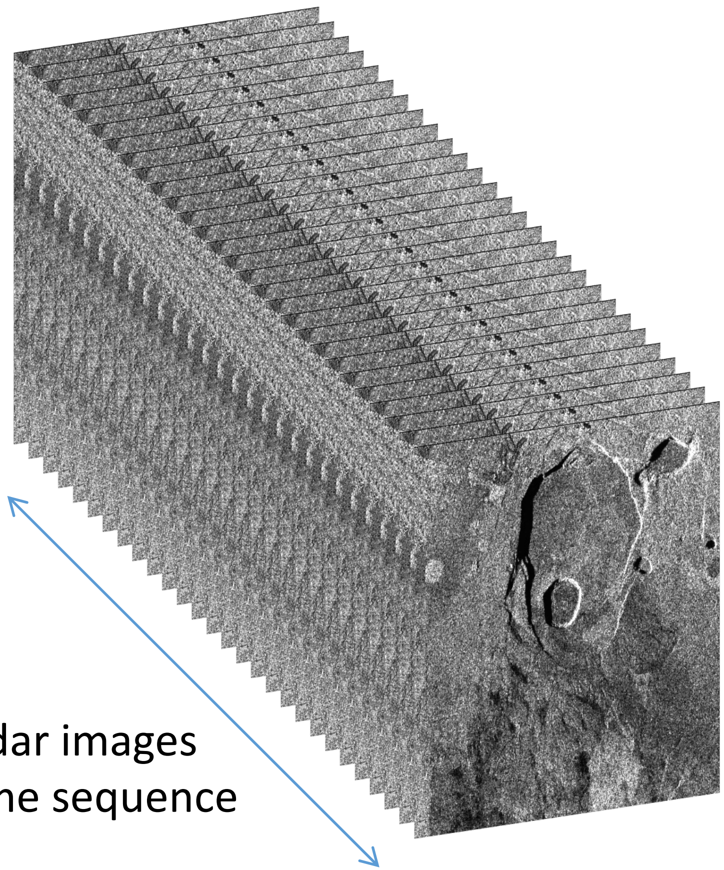
Handout 49

# Backprojection InSAR

# Why consider backprojection

- Standard data products should be user-friendly
  - Geocoded to common coordinates
  - InSAR phase corrections applied
- SLCs consistent with these allow easier analysis by non-specialists and specialists alike
- No need for intermediate format such as range-Doppler
  - Fewer resampling steps
  - Automatically applies motion compensation

# Computational burden



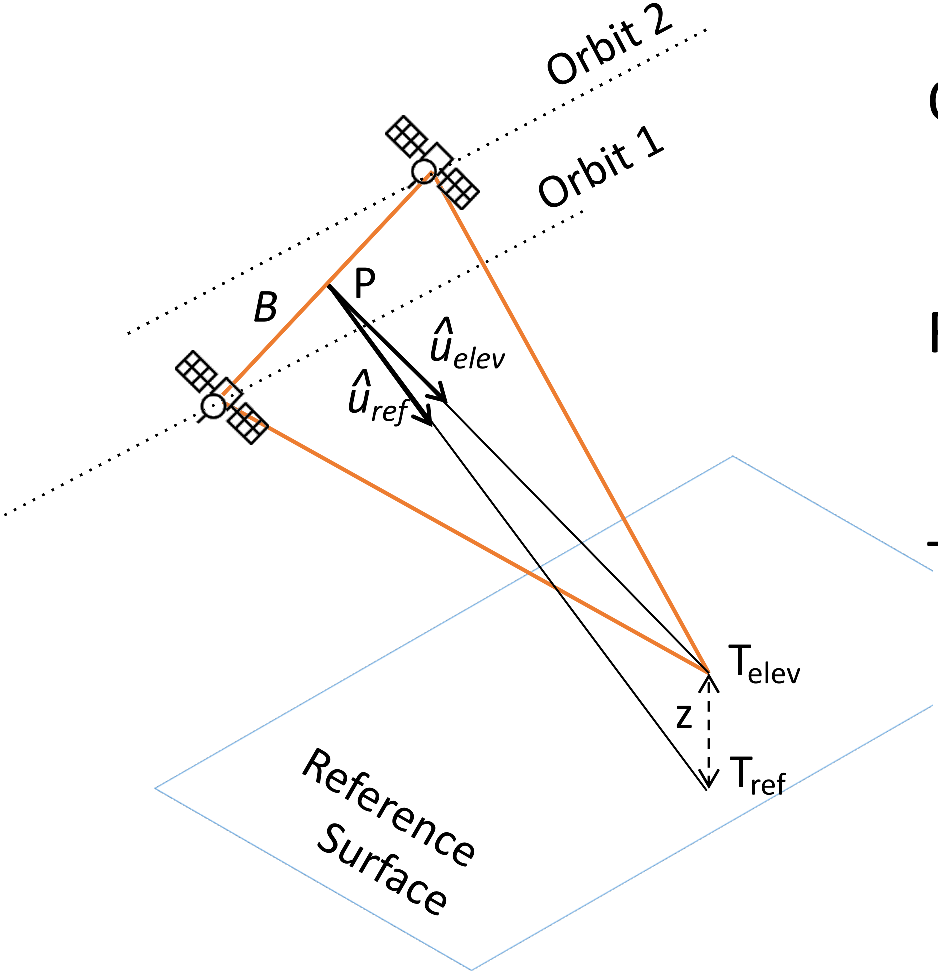
N radar images
in time sequence

- Very large data volumes
- With N radar images, we produce N(N-1)/2 interferograms
- Ex: Sequence of 100 observations -> 4950 interferograms
- Must coregister many interferogram pairs

# We used range-Doppler algorithm to date

- Convolutional processing applies the matched filter
  - Computationally efficient due to FFT
  - Robust for poorly known orbits
  - But applies same filter everywhere so phase corrections needed
- Data are produced in range-Doppler space and need phase compensation
- InSAR analysis requires precise coregistration and viewing/topographic corrections

# Traditional InSAR: 2 Phase corrections needed




Observed phase (no deformation):

$$\phi_{obs} = -\frac{4\pi}{\lambda} \hat{u}_{elev} \cdot B$$

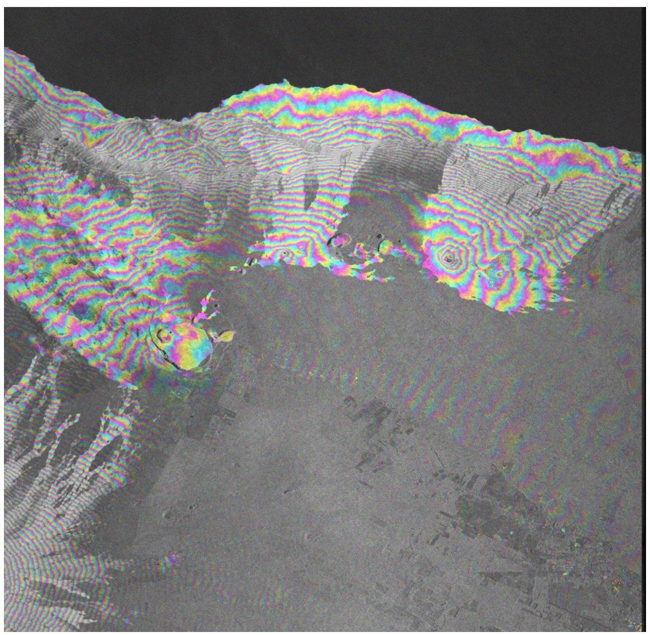
Flat-Earth correction:

$$\phi_{flat} = -\frac{4\pi}{\lambda} \hat{u}_{ref} \cdot B$$

Topographic correction:

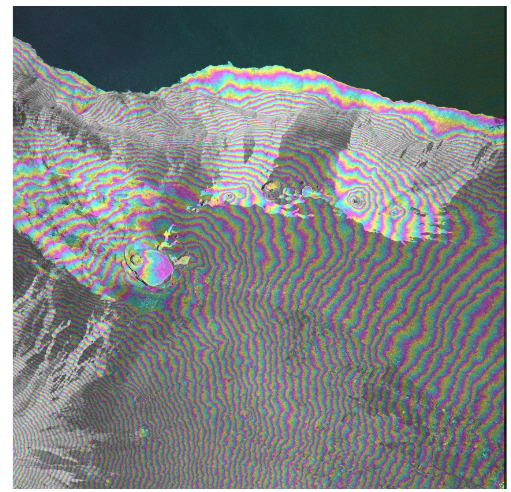
$$\phi_{topo} = -\frac{4\pi}{\lambda} \left( \hat{u}_{elev} - \hat{u}_{ref} \right) \cdot B$$

# InSAR phase compensation
## Need to remove topographic ‘nuisance’ term



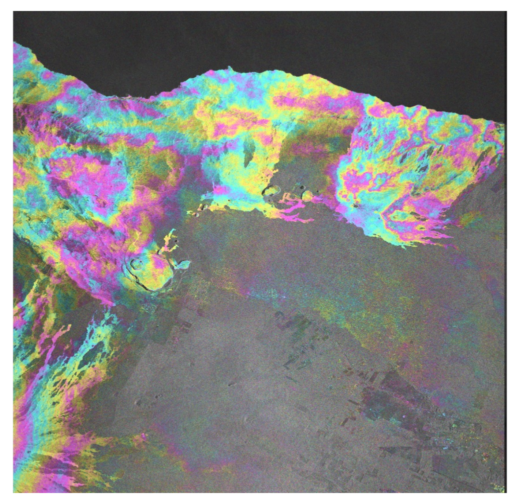
Observed fringe pattern

=



Topographic term

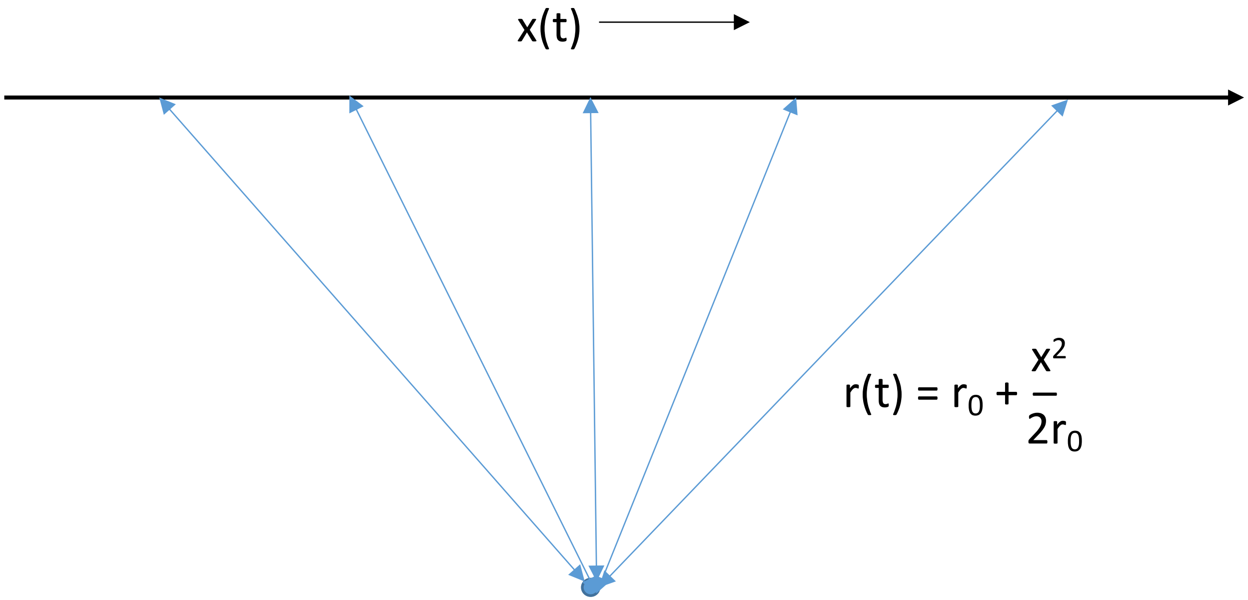
+



Deformation terms (+noise)

Hawaii 20100904-20100928
Processed from CSK Raw data

# Review: forming the synthetic aperture

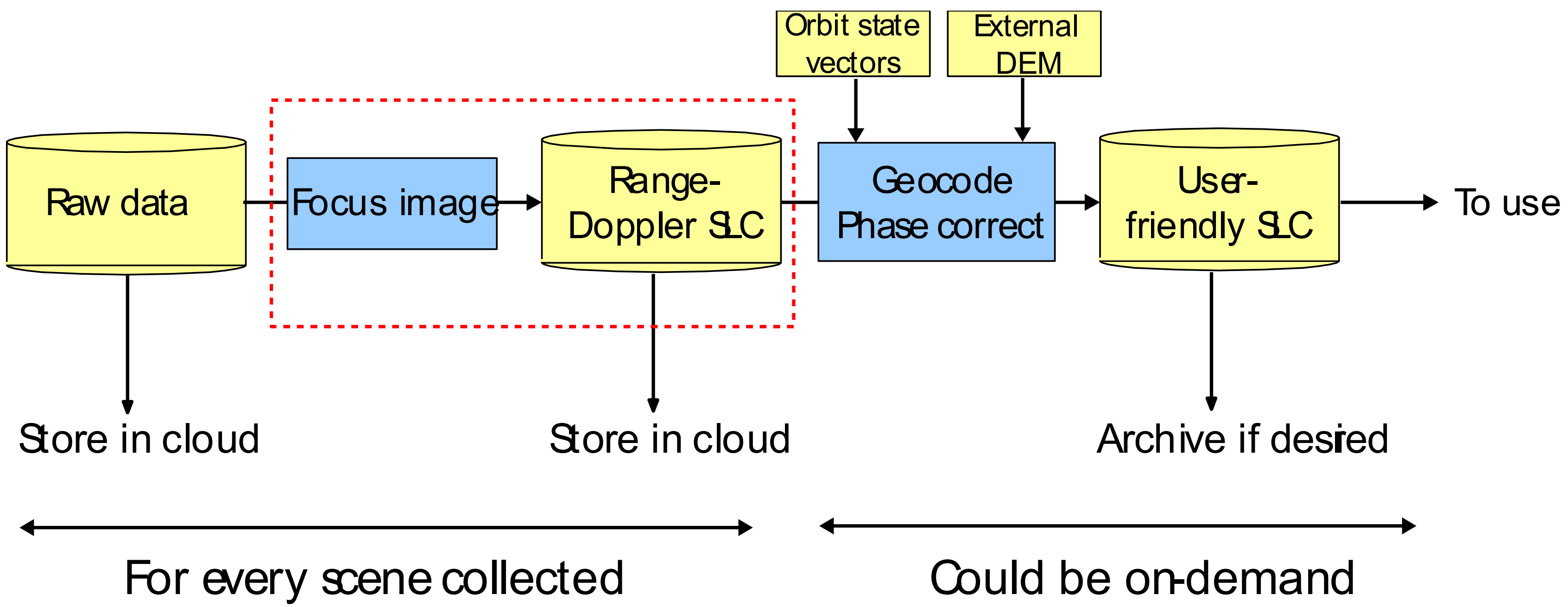



- To form the synthetic aperture, we phase shifted (quadratic phase) and delayed (migration correction) each echo so that all pulses added up in phase with each other

- We implemented this as a convolutional filter as an efficient computational approach

# Processor flow using range-Doppler

- Cost driver likely the storage of range-Doppler SLCs
  - Needed for every imaged scene
  - Larger than raw data files



# Backprojection SLC formation

- One of the earliest algorithms proposed for SAR imaging
- Was impractical due to computational inefficiency and lack of accurate platform knowledge
- Modern computers and orbit tracking enable approach

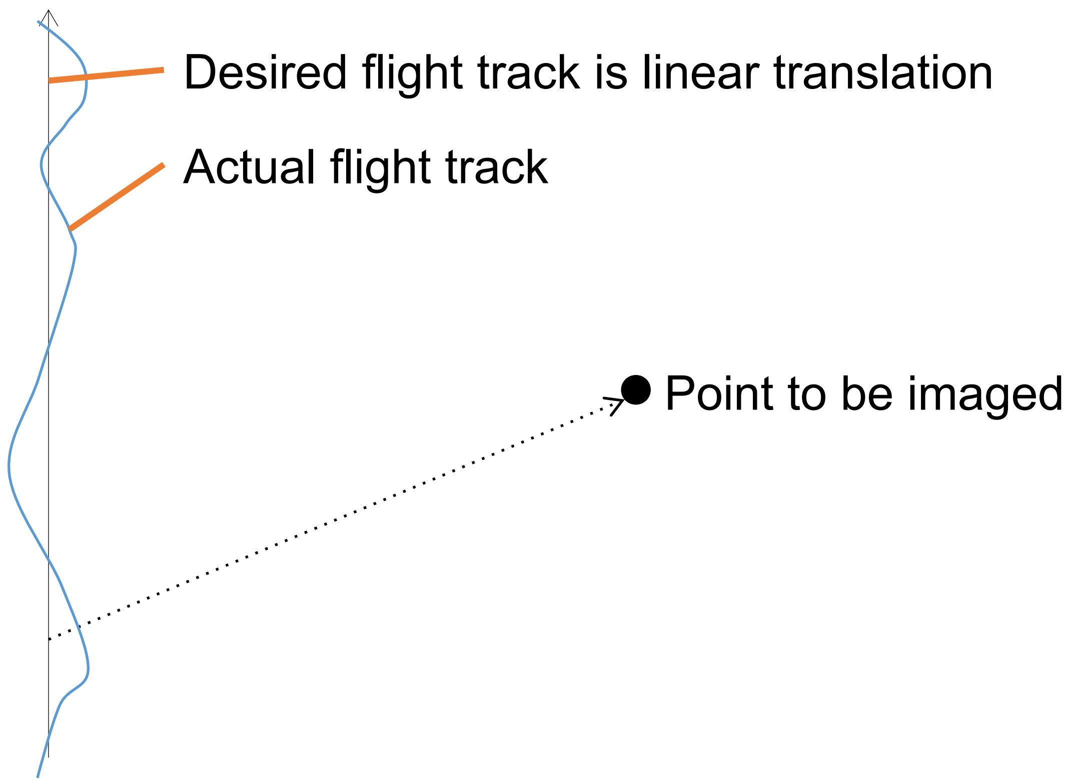
✓Forms ideal matched filter

✓Automatically applies phase corrections if DEM used

✓SLCs produced in lat/lon or other desired geometry

# Recall the motion compensation correction

- We chose a desired r(t) : apply a correction phase and delay term so that range is quadratic with time or x distance
- Computed matched filter for convolutional processing



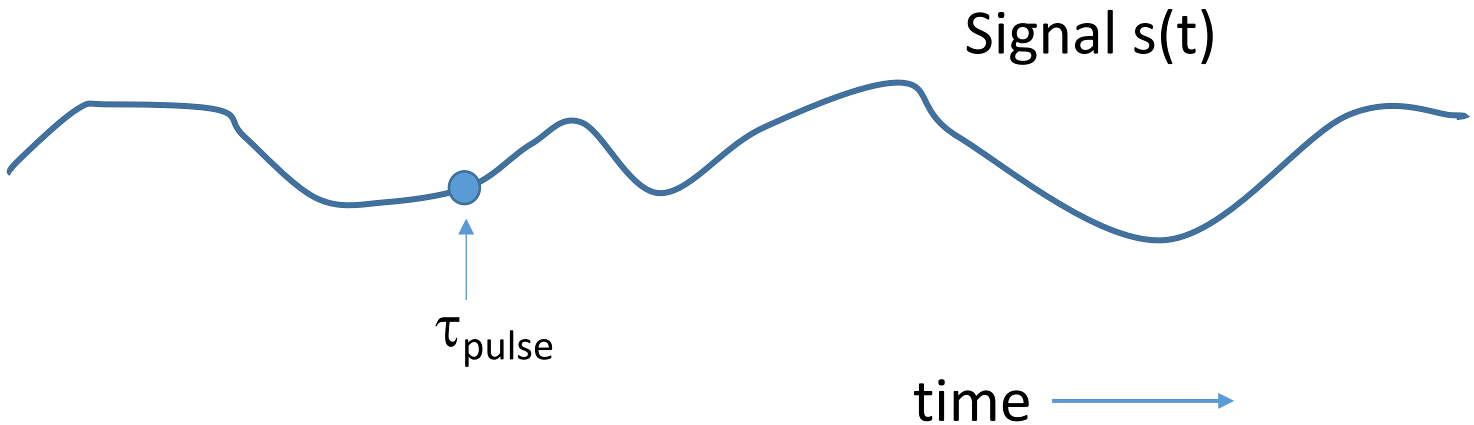
# We altered signal phase and delay

- Motion compensation baseline and time delay
  - $b = r_{act} - r$ (mocomp baseline)
  - $\tau = 2b/c$
- Motion compensation phase shift
  - $\phi_{baseline} = -4\pi/\lambda \, (r_{act} - r)$

# Backprojection algorithm

- For each point on ground, compute time delay and phase of radar pulse from total propagation distance
  - Find $r_{act}$ for each pulse
  - $\tau_{pulse}=2\, r_{act}/c$
  - $\phi_{pulse}=-4\pi/\lambda \cdot r_{act}$
- Sum these coherently to form image

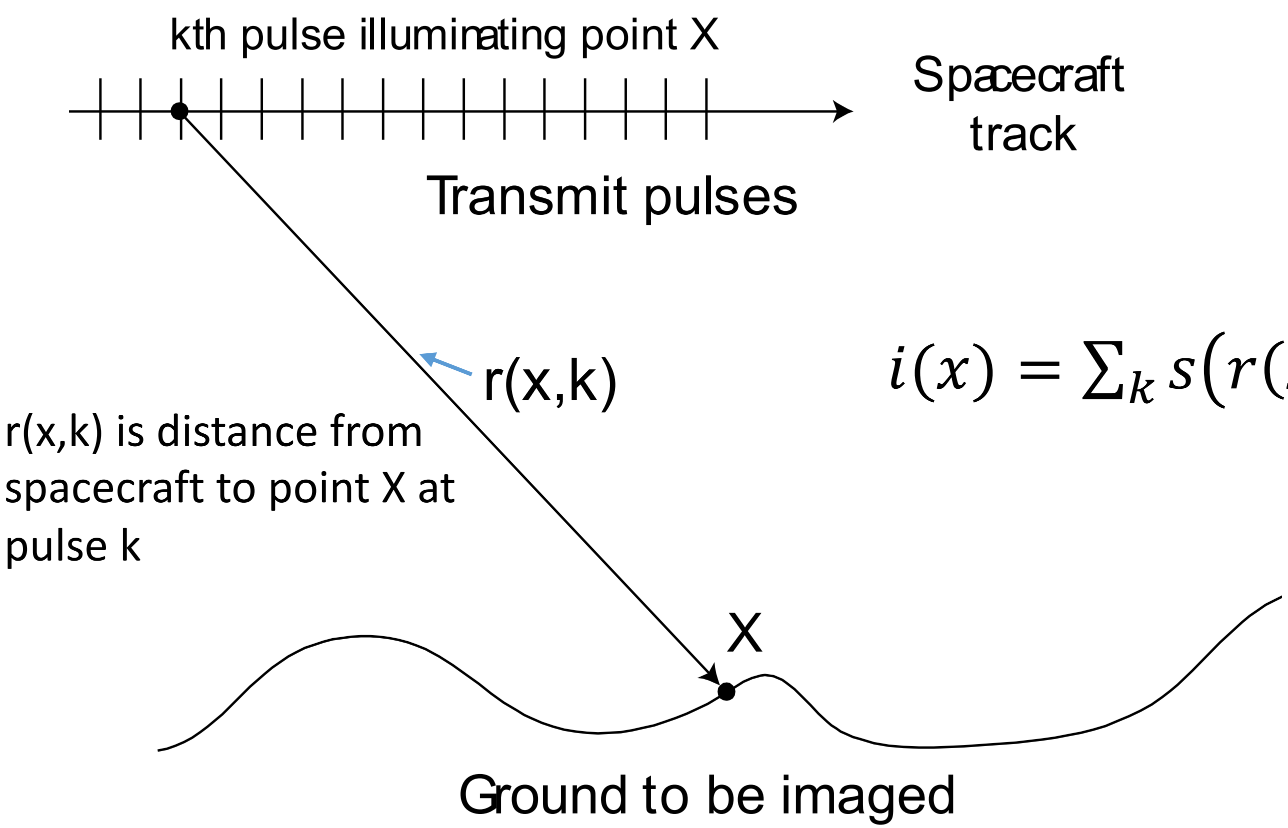
# Sample range echo for each pulse at proper time, then shift phase




Shift phase by $\phi_{pulse}$ : $s(\tau_{pulse})\, e^{-j\,\frac{4\pi}{\lambda}\,\phi_{pulse}}$

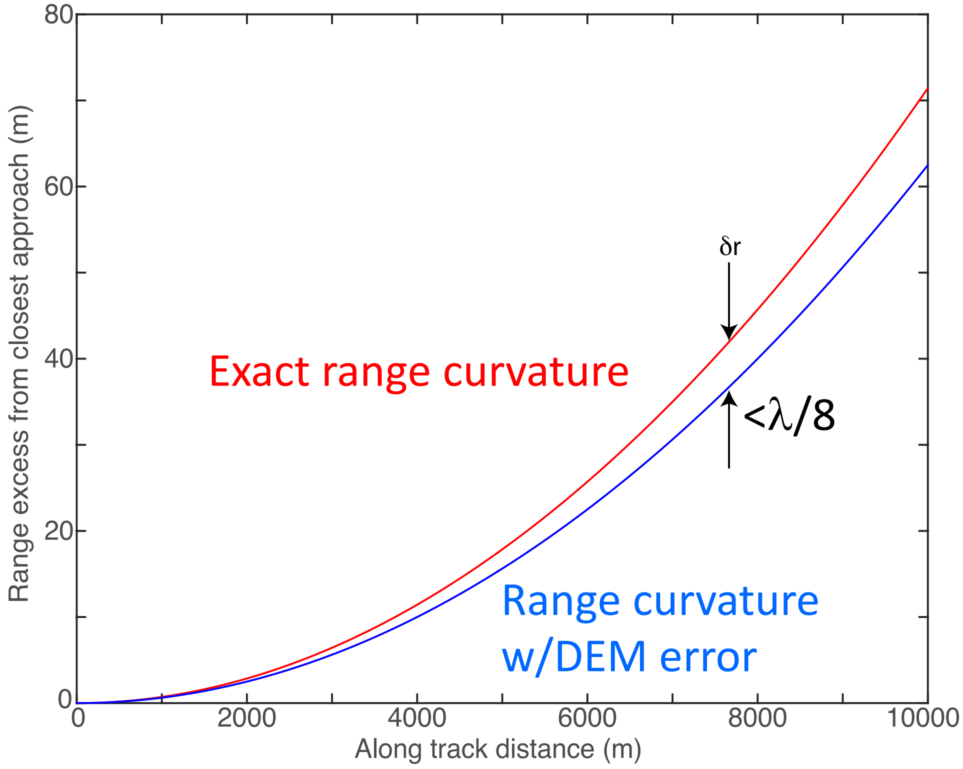
# Calculating the SLC

- Algorithm: add all echoes illuminating a point in phase
- Automatically compensates topographic phase if DEM included




$$i(x) = \sum_k s\big(r(x,k)\big)\, \mathrm{e}^{-j\frac{4\pi}{\lambda} r(x,k)}$$

# DEM accuracy affects focus




Range history

$$r(x) = (r_0^2 + x^2)^{1/2} - r_0 \approx \frac{x^2}{2r_0}$$

Error for incorrect range is then

$$r(x) - r'(x) = \frac{x^2}{2}\left(\frac{1}{r_0} - \frac{1}{r_0'}\right)$$

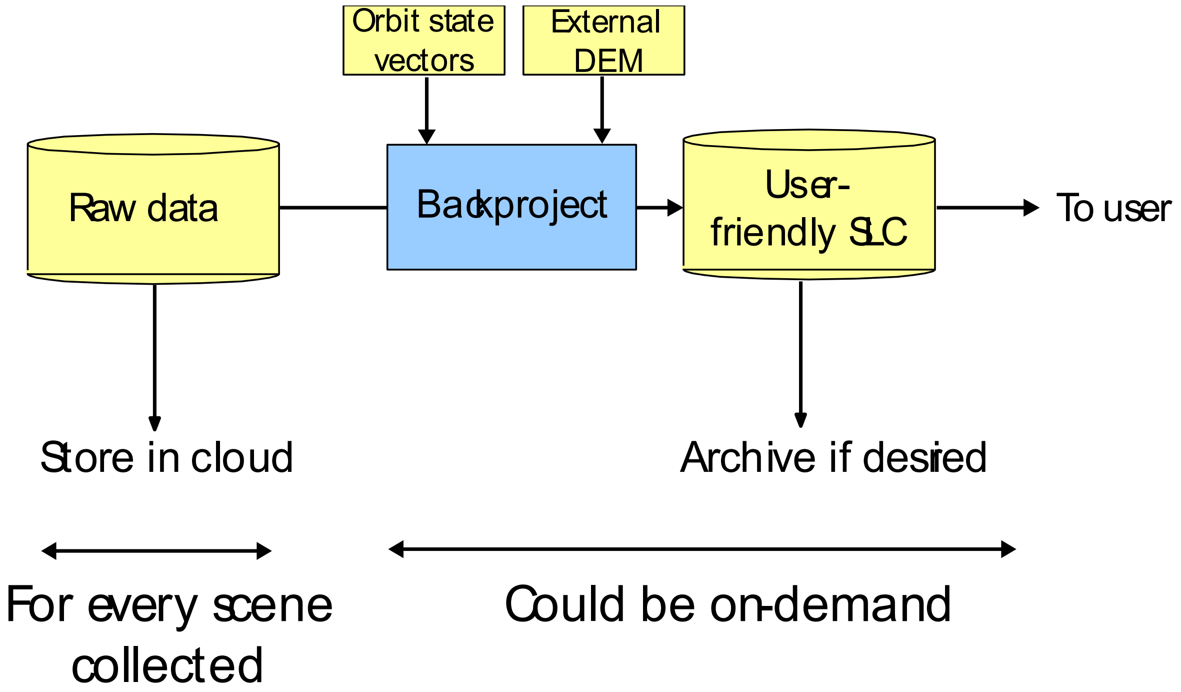
For λ/8 limit, depth of focus ~ $\dfrac{D^2}{\lambda}$

At L-band: 400 m

At C-band: 1600 m

# Processor flow - backprojection

- Backprojection avoids creating/storing range-Doppler intermediate products



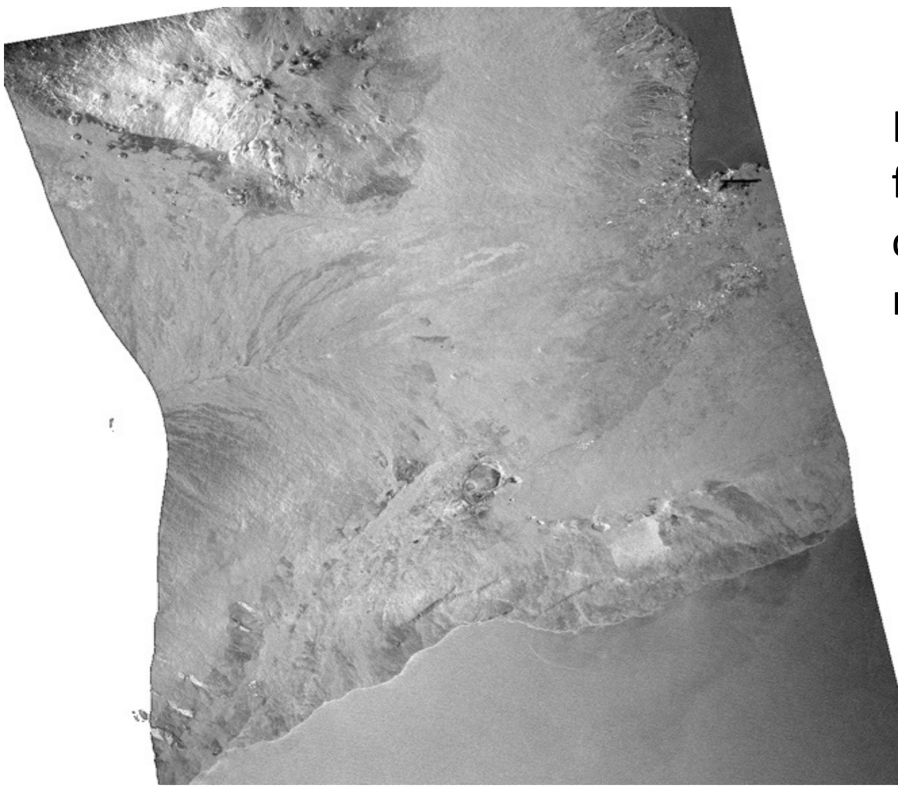
# Two example system cases

- Examples using ALOS strip map and Sentinel burst processing for wide swaths
- Added image formation processing burden eased through GPU architecture (cheap if not competing with currency miners)
- Data products more amenable to InSAR analysis

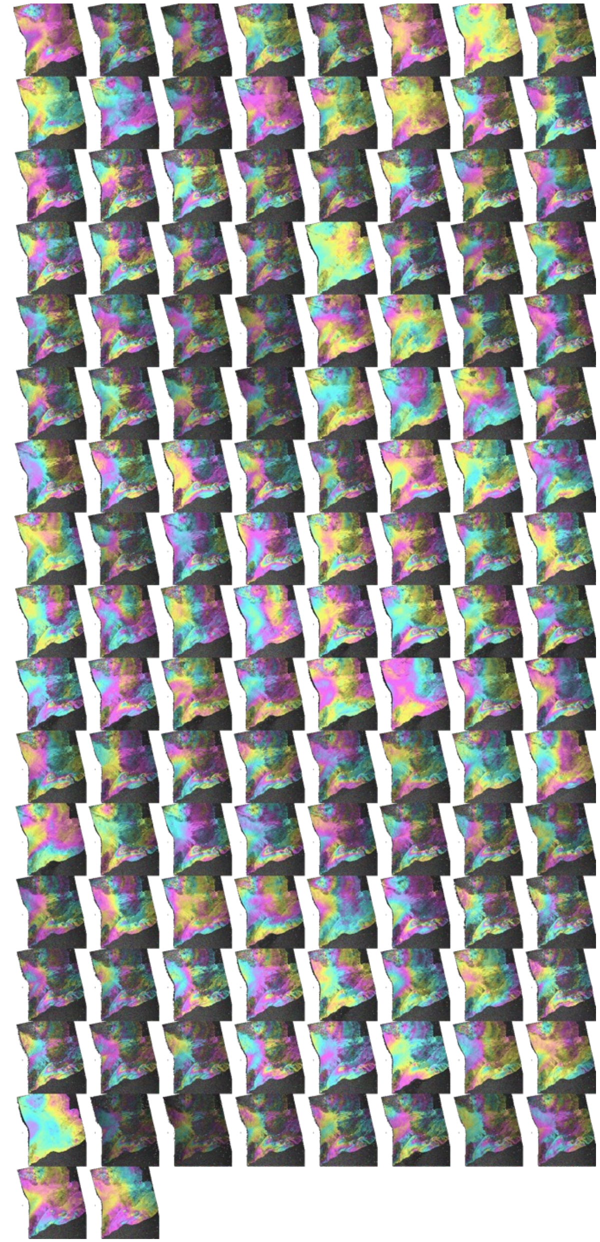
# ALOS: A simple example

- L-band, strip mode, 20 km aperture
- GPU pipelined implementation

Geocoded amplitude image, Kilauea



Interferograms from simple cross multiplication

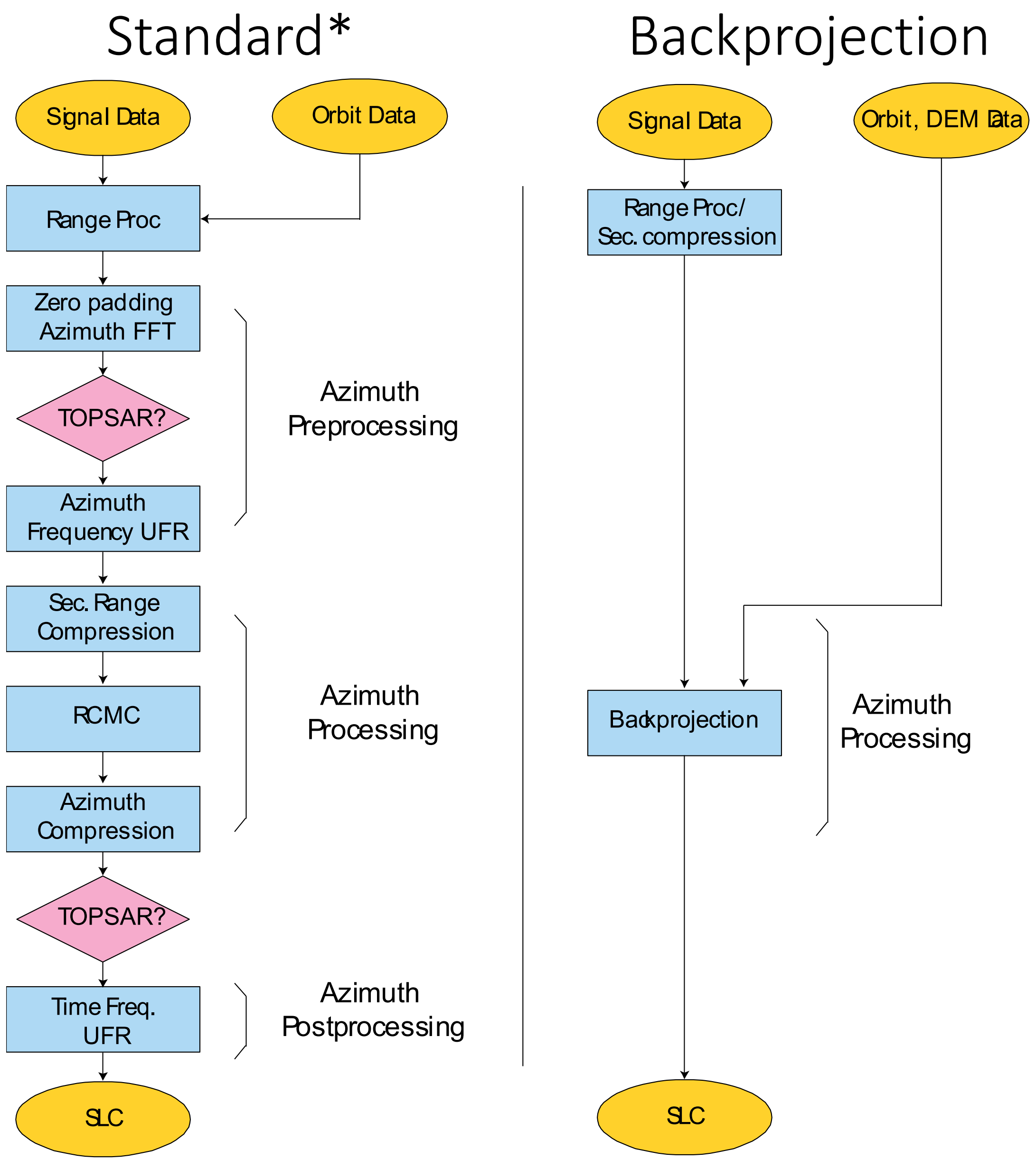


# Sentinel 1A/B - TOPS imaging

- Sentinel 1 TOPS mode permits large and frequent coverage but products complex
- Standard product hard to use due to carrier phase
- Very precise coregistration needed
- Products can be resampled to common coordinates but phase compensation requires expertise

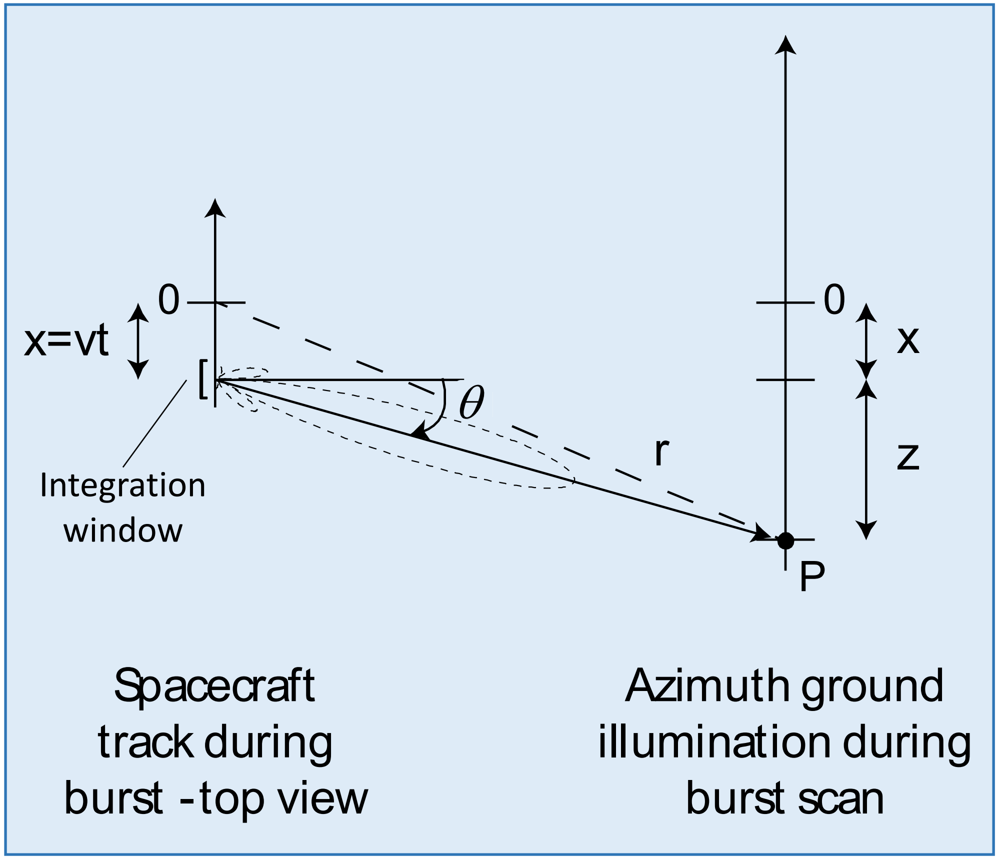
# L0 SLC processing

- Dealiasing computationally expensive and very intricate though elegant
- Backprojection same for all modes
- Short integration time makes backprojection efficient




*Sentinel 1 SAR Technical Guide

# TOPS integration window




For target P at $f_{Dop,0}$ wrt burst midpoint and TOPS steering angle $\theta$:

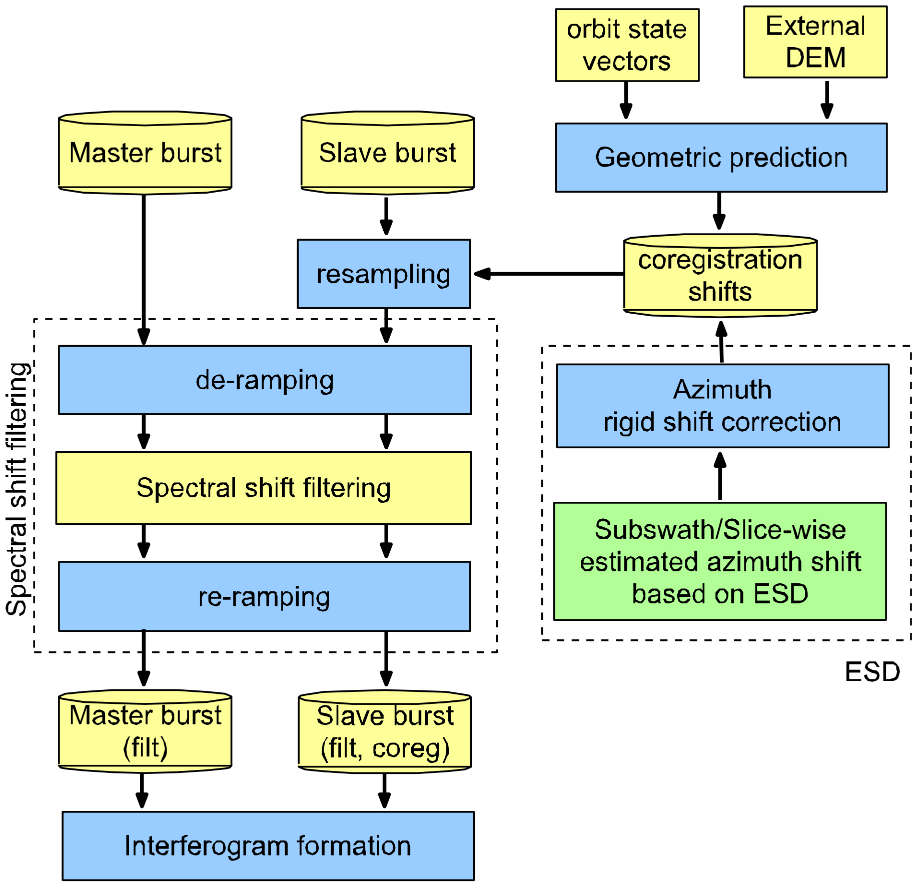
$$f_{Dop,0} = \frac{2v}{\lambda}\frac{x}{r} + \frac{2v}{\lambda}\theta$$

$$where\ \theta = c_1 t + c_0$$

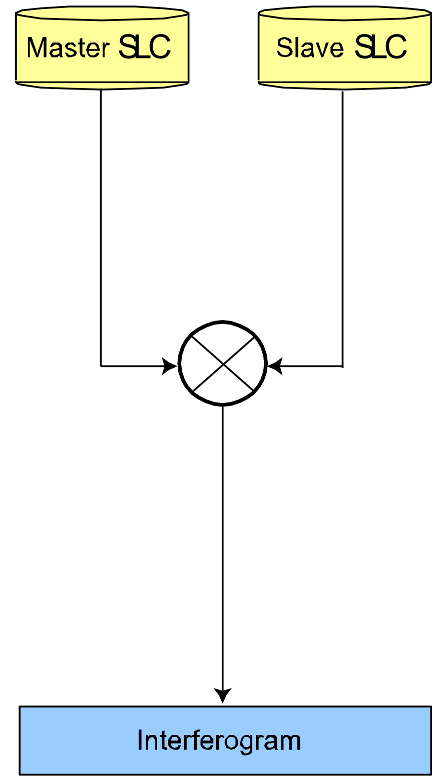
$$\rightarrow t = \frac{\frac{r\lambda}{2v^2} f_{Dop,0} - \frac{rc_0}{v}}{1 + \frac{rc_1}{v}}$$

# Interferogram formation – by user

## Standard (Yague-Martinez et al.,2016)



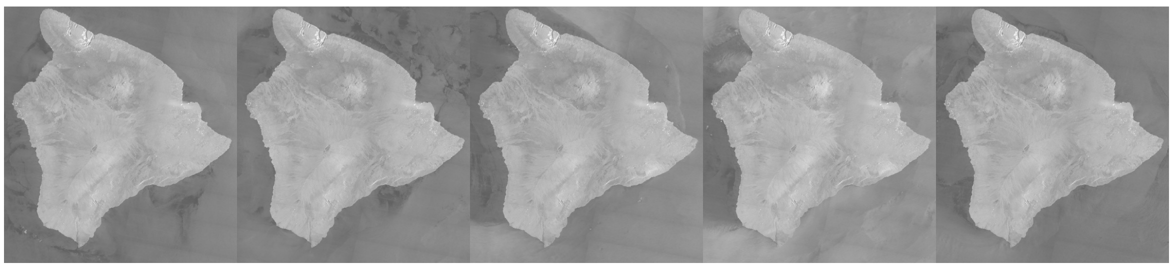

## Backprojection



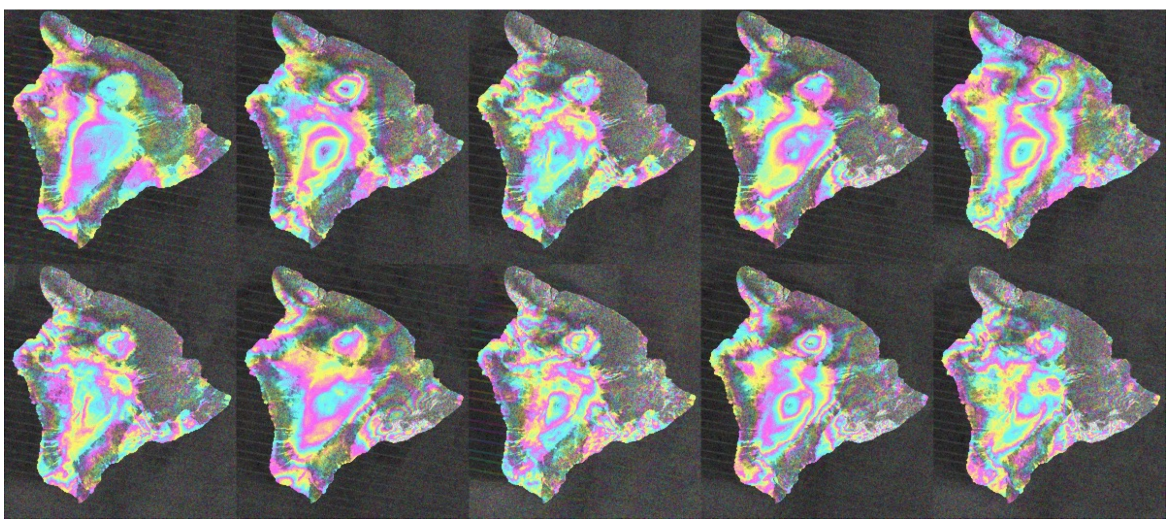
# Sentinel 1B backprojection products

- Standardized, geocoded, phase corrected InSAR enables huge potential community

Island of Hawaii



Geocoded SLCs



Backprojected phase corrected Sentinel-1B data facilitate easy interferogram analysis

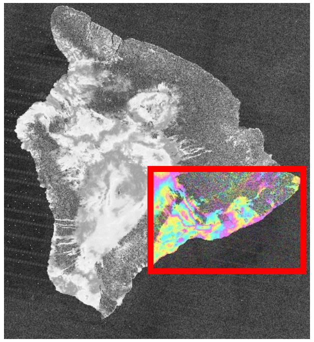
User-friendly interferograms

# User-friendly products

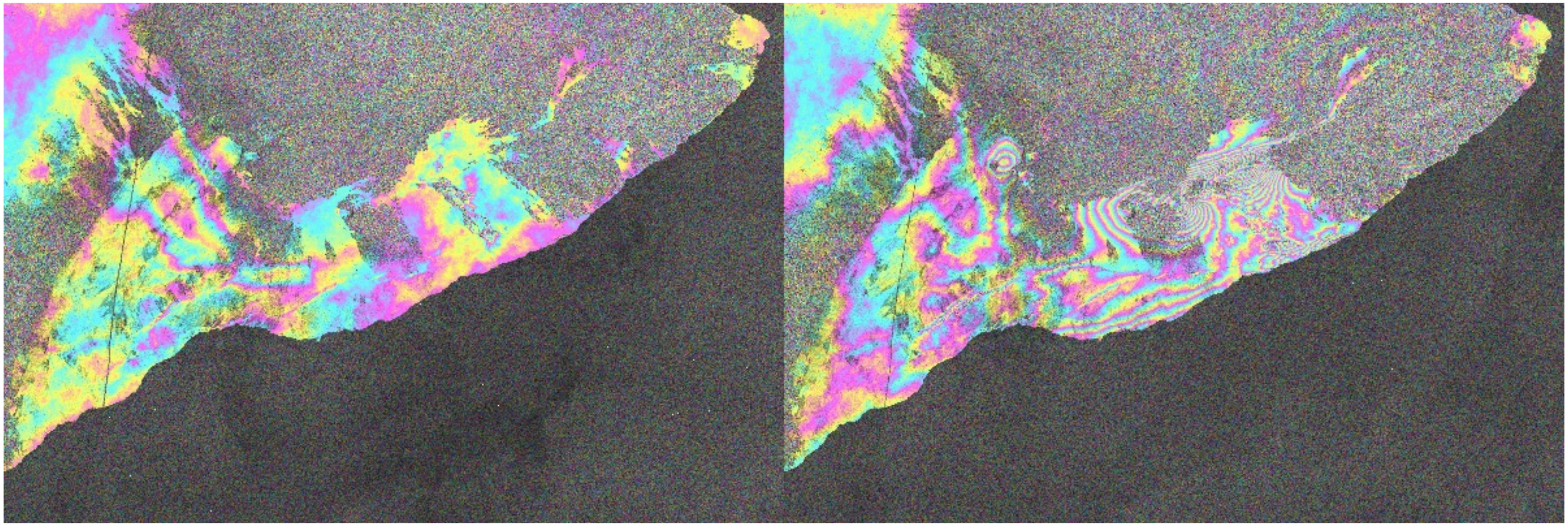
- Simplified time series view of Kilauea eruption

# User-friendly products

- Simplified time series view of Kilauea eruption

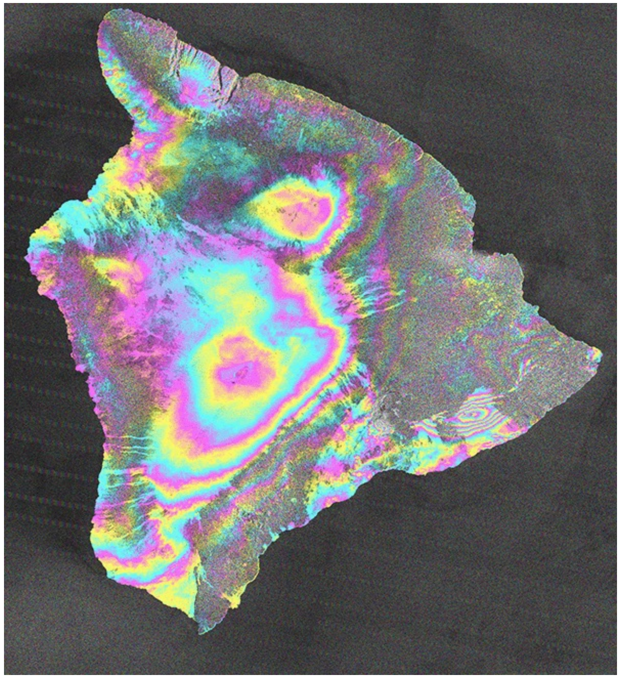


29 JAN 2018 – 11 APR 2018 | 11 APR 2018 – 05 MAY 2018

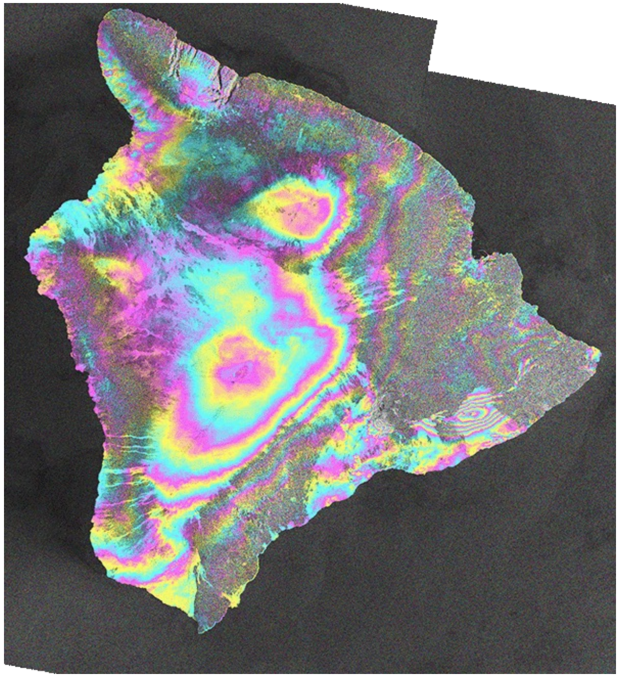


# Product comparison

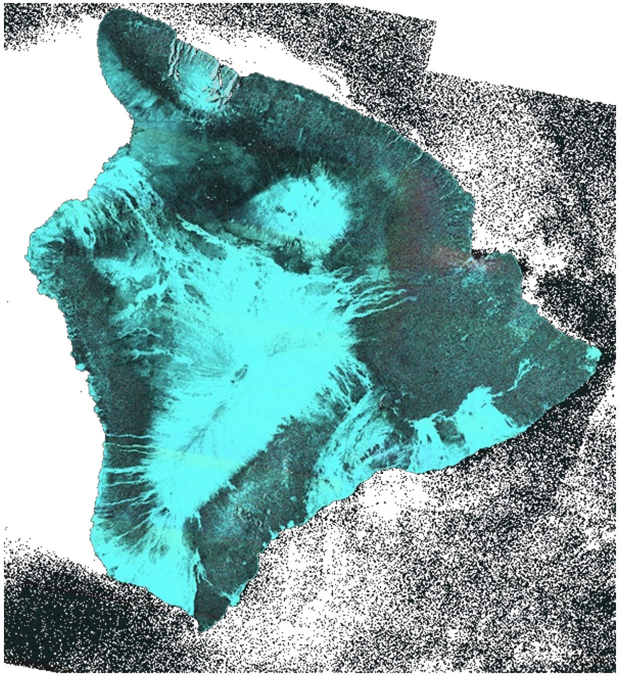
- End products are very similar
- Choice based on efficiency and ease of use



From L1 SLC



From L0 Raw



Cross-interferogram

# Why some groups use backprojection today

- Product generation from range-Doppler SLCs difficult for both producer and end user
- Backprojection
  - Generates user-friendly products directly
  - Simplified SLC processing stream
  - Simplified interferogram generation
  - Computationally efficient with GPU implementation

-> No need to create/store range-Doppler products