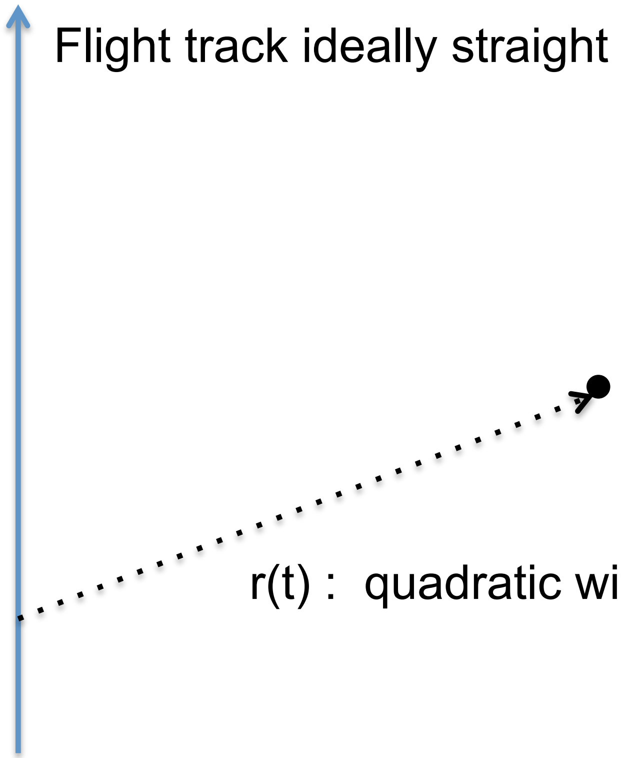
EE355/GP265 Handout #45

Motion compensation InSAR processing

Historical motivation for motion compensation

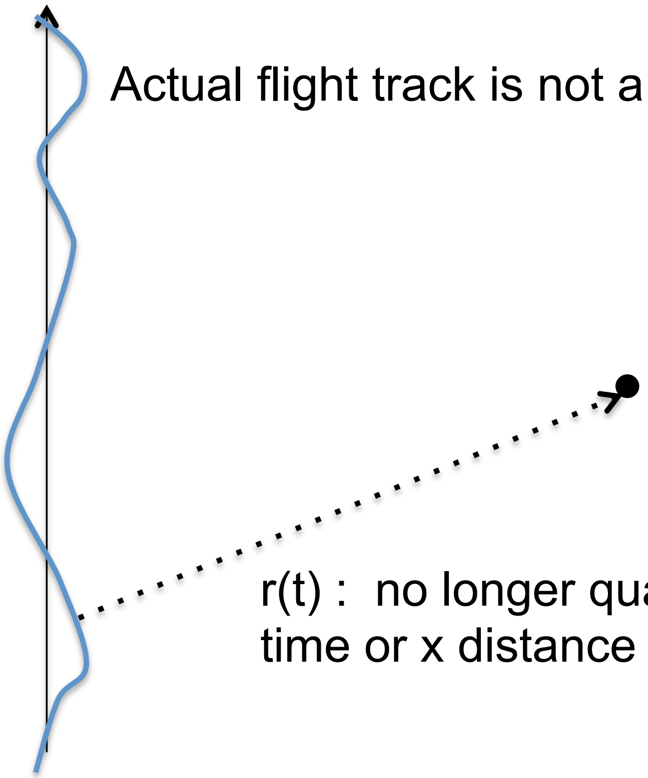


Flight track ideally straight line

Point to be imaged

r(t) : quadratic with time or x distance

Need for motion compensation

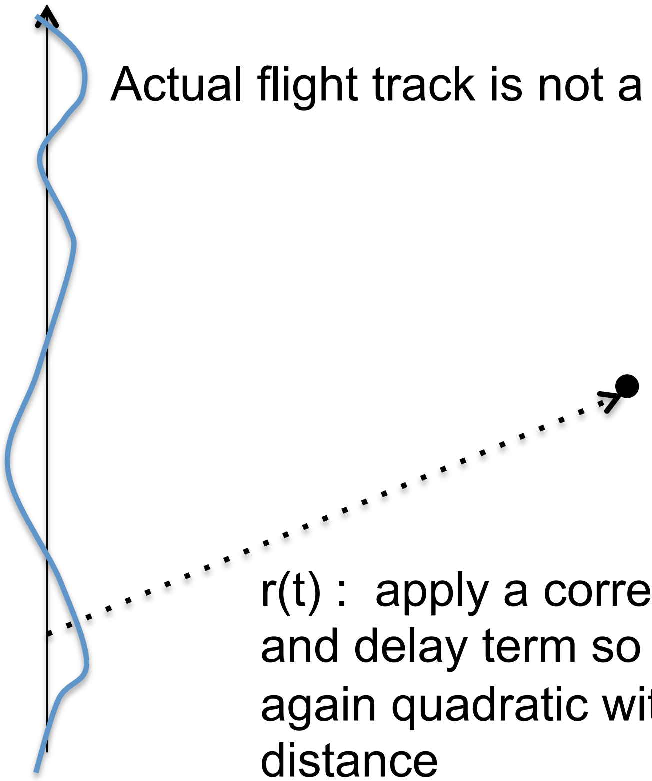


Actual flight track is not a single linear translation

Point to be imaged

r(t) : no longer quadratic with
time or x distance

The motion compensation correction

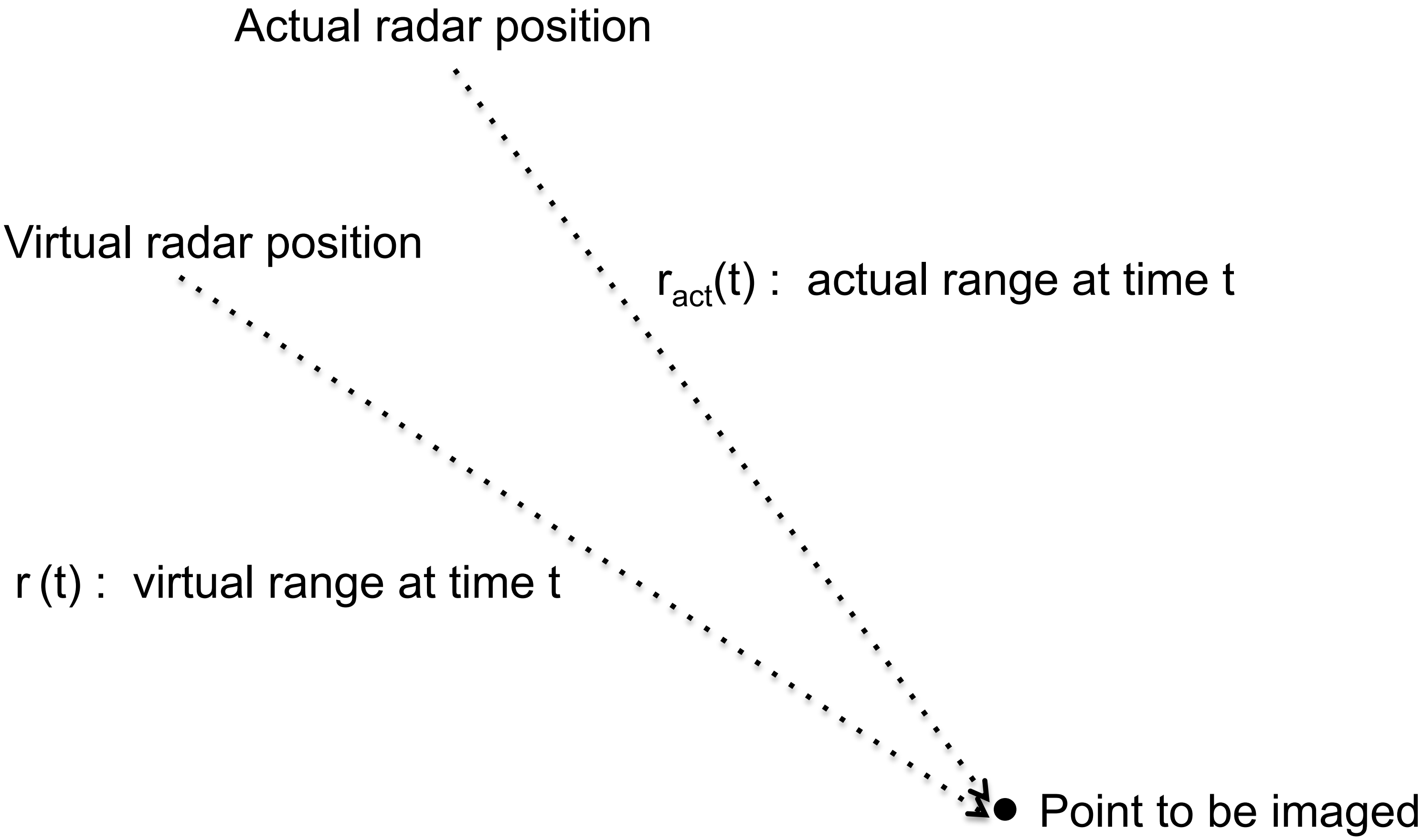


Actual flight track is not a single linear translation

Point to be imaged

r(t) : apply a correction phase and delay term so that range is again quadratic with time or x distance

Computing motion compensation correction



Actual radar position

Virtual radar position

$r_{act}(t)$: actual range at time t

$r\,(t)$: virtual range at time t

Point to be imaged

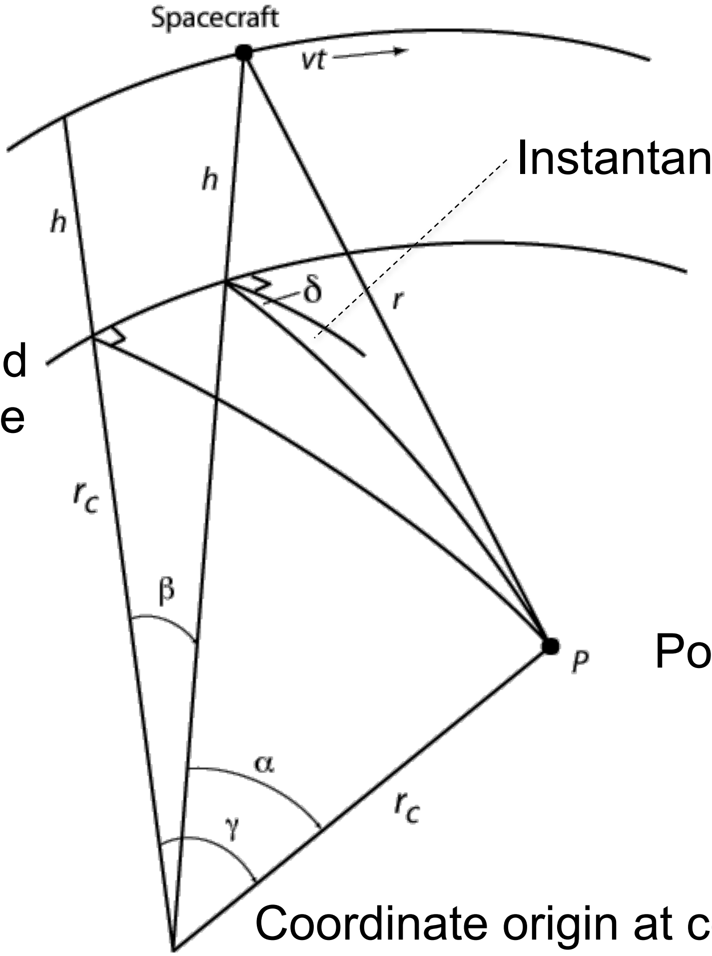
Motion compensation phase and delay

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

Application for InSAR

- Can use motion compensation approach to coregister slcs by processing to single reference track
- Define perfectly spherical reference orbit to processing geometry equations simple
- Avoid coregistration problems

Definitions for orbital geometry



Reference orbit

Instantaneous squint angle

Orbit track projected
on reference sphere

Point to be imaged

Coordinate origin at center of
sphere with local Earth radius
of curvature

Remember range/Doppler basics

Phase and range relations

$$\phi(t) = -\frac{4\pi}{\lambda} r(t)$$

$$2\pi f(t) = -\frac{4\pi}{\lambda} \dot{r}(t)$$

Doppler relations

$$f_D = -\frac{2}{\lambda} \dot{r}$$

$$f_{rate} = -\frac{2}{\lambda} \ddot{r}$$

Focus and position equations in our geometry

$$f_D = -\frac{2}{r\lambda} r_c (h + r_c) \cos\gamma \sin\beta\dot{\beta}$$

$$f_{rate} = \frac{2}{\lambda}\left[\frac{\dot{r}^2}{r} - \dot{r}\frac{\cos\beta}{\sin\beta}\dot{\beta}\right]$$

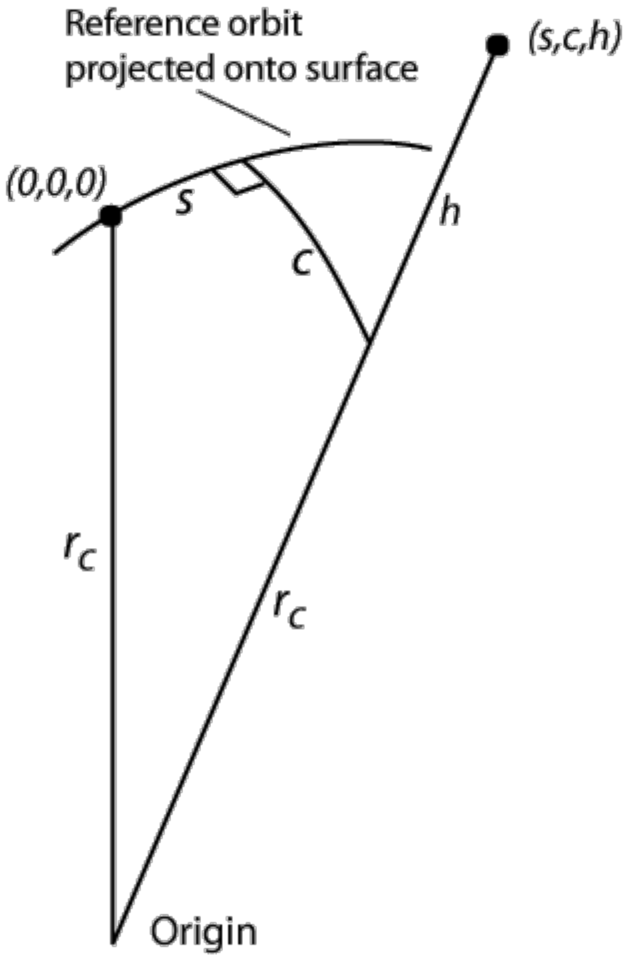
SCH coordinate system

r_c – local radius of curvature, not Earth radius

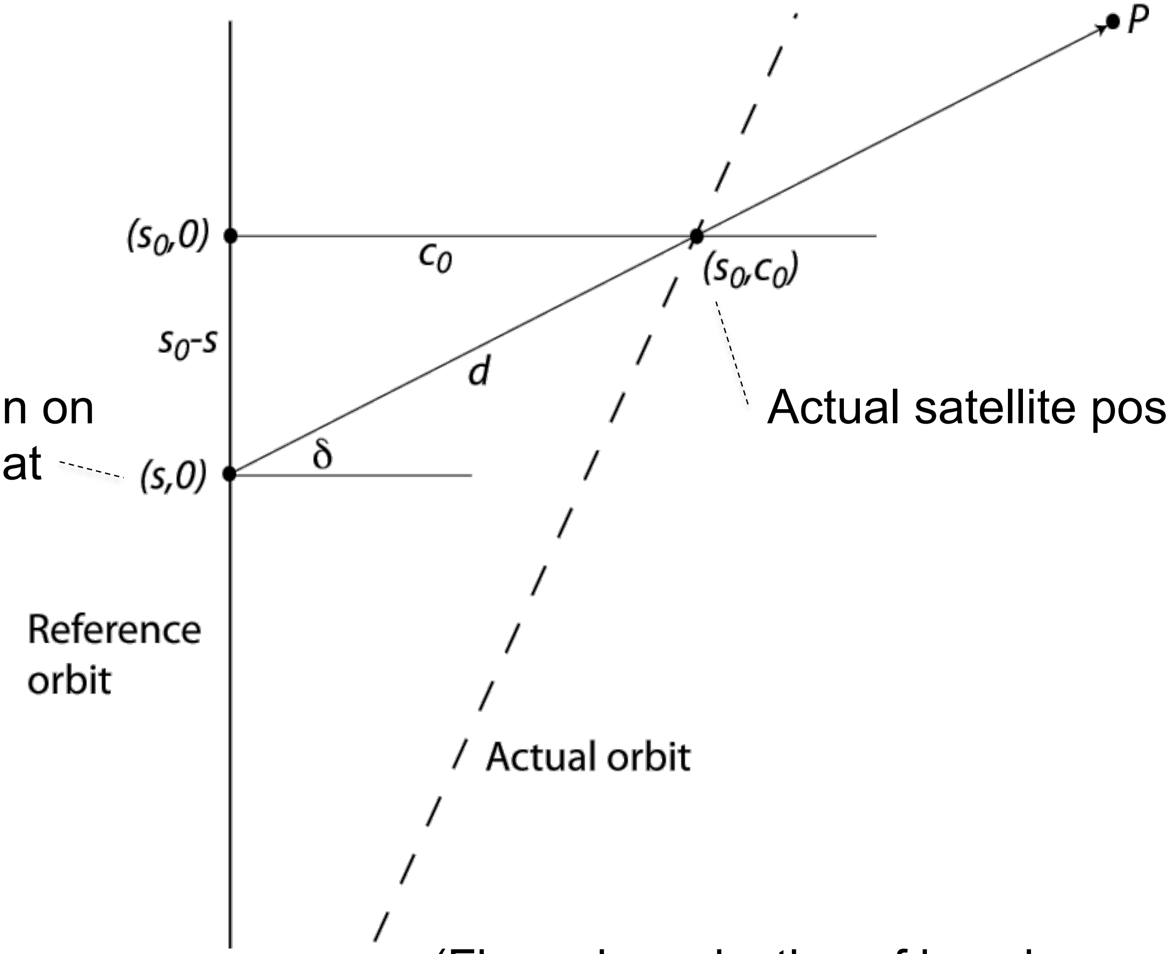
s – along track distance on local sphere from reference point

c – across-track distance on local sphere

h – height above local sphere



Geometry for motion compensation distance and phase



Satellite position on reference orbit at same squint direction

Actual satellite position

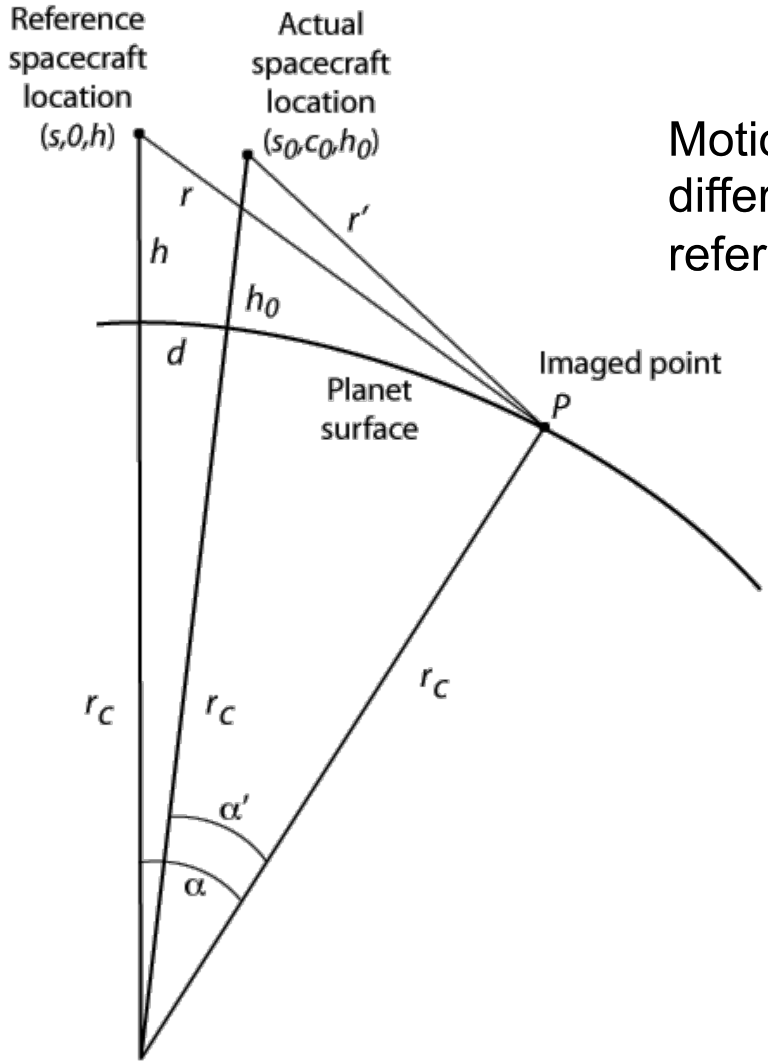
(Figure is projection of imaging geometry onto the reference sphere)

Finding the position on the reference orbit for an actual spacecraft location

$$\sin\delta = \frac{(\cos\gamma - \cos\beta\cos\alpha)}{\sin\beta\sin\alpha}$$

$$s = s_0 - r_c \sin^{-1}\left(\tan\delta\tan\frac{c_0}{r_c}\right)$$

Motion compensation distance calculation



Motion compensation baseline is difference between actual range r’ and reference orbit range r

Motion compensation algorithm

Derivation of reference distance r:

$$\cos\frac{d}{r_c} = \cos\frac{s_0 - s}{r_c}\cos\frac{c_0}{r_c}$$

$$\cos\alpha = \cos\alpha'\cos\frac{d}{r_c} - \sin\alpha'\sin\frac{d}{r_c}$$

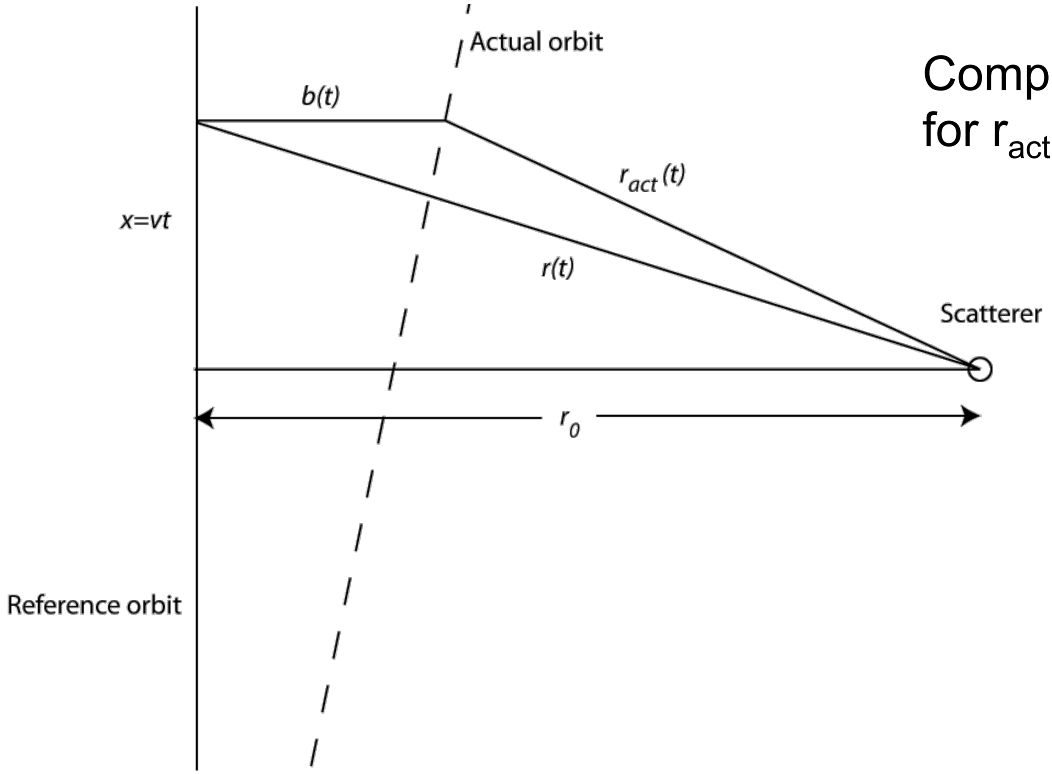
$$r = \sqrt{\left(r_c + h\right)^2 + r_c{}^2 - 2\left(r_c + h\right)r_c\cos\alpha}$$

Mocomp distance and phase corrections:

$$b = r'(r) - r$$

$$\phi_{baseline} = \frac{4\pi}{\lambda}\left(r'(r) - r\right)$$

Phase history for mocomped scatterer



Compare phase histories for $r_{act}(t)$ and $r(t)$

Focus corrections

Quadratic phase correction from processing at wrong distance:

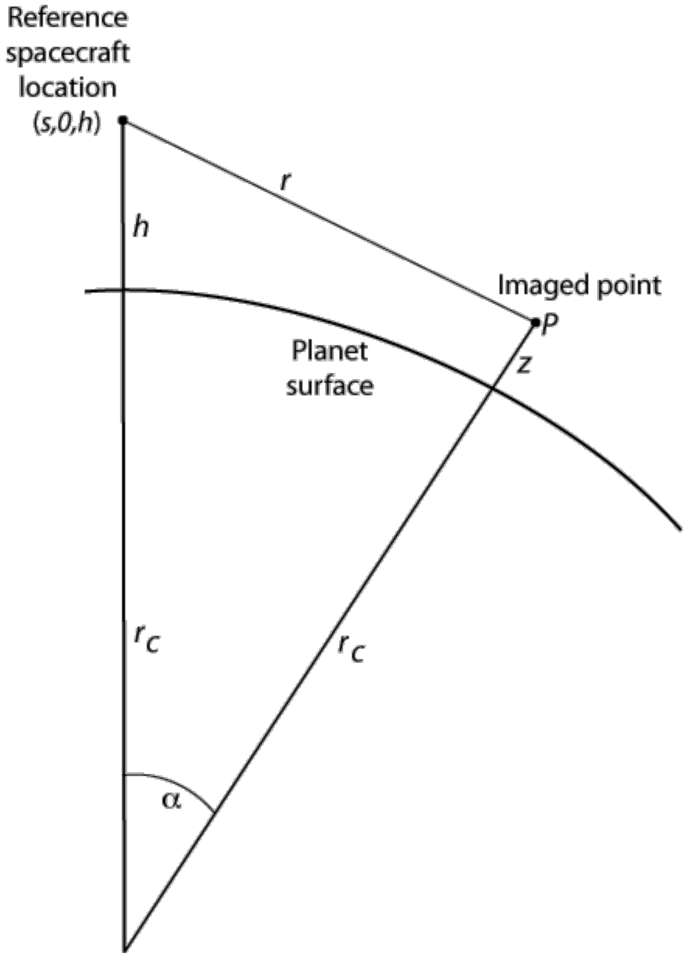
$$r_{mocomp}(t) = r_0 + \frac{1}{2}\frac{v^2 t^2}{r_0}(1 + \frac{b(t)}{r_0})$$

Frequency domain phase term from range-varying motion compensation phase:

$$\phi_{correction} = r_{migration} \cdot \frac{\partial}{\partial r}\left(\frac{4\pi}{\lambda}(r'(r) - r)\right)\Bigg|_{r=r_0}$$

$$= \frac{\pi}{f_{rate}} \cdot f^2 \cdot \frac{\partial}{\partial r}\left(\frac{4\pi}{\lambda}(r'(r) - r)\right)\Bigg|_{r = r_0}$$

Topographic correction

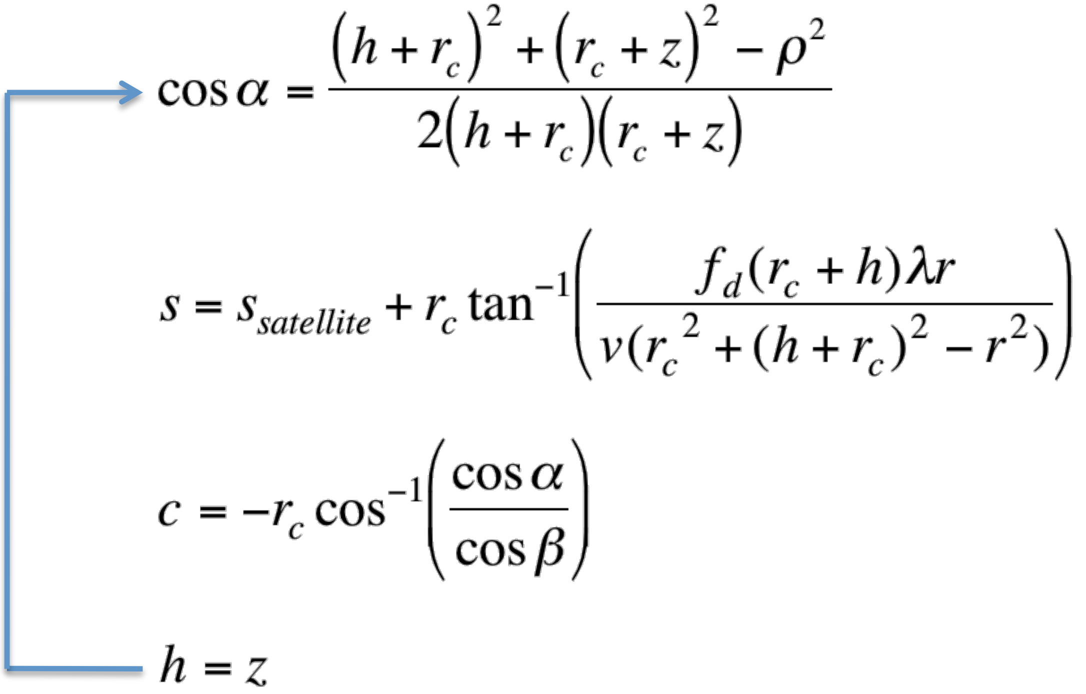


- Processor computes SLCs assuming perfectly spherical Earth

- No easy closed form solution for position so use iterative method to find pixel location in 3-space

- Apply phase correction based on pixel elevation

Iterative topography correction



$$\cos\alpha = \frac{(h + r_c)^2 + (r_c + z)^2 - \rho^2}{2(h + r_c)(r_c + z)}$$

$$s = s_{satellite} + r_c \tan^{-1}\left(\frac{f_d(r_c + h)\lambda r}{v(r_c{}^2 + (h + r_c)^2 - r^2)}\right)$$

$$c = -r_c \cos^{-1}\left(\frac{\cos\alpha}{\cos\beta}\right)$$

$$h = z$$

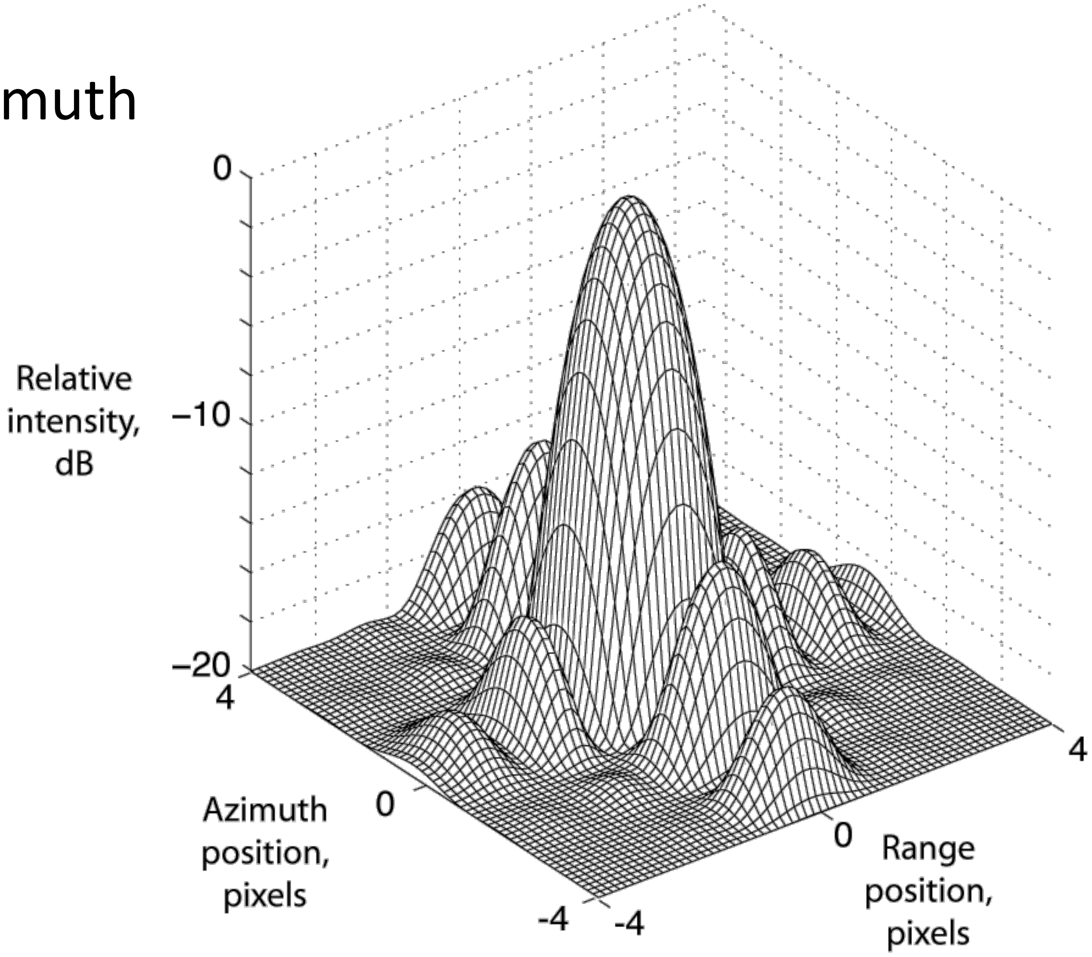
Topographic phase correction:

$$\phi_{elevation} = \frac{4\pi}{\lambda}\left(u_{line-of-sight}^{elevation} - u_{line-of-sight}^{zero\ height}\right) \bullet \mathbf{b}(t)$$

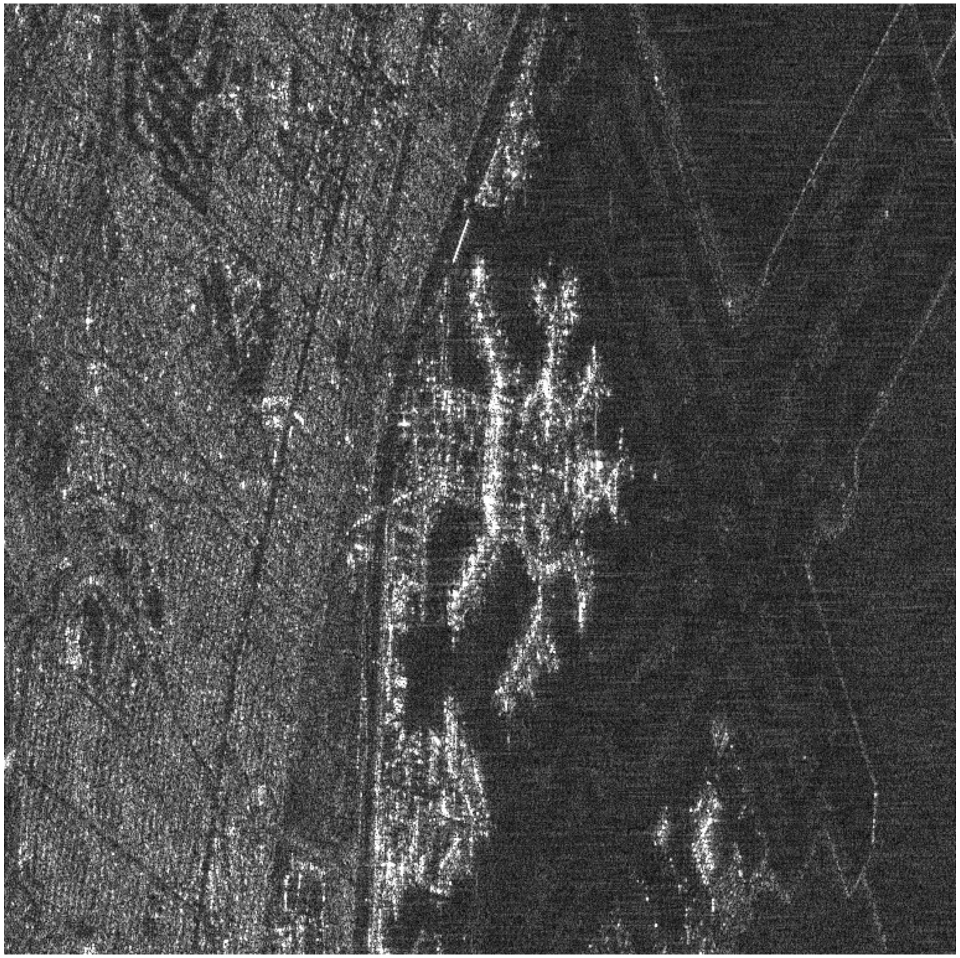
Impulse response

Impulse resolution:
5.3 m range, 4.0 m azimuth

Figure for mocomp baseline of 1500 m (InSAR baseline 3km)



Single look complex image of SFO



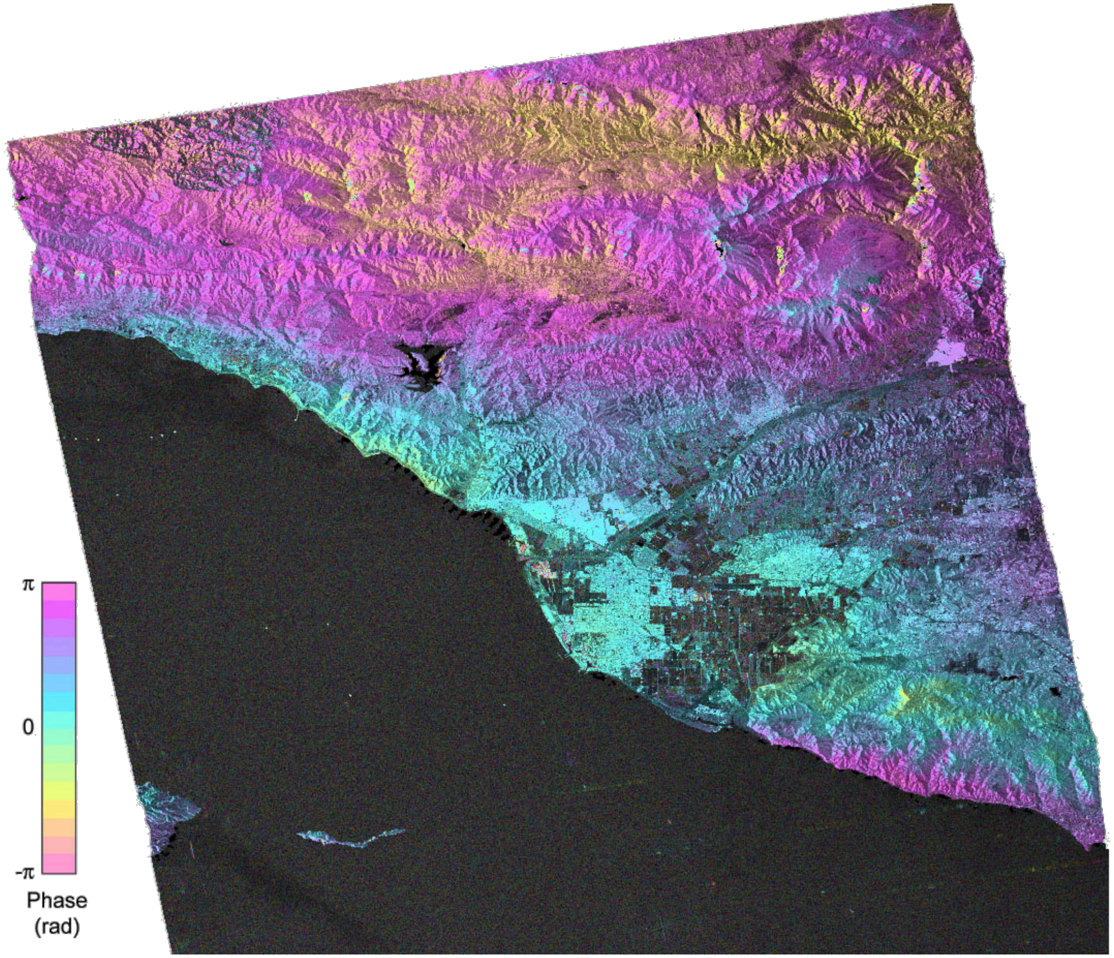
Geodetic accuracy – Pinon Flat Corner Reflector Locations

Measurement	Latitude (deg)	Longitude (deg)	Latitude error (m)	Longitude error (m)
Reflector aligned with ascending orbit				
InSAR location, unregistered image	33.61233	-116.4570	9	-18
InSAR location, registered image	33.61215	-116.4567	-11	9
Ground GPS survey	33.61225	-116.4568	--	--
Reflectors aligned with descending orbit				
InSAR location, unregistered image	33.61215	-116.4579	-11	0
InSAR location, registered image	33.61213	-116.4577	-13	18
Ground GPS Survey	33.61225	-116.4579	--	--
InSAR location, unregistered image	33.60729	-116.4517	-9	9
InSAR location, registered image	33.60727	-116.4516	-11	18
Ground GPS survey	33.60737	-116.4518	--	--

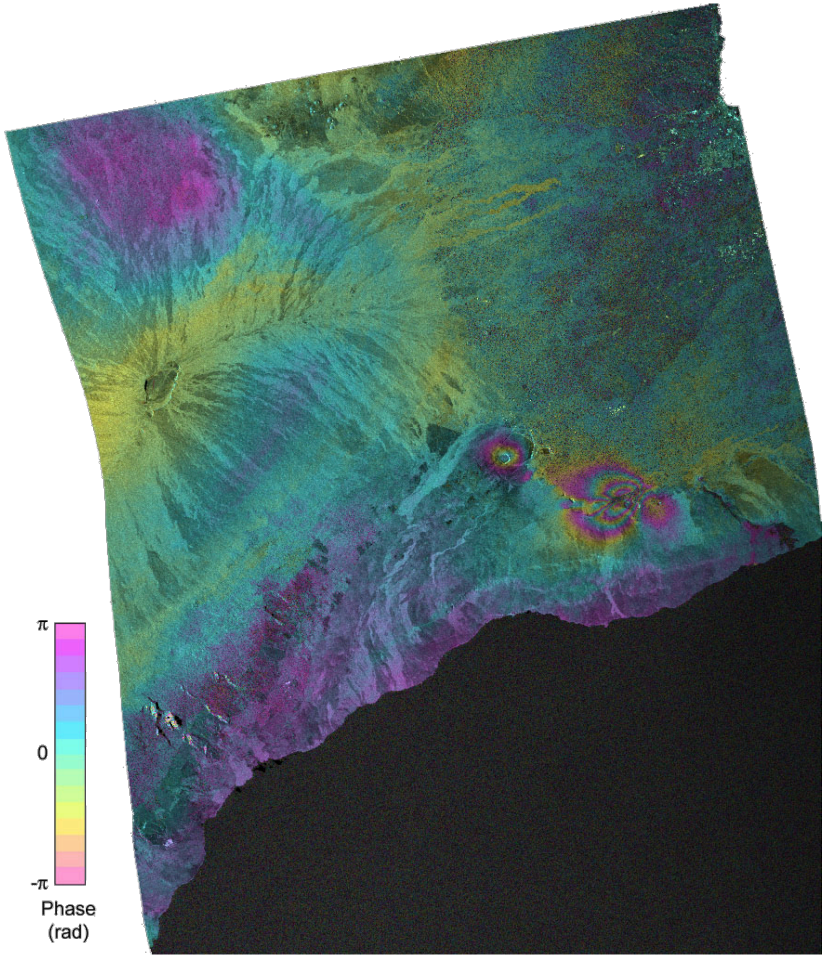
Geodetic accuracy – Image offsets from SRTM DEM

	Range offset	Azimuth offset	Additional stretch	
Scene	at center (m)	at center (m)	Range (m)	Azimuth (m)
Ventura	-15.8	18.2	9.4	15.2
Hawaii	-21.5	24.0	14.1	25.4
Iceland	2.0	2.9	44.0	29.4

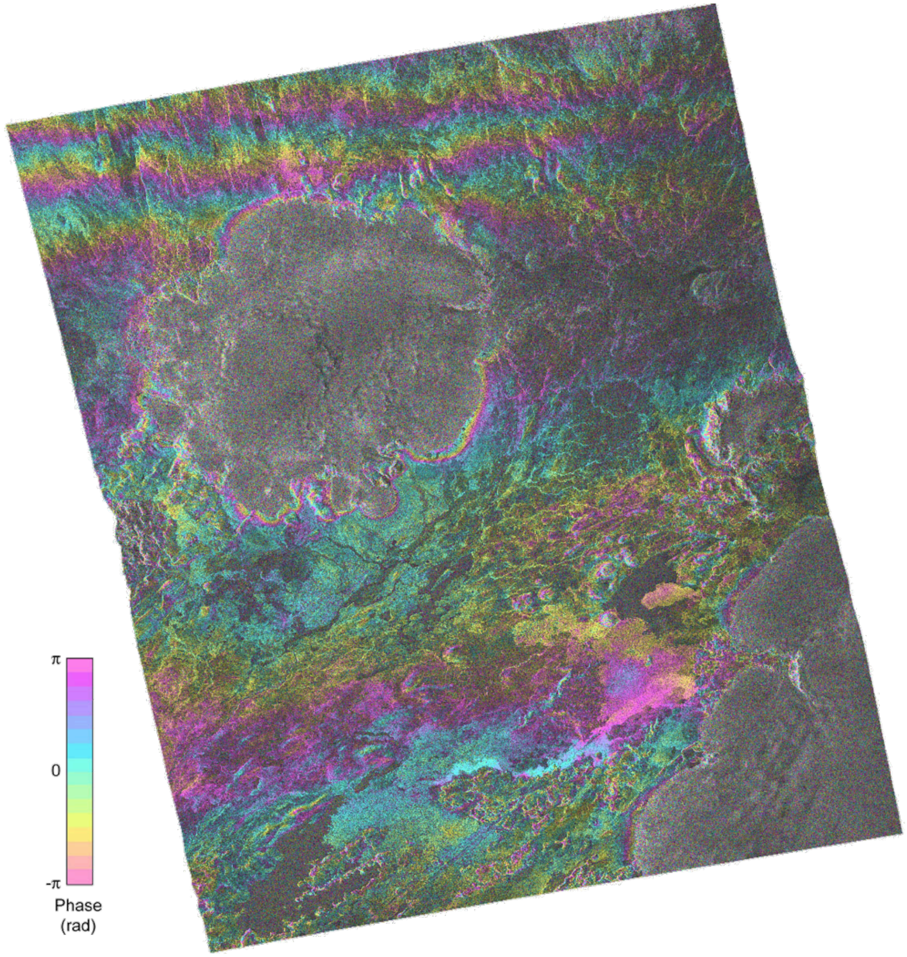
Ventura, CA – Atmospheric phases



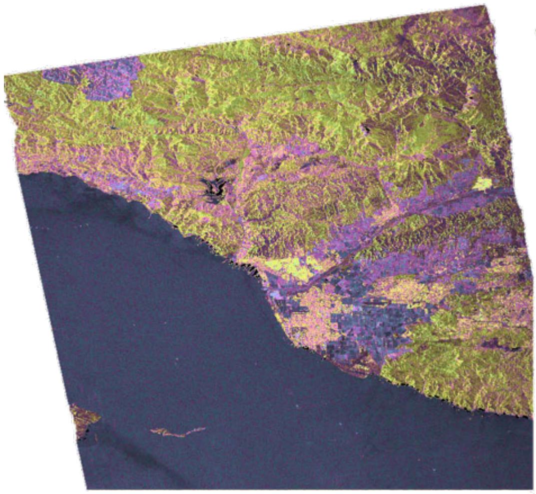
Hawaii – deformation plus atmosphere



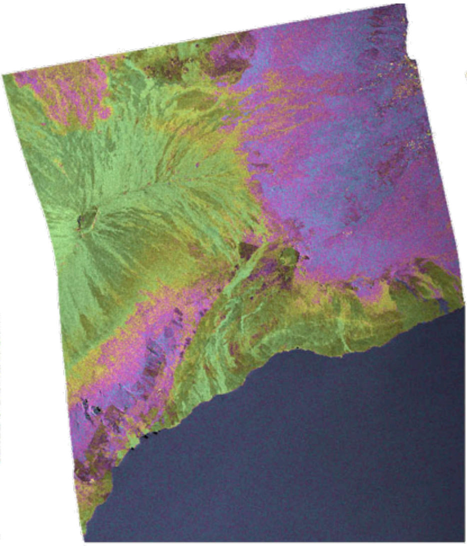
Iceland – significant ionospheric artifact



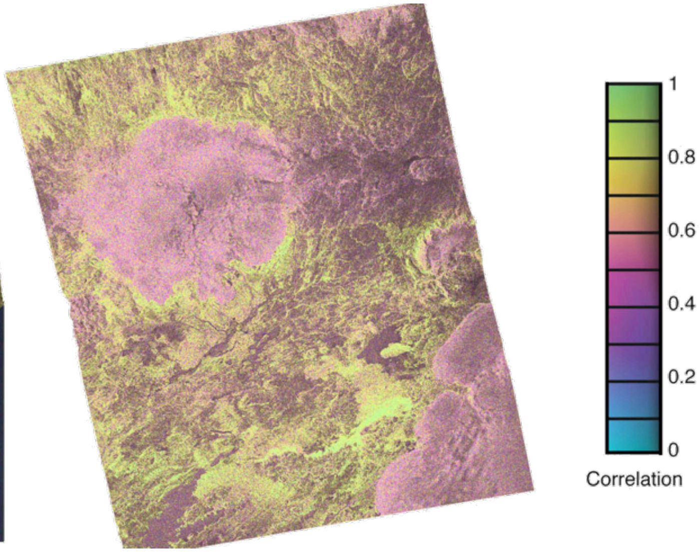
Correlation images



Ventura



Hawaii



Iceland