Pi-SARの繰り返し干渉によるDEM作成

Repeat pass SAR interferometry of the Pi-SAR (L) for DEM generation

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Introduction and Objectives

L-band SAR is characterized by higher signal penetration, and the repeat-pass SAR interferometry can be achieved.

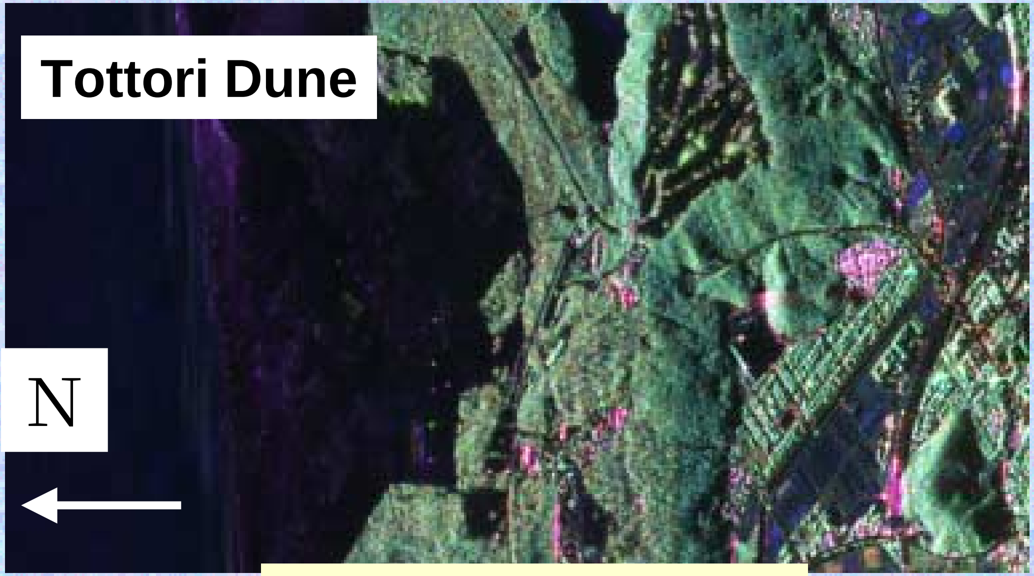
High band width of Pi-SAR L band (50 MHz) achieves higher resolution imaging and the repeat pass interferometric flights (Critical B_{perp} is 400m and B_{perp} <= 100m for higher coherence).

As the preparation study of surface deformation monitoring using the airborne SAR, we conducted the Pi-SAR repeat pass Interferometric flights and InSAR processing.

We derived an InSAR DEM, and discussed the accuracy and related problems for the future objectives.

Pi-SAR

Frequency		1.275e9 Hz
Band width		50 MHz
Sampling freq.		61.275MHz
Height		6~12Km
Image swath		<=15Km
AD(I/Q)		8 bits
ρ (R)	slant	2.4 m
ρ (A)	4look	3.2 m
σ^0		1.1 dB
NEσ0		-30 dB
Inci. Angle		10~60
Polarimetry		Full
τ		10μs
Pt		3.5KW
Beam width(A)		8.4 degrees



SIGMA-SAR processor

R:HH,G:HV,B:VV

Inertial Navigation System

WGS84: Reference Earth

Interface ARINC 429

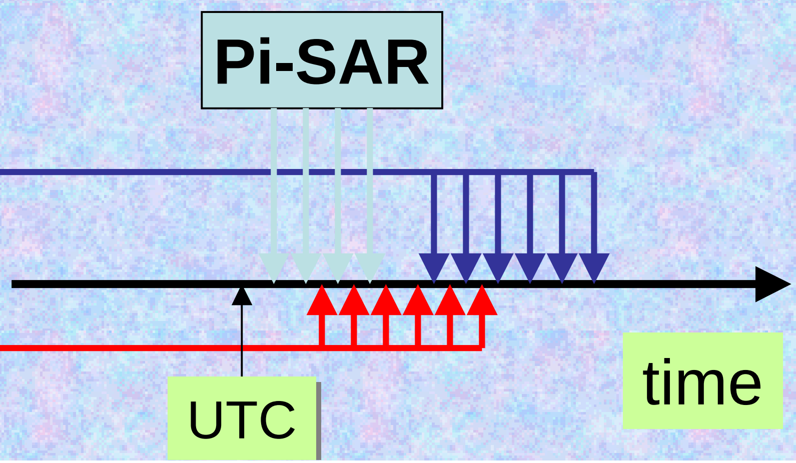
LITTON AERO PRODUCTS, LTN-2001 Mk.1 made year 1989

GPS	
Lat	1 sec.
Lon	1 sec.
Height	1 sec.
V in EW	1 sec.
V in NS	1 sec.
V in H	1 sec.

Problems

- **Ancillary Data not Synchronized with Pi-SAR**
- **Position Accuracy (GPS)**

INS	
Body Pitch Rate	64 Hz
Body Yaw Rate	64 Hz
Body Roll Rate	64 Hz
Body Long. ACCEL	64 Hz
Body Lateral ACCEL	64 Hz
Body Normal ACCEL	64 Hz



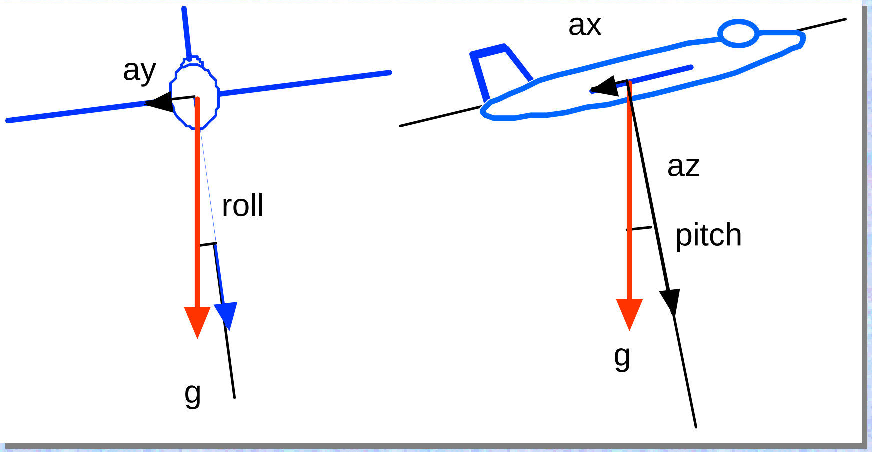
Motion Equation of G-II (I)

$$\mathbf{A}_2(t) = \mathbf{M}_2^{-1}(\mathbf{A}_m - \mathbf{N}\cdot\mathbf{M}_0\cdot\mathbf{g}_0 + \boxed{\mathbf{a}}) + \omega \times \mathbf{v}_{ECR}$$

$$\mathbf{M}_2^{-1} = \mathbf{M}_\lambda^{-1}\cdot\mathbf{M}_\varphi^{-1}\cdot\mathbf{M}_\chi^{-1}\cdot\mathbf{M}_r^{-1}\cdot\mathbf{M}_p^{-1}\cdot\mathbf{M}_y^{-1}$$

$$\bar{\mathbf{v}}(t) = \int_0^t A_2(t')dt' + \mathbf{v}_0 + \boxed{\mathbf{b}}$$

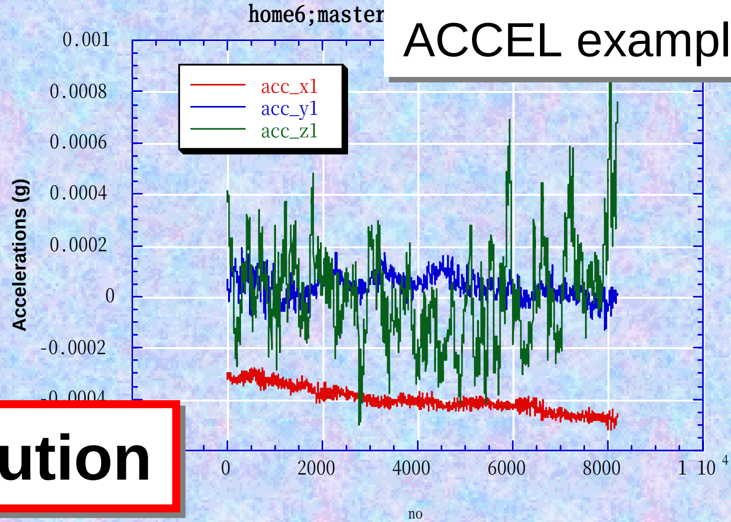
$$\bar{r}(t) = \int_0^t \bar{v}(t')dt' + r_0 + \boxed{\mathbf{c}}$$



M_k:rotation matrix on Euler angle

ACCEL offsets **a and leakage of the gravity**

Unknowns:
a (acceleration offset),
b (Initial velocity error),
c (initial position error)

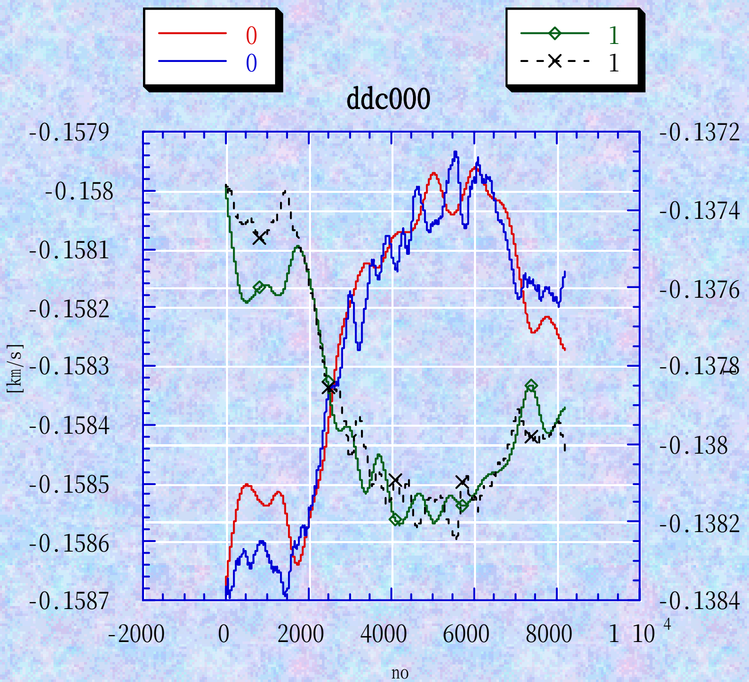


Least Squared minimization -> Solution

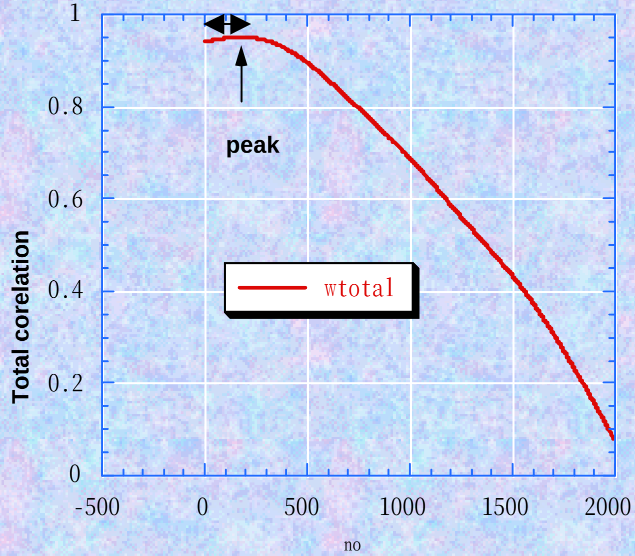
Motion Equation of G-II (II)

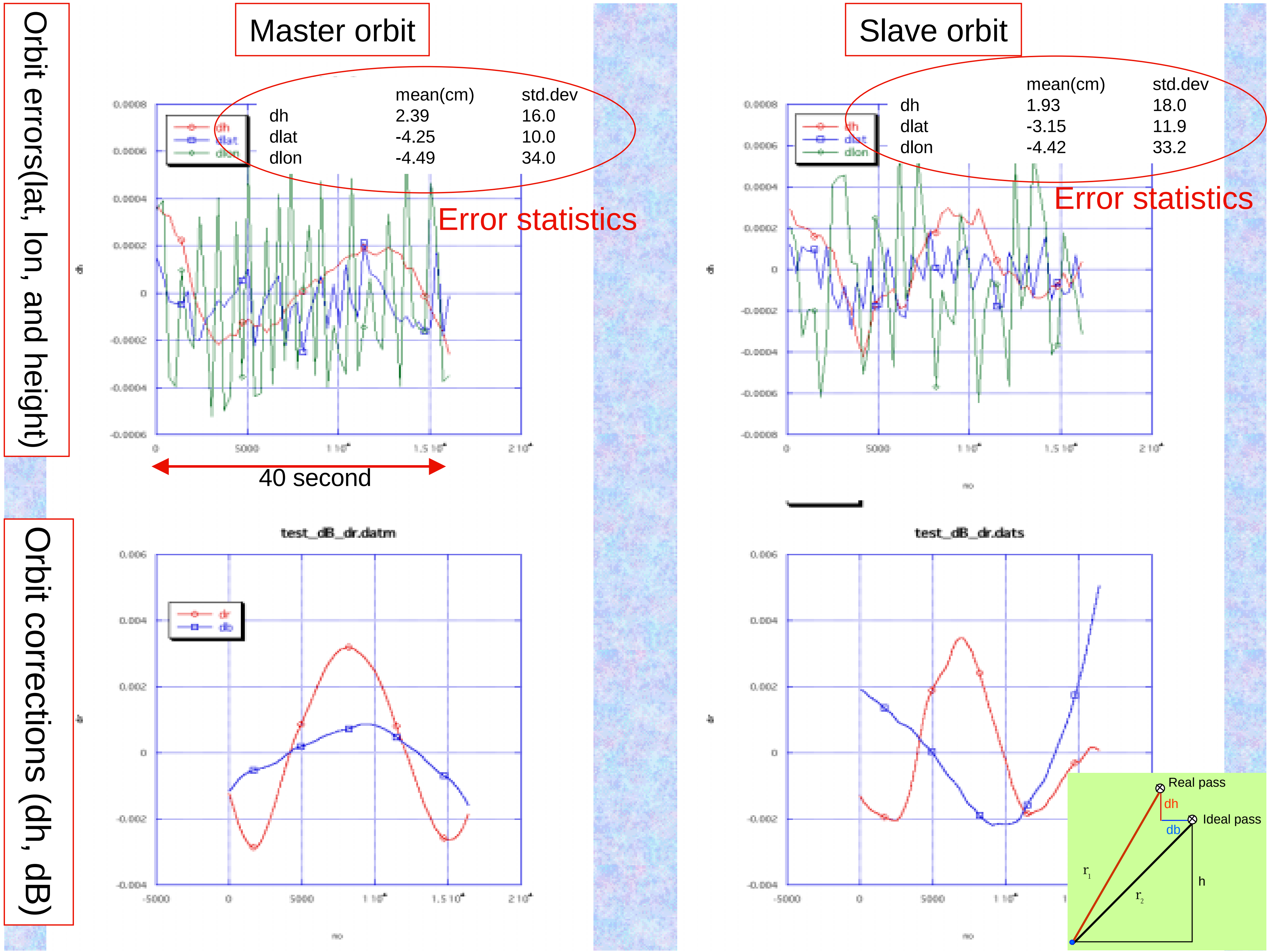
1) **Shift of the time: < 1sec**
2) **Parameter estimation**
3) **Re-generate the track**
4) **Calculate the horizontal and vertical shift (dh and db)**
5) **Interpolation and phase shift before range correlation**
6) **Azimuth Correlation**

time offset	GPS	: 20 ms
	accel. attitude	: 6 ms



Time offset





Orbit errors(lat, lon, and height)
Orbit corrections (dh, dB)
Master orbit
mean(cm) std.dev
dh 2.39 16.0
dlat -4.25 10.0
dlon -4.49 34.0
Error statistics
40 second
test_dB_dr.datm
Slave orbit
mean(cm) std.dev
dh 1.93 18.0
dlat -3.15 11.9
dlon -4.42 33.2
Error statistics
test_dB_dr.dats
Real pass
Ideal pass
dh
db
h

Interferometry(I)

Wrapped phase of master and slave images, ϕ, is expressed by

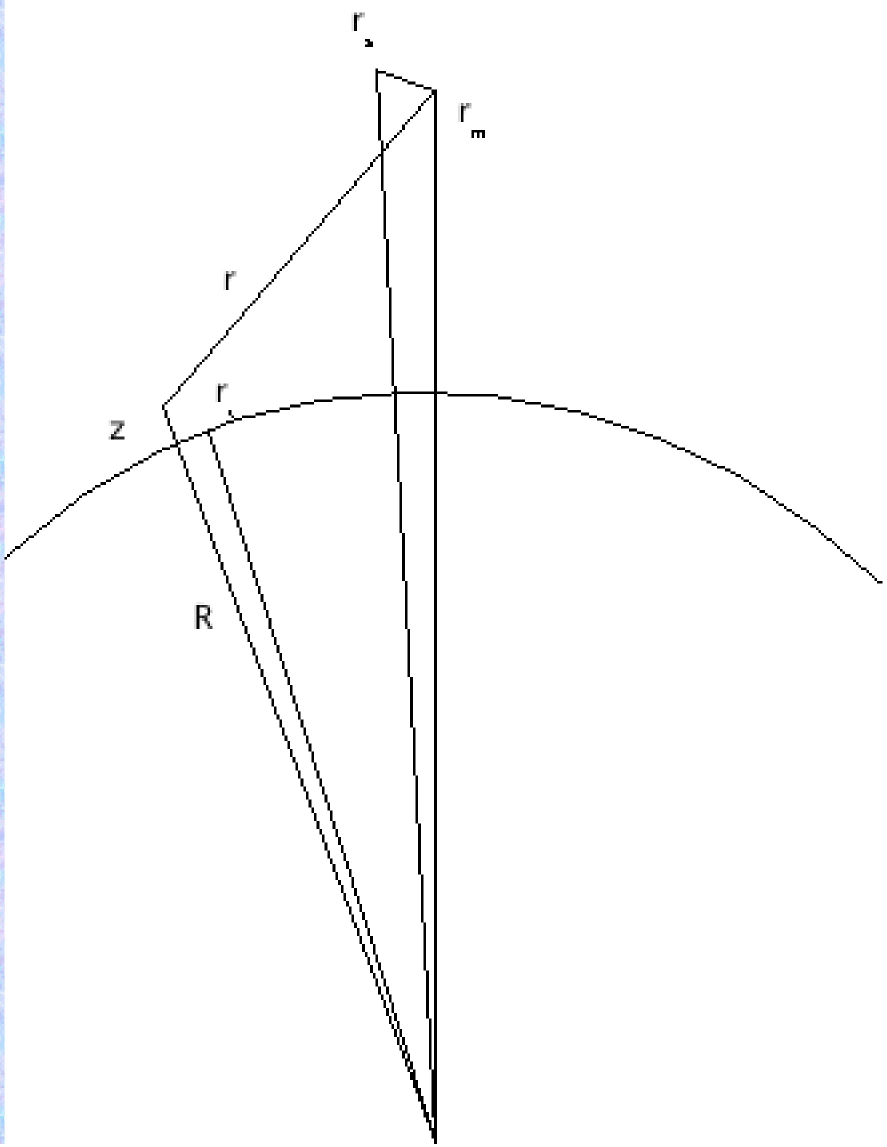
$$\phi = \frac{2\pi}{\lambda} r \left(1 - \sqrt{1 + \frac{2\mathbf{b} \cdot (\mathbf{r}_t - \mathbf{r}_m)}{r} + \frac{|\mathbf{b}|^2}{r^2}} \right)$$

$$\mathbf{b} = \mathbf{r}_m - \mathbf{r}_s$$

$$z = |\mathbf{r}_t| - R(\mathbf{r}_t)$$

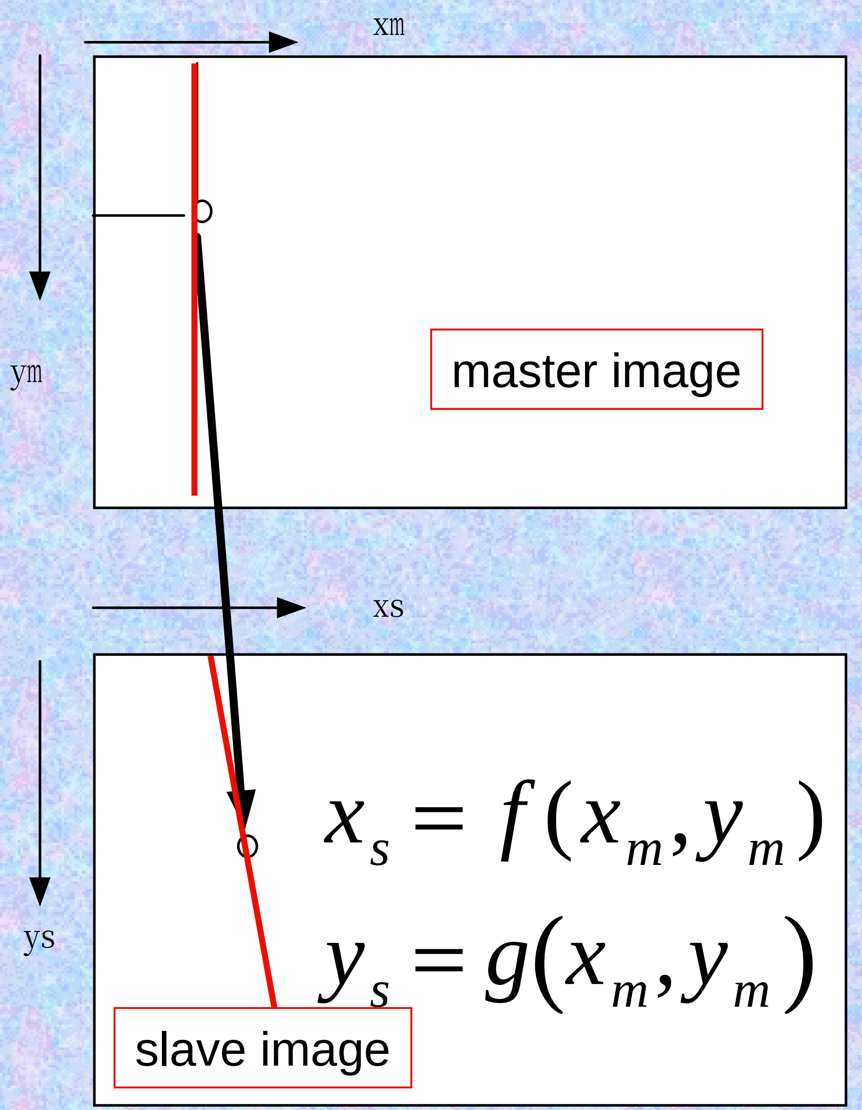
where

r	slant range,
r_t	target vector
r_m	master orbit,
r_s	slave orbit,
z	height,
R	radius of the earth



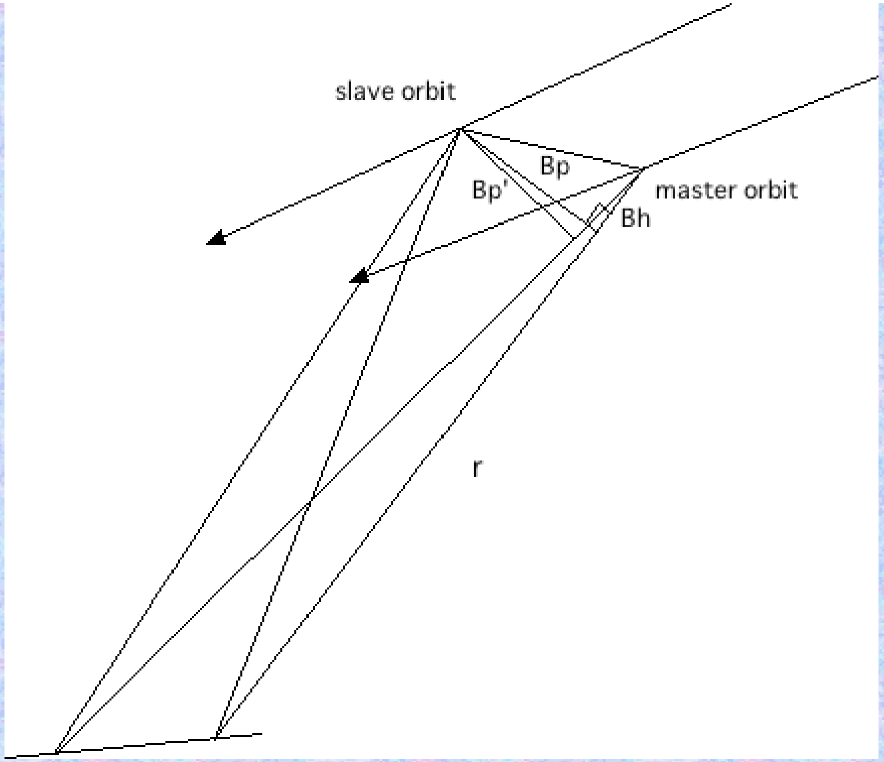
Interferometry(II)

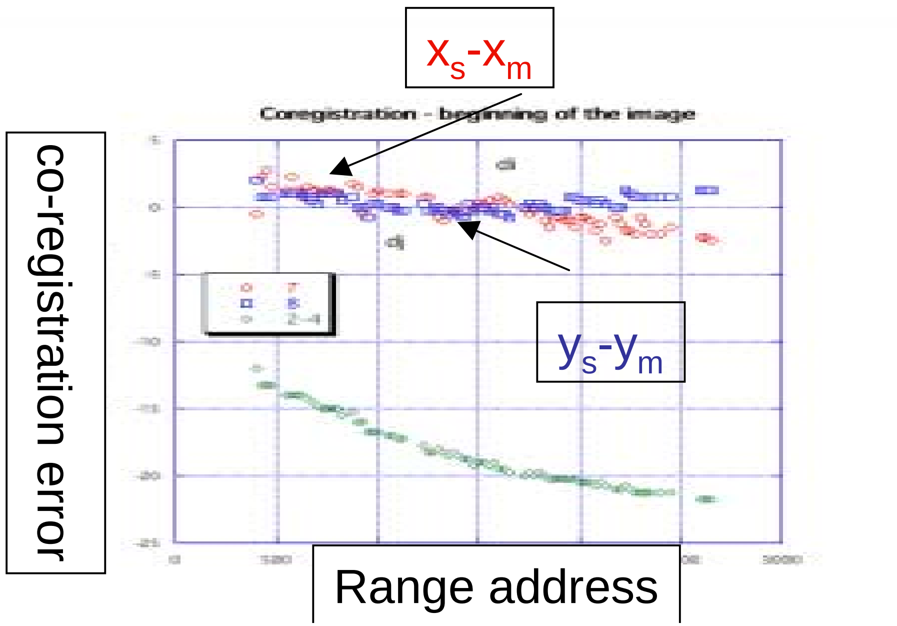
Co-registration of two images



$$x_s = f(x_m, y_m)$$

$$y_s = g(x_m, y_m)$$



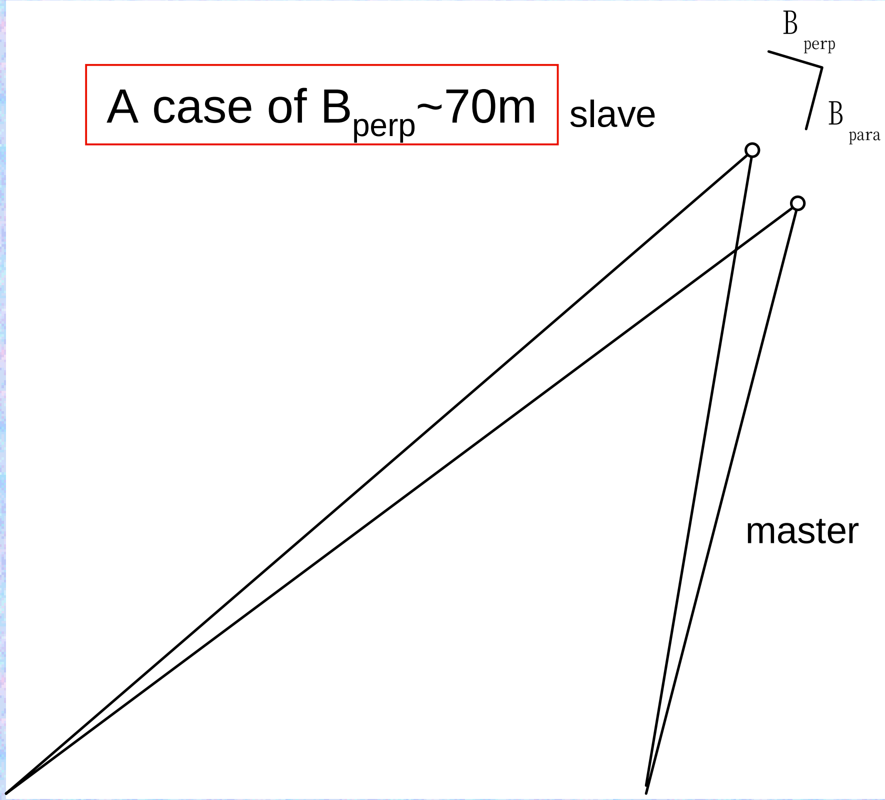


Test area	**:**	**Tottori City area, including Tottori dune, river, hill side**
Topography	**:**	**0 m ~ 200m**
Observation	**:**	**Oct. 6 2000**
Flight direction	**:**	**East -> west**
Height	**:**	**8000 m**
Purpose	**:**	**Polarimetric calibration** **Interferometric evaluation**
Averaged B_{perp}	**:**	**~70 meter**

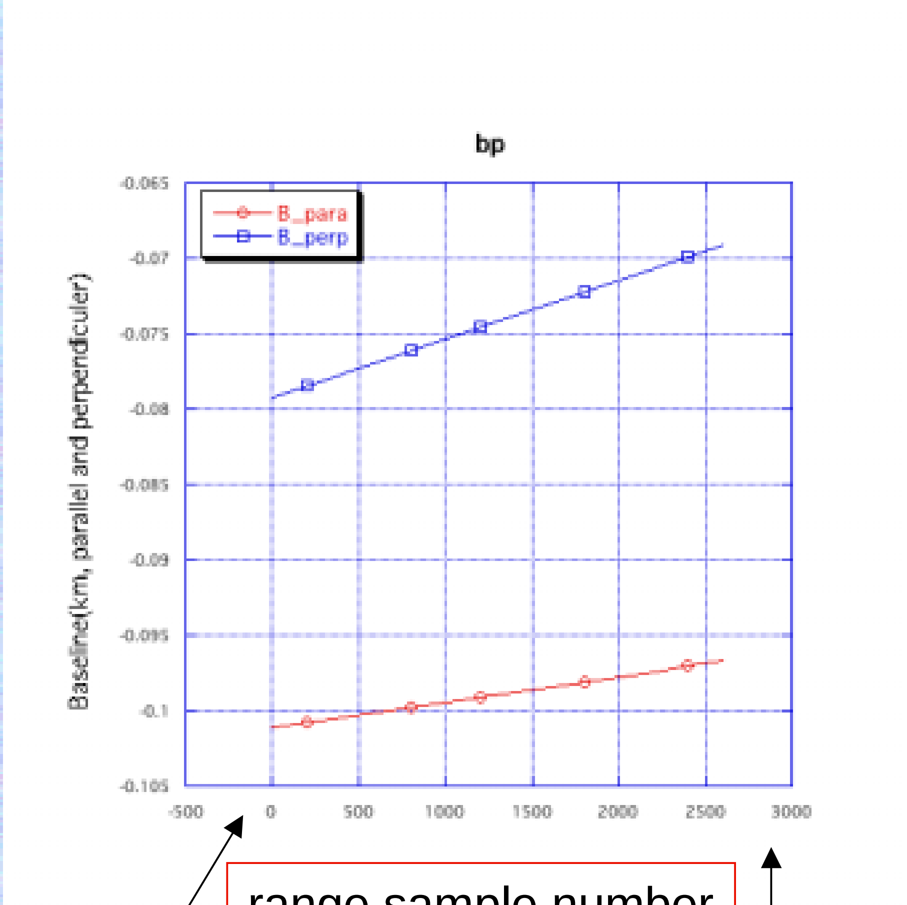
Interferometry(III)

Baseline analysis

Baselines(B_{perp} and B_{para}) dramatically change with incidence angle when tube diameter is too small.



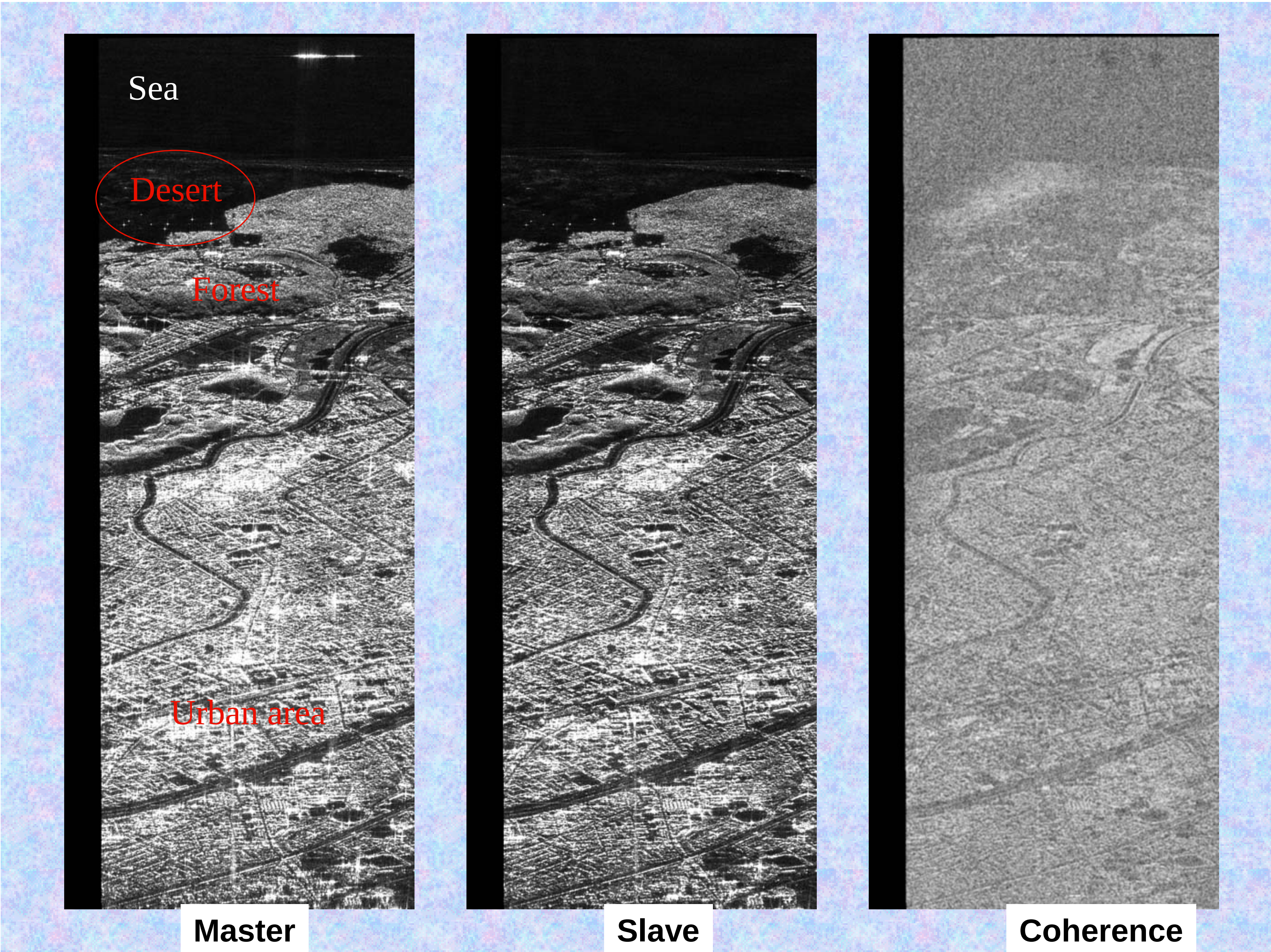
Ground range



range sample number

20 degrees of incidence angle

50 degrees


Sea
Desert
Forest
Urban area
Master
Slave
Coherence

Orbit correction

•Flat earth corrected fringe contains undesirable fringe due to the orbital error.

•Unwrap the raw fringe and harmonize the theoretical unwrapped model which contains three unknowns, horizontal disp.(ΔB), vertical disp.(Δr), and vertical velocity disp.(Δv) after the least square parameterization.

•Ground truth data are obtained from the Digital Elevation Model of GSI (Geophysical survey of institute) and geoids height by comparing the simulated SAR image using DEM and the SAR amplitude image.

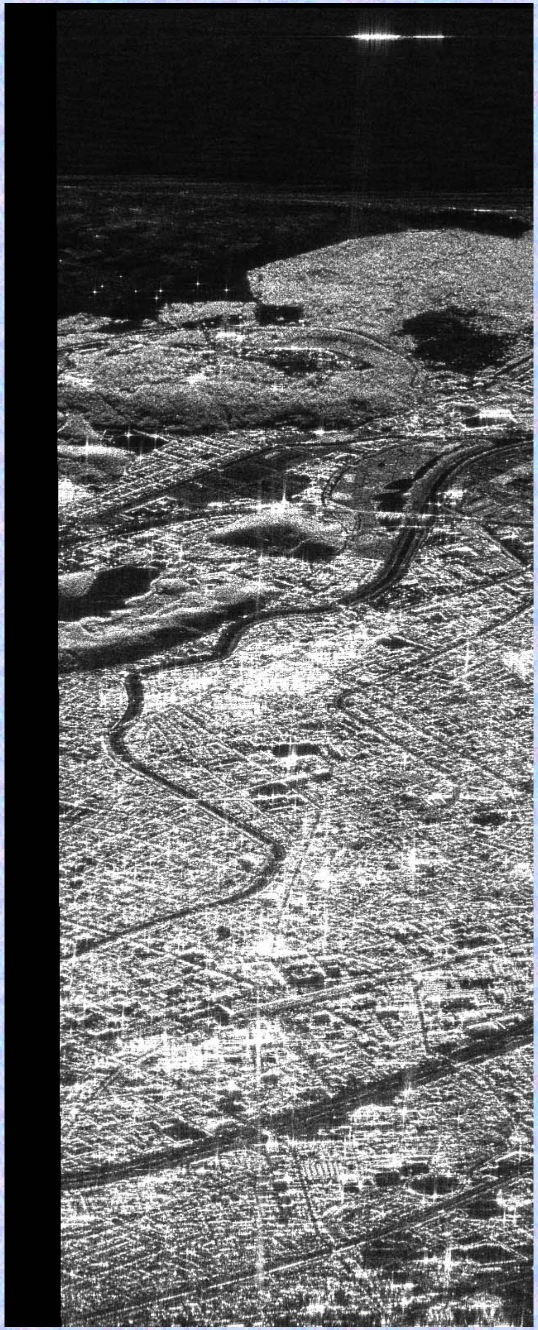
•Finally retune the fringe data.

Least square minimization ⇒

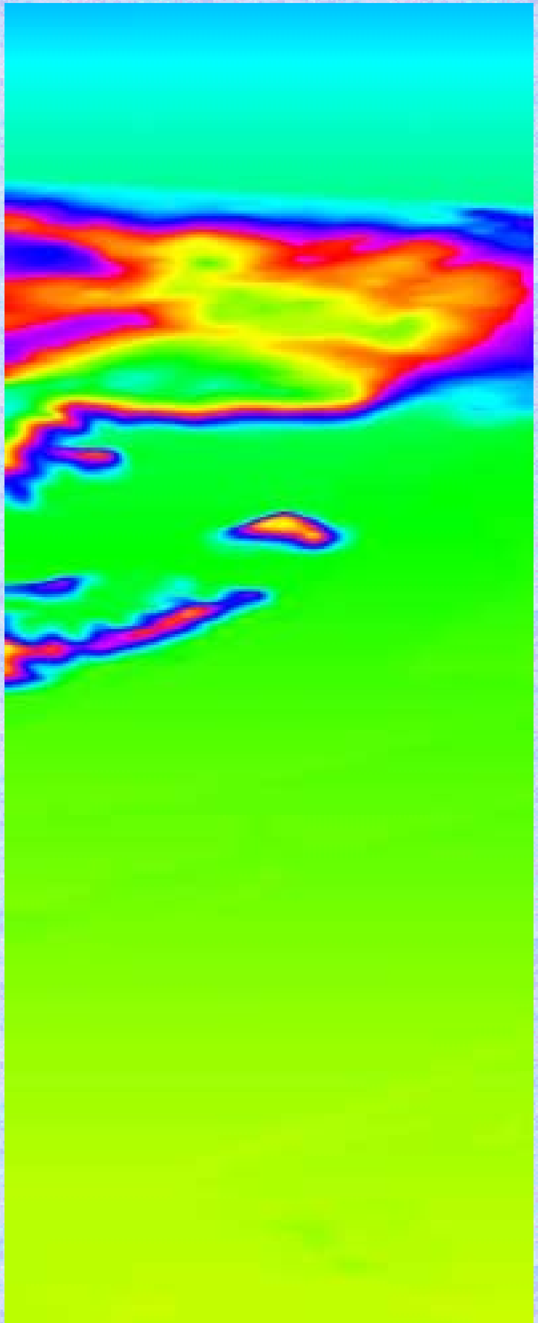
$$\mathbf{r} = \left(\mathbf{r}_0 + \mathbf{v}_0 t + \frac{1}{2}\mathbf{a}_0 t^2 \right) + (\Delta\mathbf{B} + \Delta\mathbf{r}) + (\Delta\mathbf{v})t$$

Processing flow

1) generate single look complex using the band width tuning
2) co-register two images using predefined GCPs
3) Generate the co-registration frame
4) Generate the raw fringe and simulated images for master/slave images
5) Calibrate the orbit error using the simulated and the SAR images
6) Unwrap the first step flat earth corrected fringe and estimate the orbital errors using the least squared error minimization
7) Regenerate the final wrapped fringe using the regenerated orbital information using the co-registration frame
8) Unwrap the above fringes and calibrate it using the GCP
9) Convert the slant range DEM to the ground range DEM.

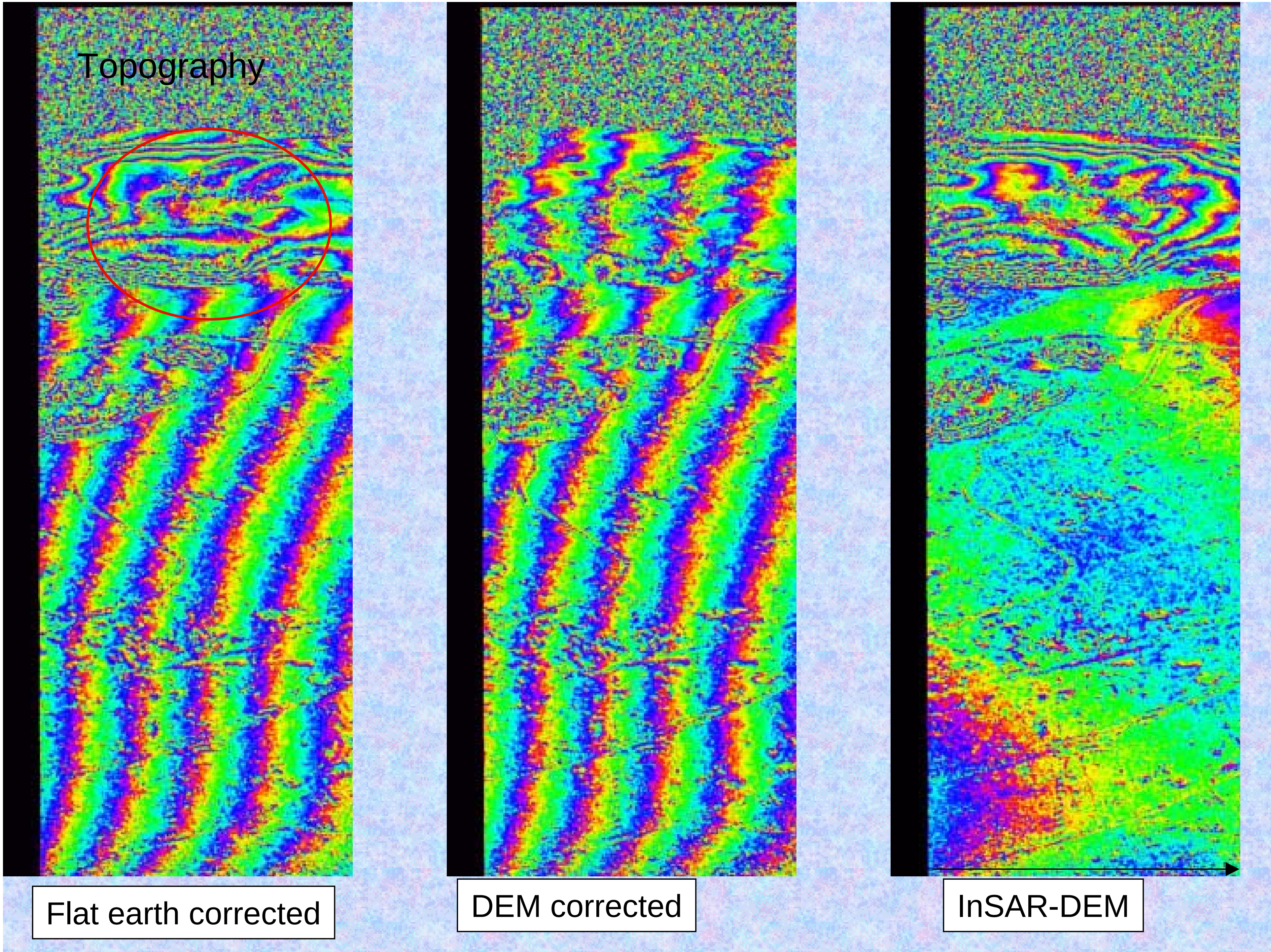


Amplitude image



True height

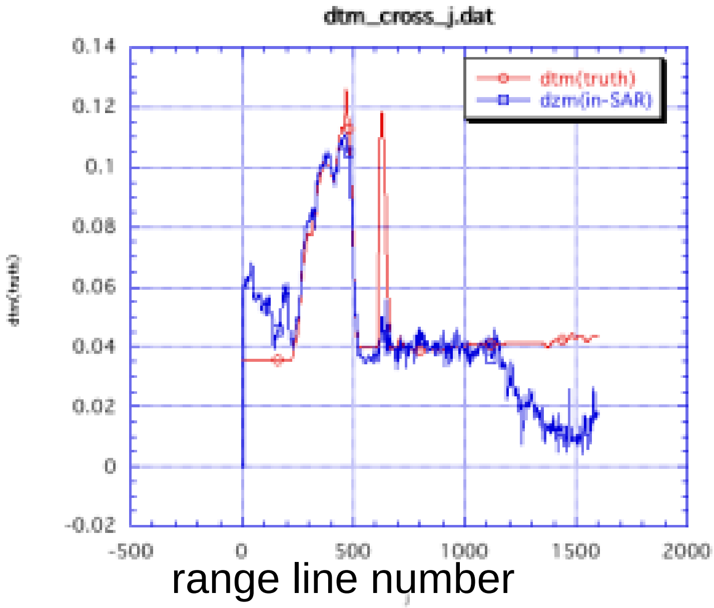
Simulated image

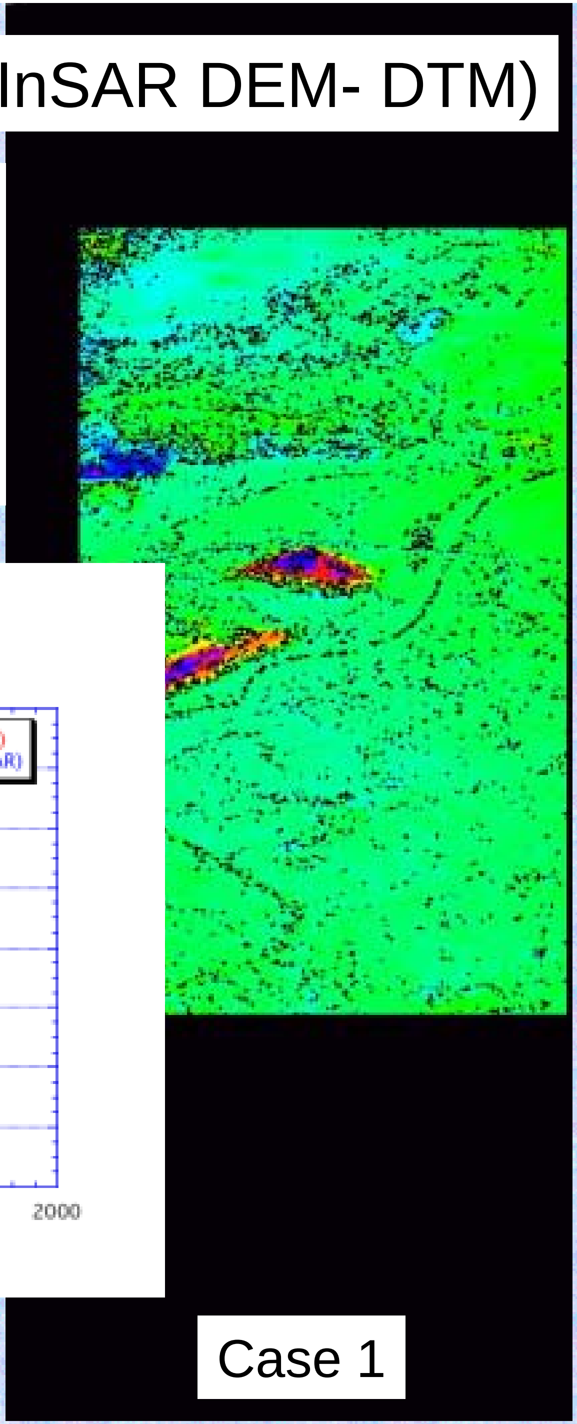

Topography
Flat earth corrected
DEM corrected
InSAR-DEM

Error analysis(Error =InSAR DEM- DTM)

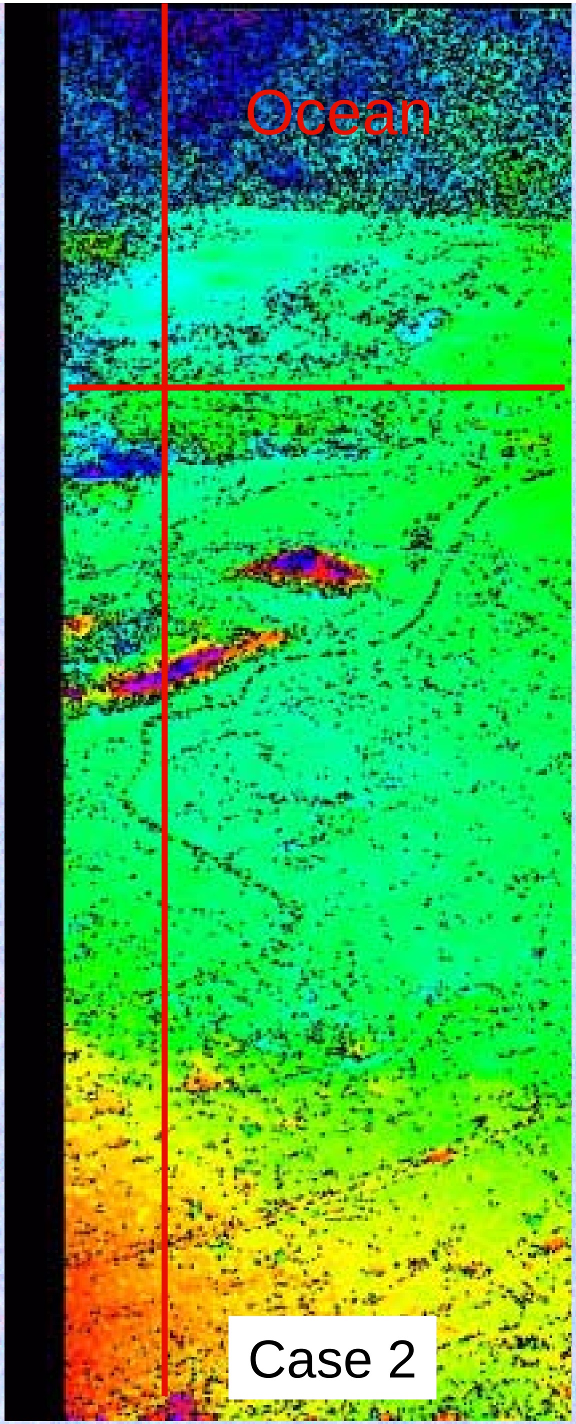
Case1: Mean:2.7m
Std dev.:7.4m

Case2: Mean:8m
Std. Dev.:15m



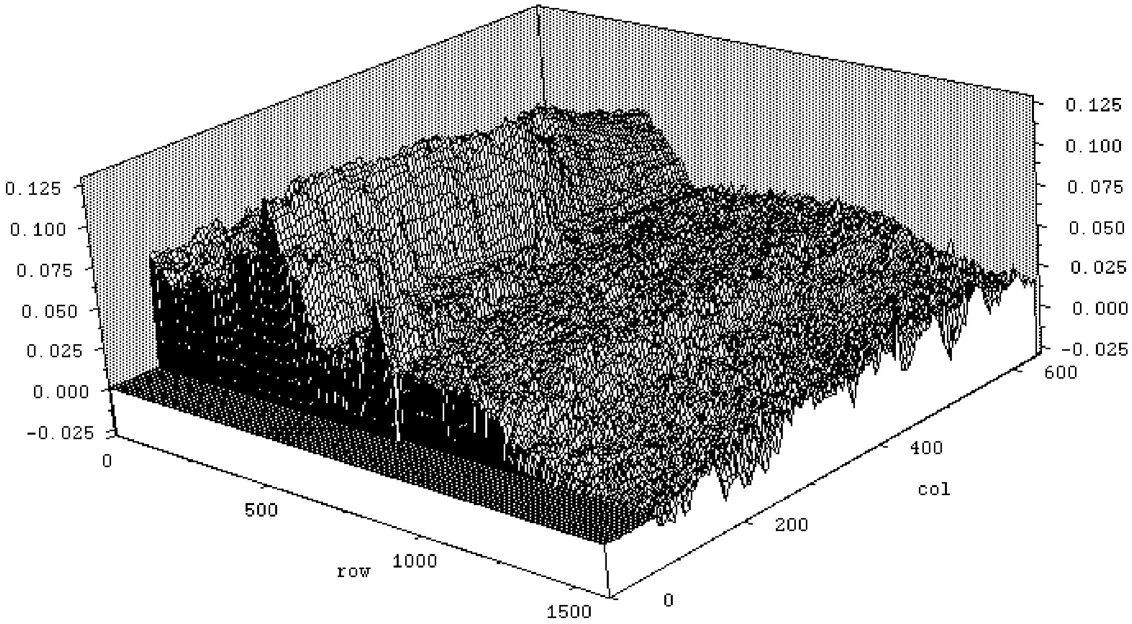


Case 1

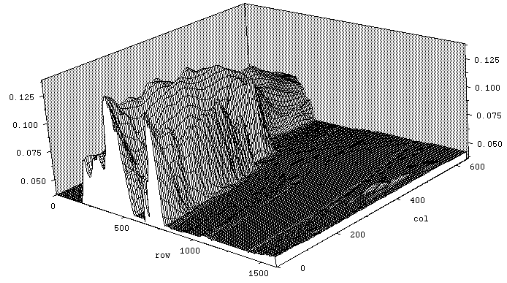


Case 2

Three dimensional expression of the generated DEM (small area case)

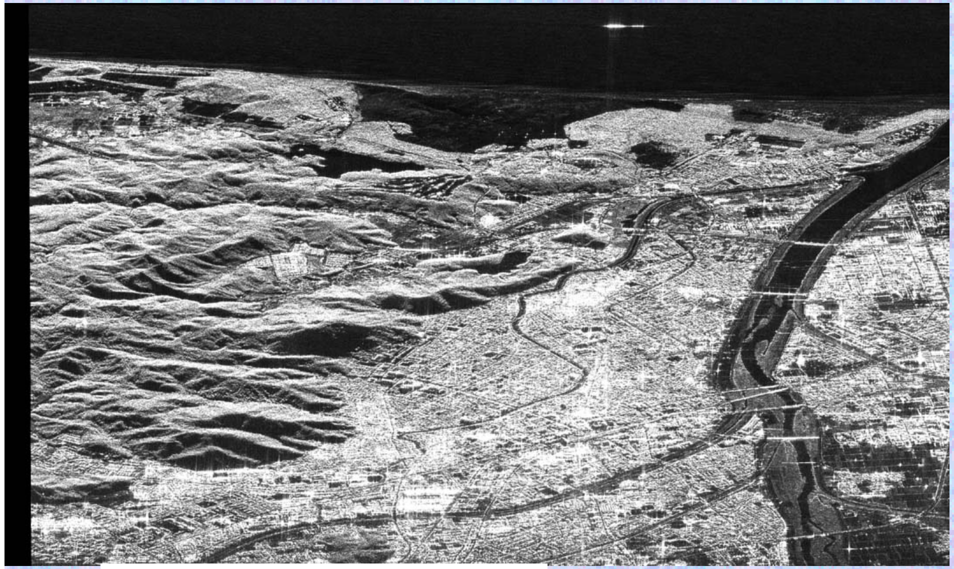


Tottori dune test site



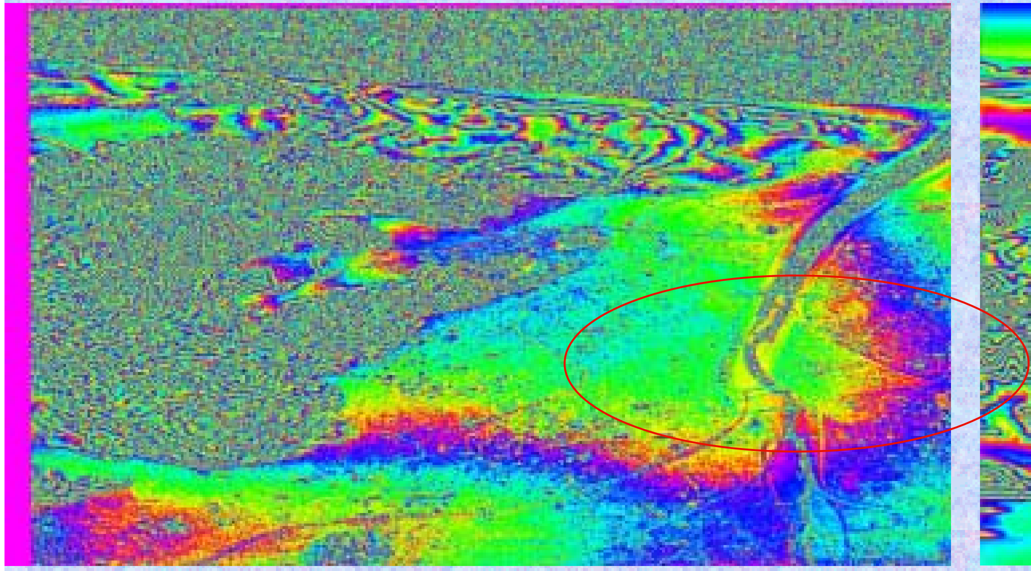
Ground truth DEM

Processing example for wider area (Tottori case)

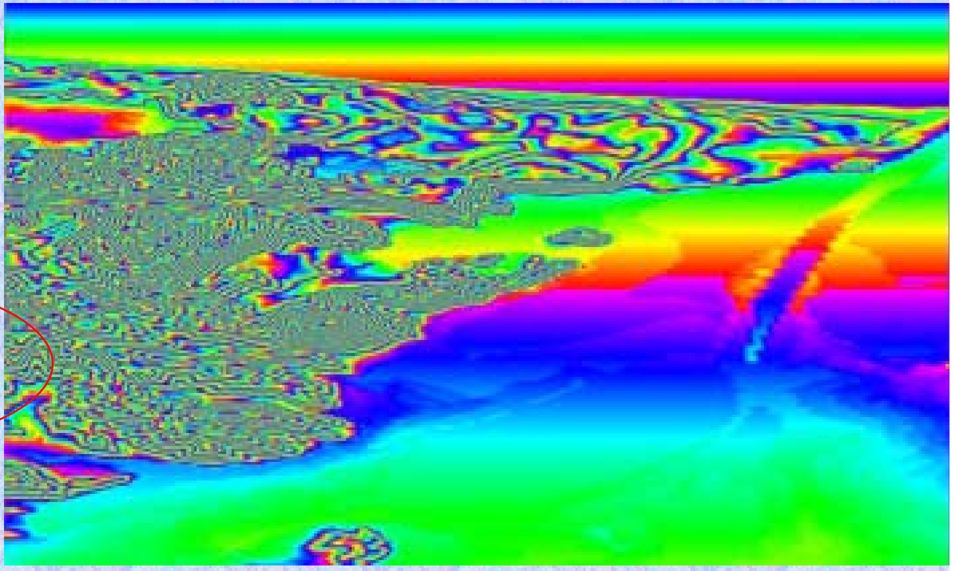


Amplitude image(HH)

Height error



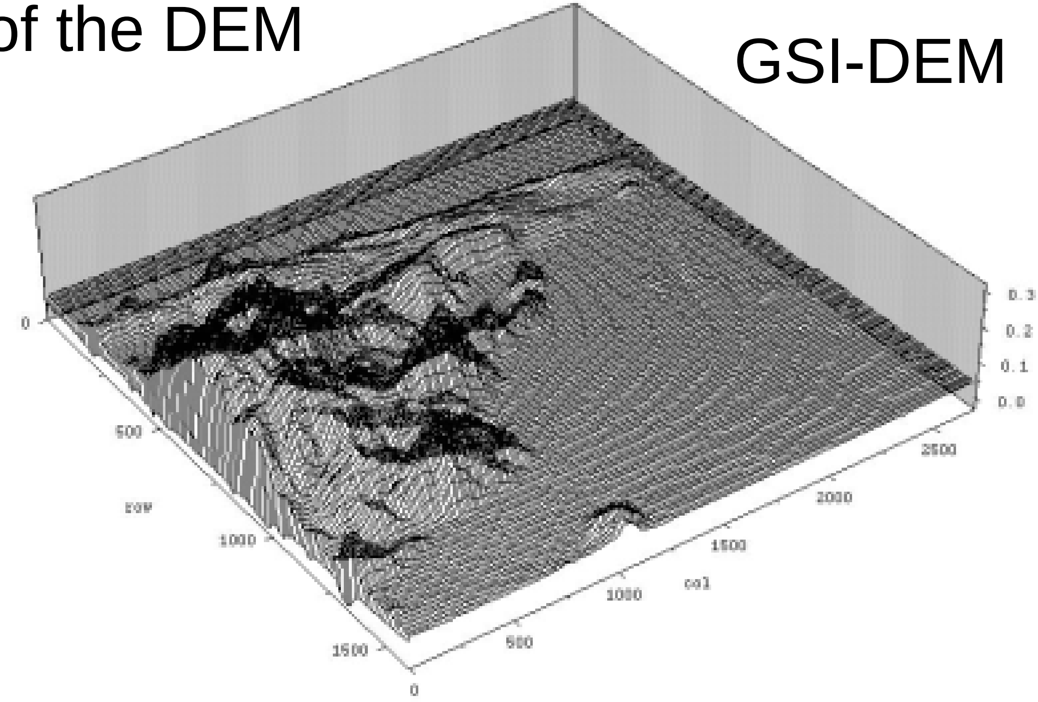
Generated DEM (Wrapped)

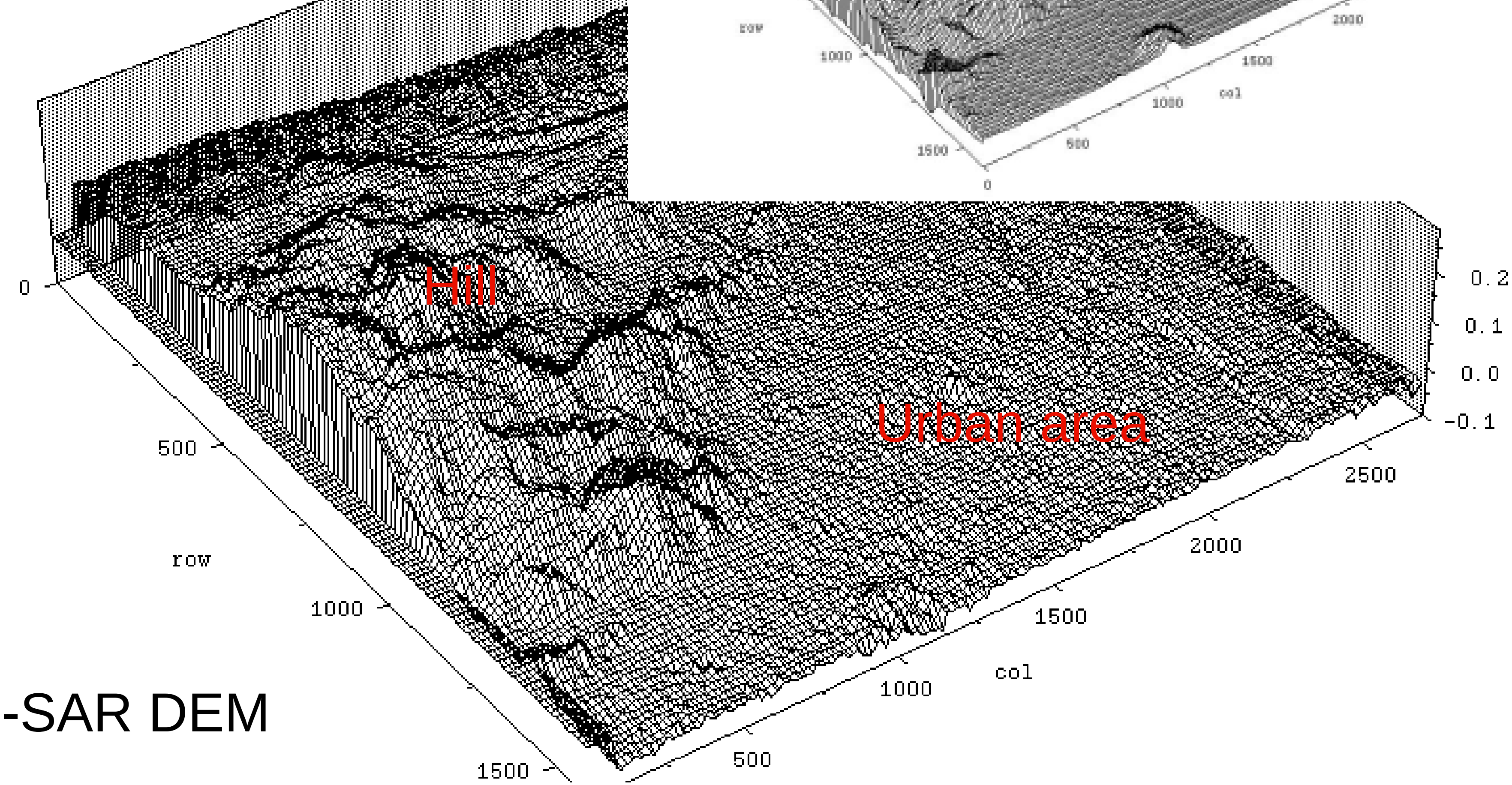


Ground truth (GSI DEM)

Three dimensional view of the DEM

GSI-DEM





In-SAR DEM

Conclusion and future work

We have conducted the experimental study to extract the DEM using the L band repeat pass airborne SAR interferometry (Pi-SAR).

One image pair flying over the Tottori dune has 70 m of B_{perp} preserving a good coherence.

DEM generated from Tottori image pair was corrected for the three unknowns, height, cross track, and cross track velocity of the restituted orbit using the ground control points given from the DSI-DEM and theoretical model.

The result shows some variation in the DEM but gives an accuracy order of 2.7 meter offset and standard deviation of 7.4 meter (Best case).

Motion compensation is a key component for generation of the SAR image. The required accuracy for generating image is not good enough for generating DEM.

Future work:
Improvement of the motion compensation using the denser ground control points (GSI-DEM) and needs nonlinear orbit correction model.

今後の検討

動揺補正の高精度化

相関係数の二次元分布の利用

異なる開口長の利用

校正

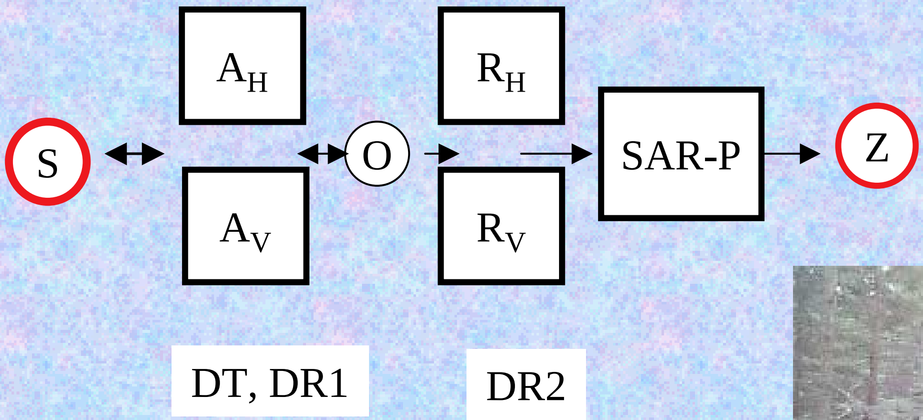
仮定

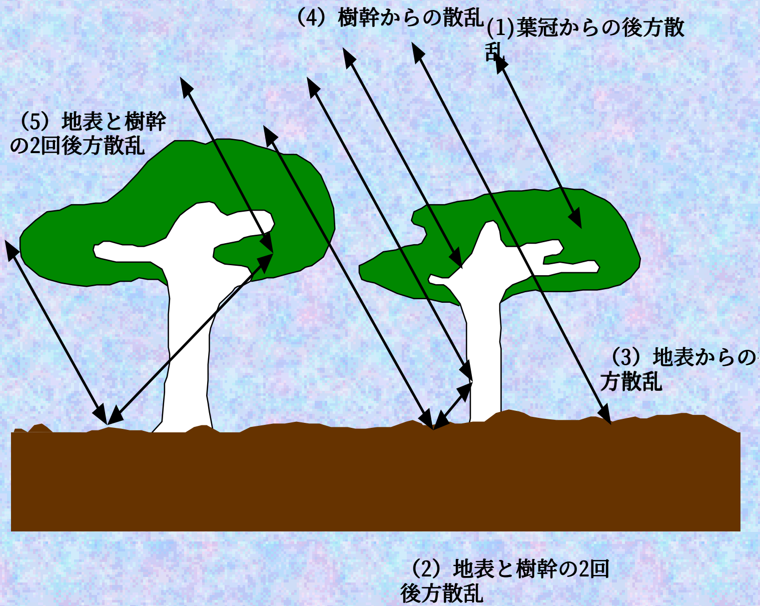
1) SARは送信と受信の歪み行列で表現される。

2) L バンドの一様森林からの散乱は体積散乱成分と2回散乱成分が支配的で、表面散乱成分はゼロである。

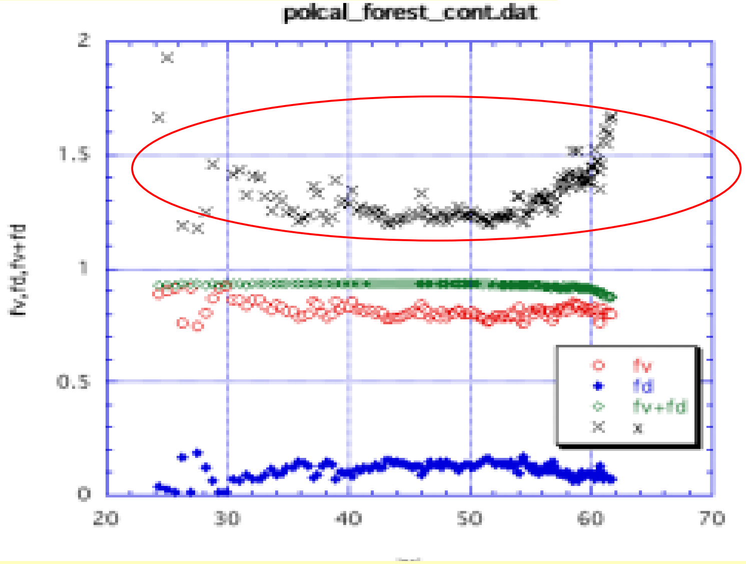
$$\begin{pmatrix} Z_{hh} & Z_{hv} \\ Z_{vh} & Z_{vv} \end{pmatrix} = Ae^{\frac{-4\pi r}{\lambda}} \begin{pmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{pmatrix} \begin{pmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{pmatrix} \begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{pmatrix} + \begin{pmatrix} N_{hh} & N_{hv} \\ N_{vh} & N_{vv} \end{pmatrix}$$

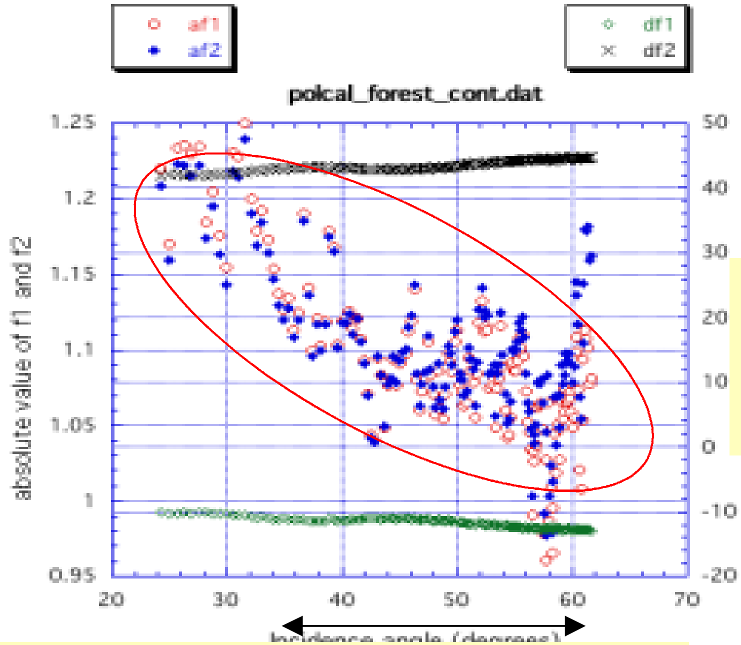
→ 収束演算と解析手法の解を得る





CASE-1:Nov. 2 2002



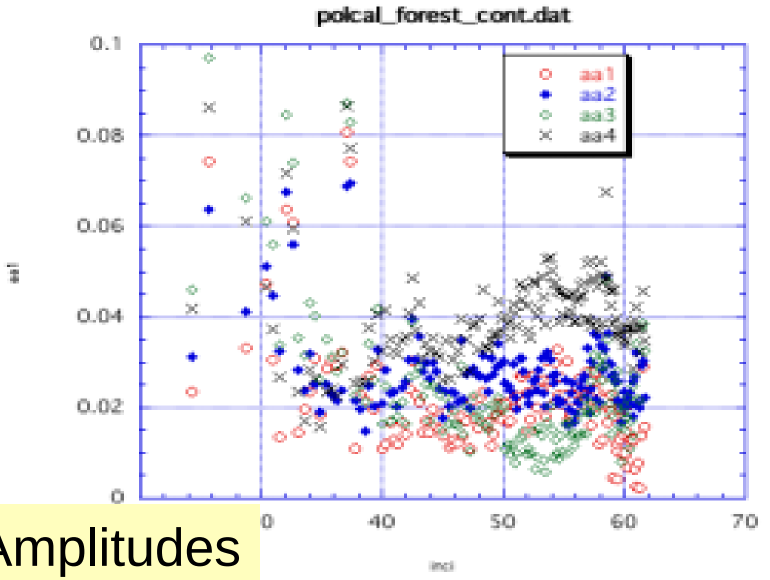


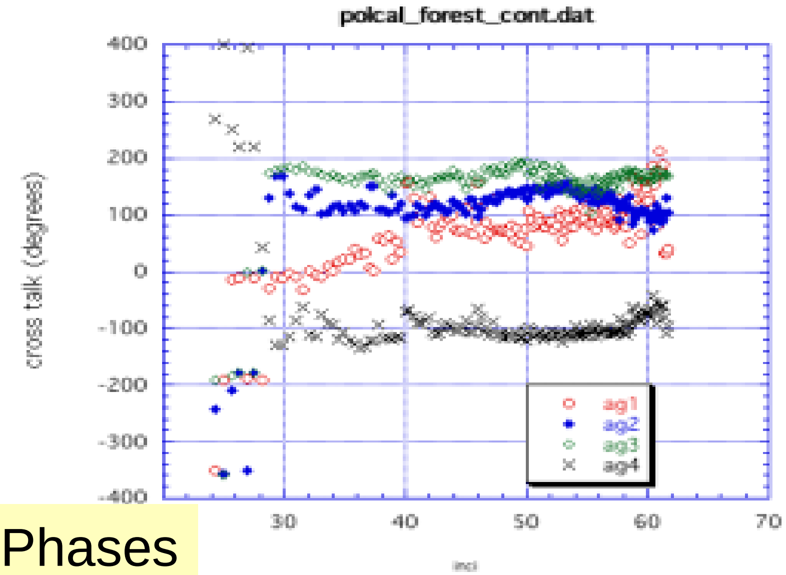
Phases

Volume scattering, double bounce

Channel imbalances (f_1 and f_2)

Cross talks (δ1, δ2, δ3, and δ4)



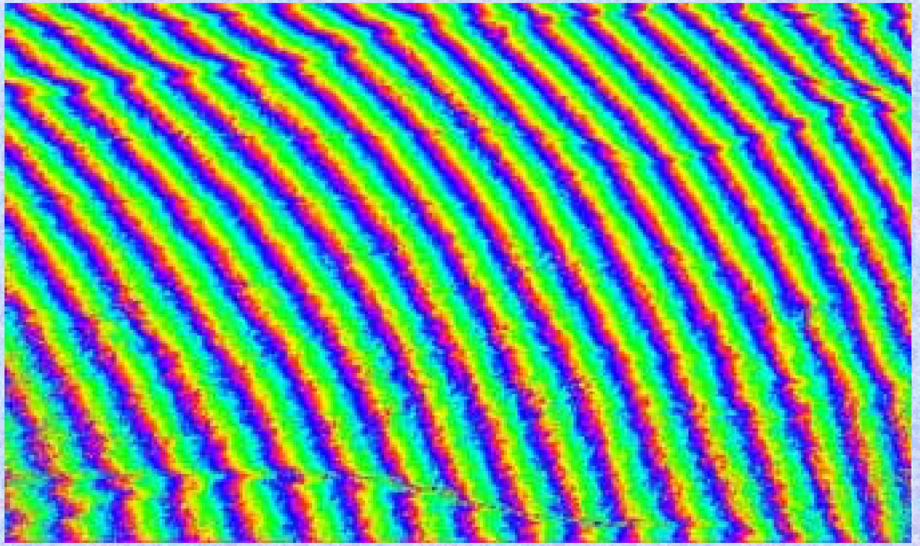


Amplitudes

Phases

Interferometry - 苫小牧forest (HH-VV)

振幅画像



位相差画像

Coherence HH：μ183.90／σ29.21

Coherence VV：μ178.91／σ27.54

Unwrapping

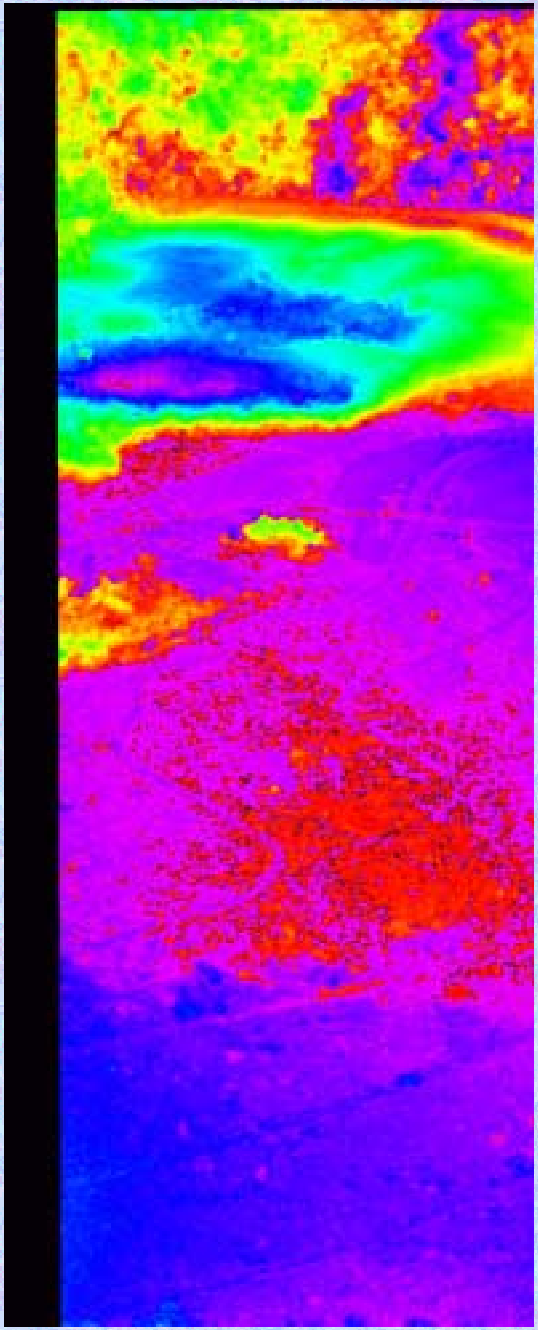
Methods

1)Branch cut (preserve the phase)
2)PCG, Pseudo Conjugate Gradient (slightly loose the phase)

Needs for

•Orbital tuning using the GCPs

•Ground range conversion



One example of unwrapped image