded SLCs as a Level-2 product

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- Potential Level-2 SAR product to coalesce around
  - One of the products in NISAR suite
- Pros:
  - GIS-friendly - same tools as other EO datasets
  - Can support backscatter and InSAR applications, including radiometric terrain correction - i.e, most common workflows
  - Preserves resolution of original acquisitions
  - Allows for standardization in framing / pixel spacing like other EO datasets
  - Scalability and simplicity of maintenance - same as other EO datasets
- Cons:
  - Esoteric/ AOI-specific applications requires going back to Level-1 SLCs
  - More stringent requirements on data quality for providers
  - **Caution:** DEM quality.

Thank you!

References

Descartes Labs

- Geocoded bursts: Single ARD product to support backscatter and InSAR analysis with Sentinel-1 SAR data (ARD 2020)
  - https://www.youtube.com/watch?v=Er7ZOdT4bsM&t=550s
- Global near real-time backscatter and InSAR products derived from Sentinel-1 geocoded bursts (ESA FRINGE 2021)
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- Global Rapid Full Resolution InSAR Derived From Sentinel-1 Geocoded Bursts, Leveraging Scalable Computing (ESA FRINGE 2021)
  - https://www.youtube.com/watch?v=rFBb9CBX2rM
- Global scale InSAR analytics with Sentinel-1 (ARD 2021)
  - https://www.youtube.com/watch?v=9X2Yv-7485w&t=7260s