ALOS, ALOS-2 and Solid Earth Observations

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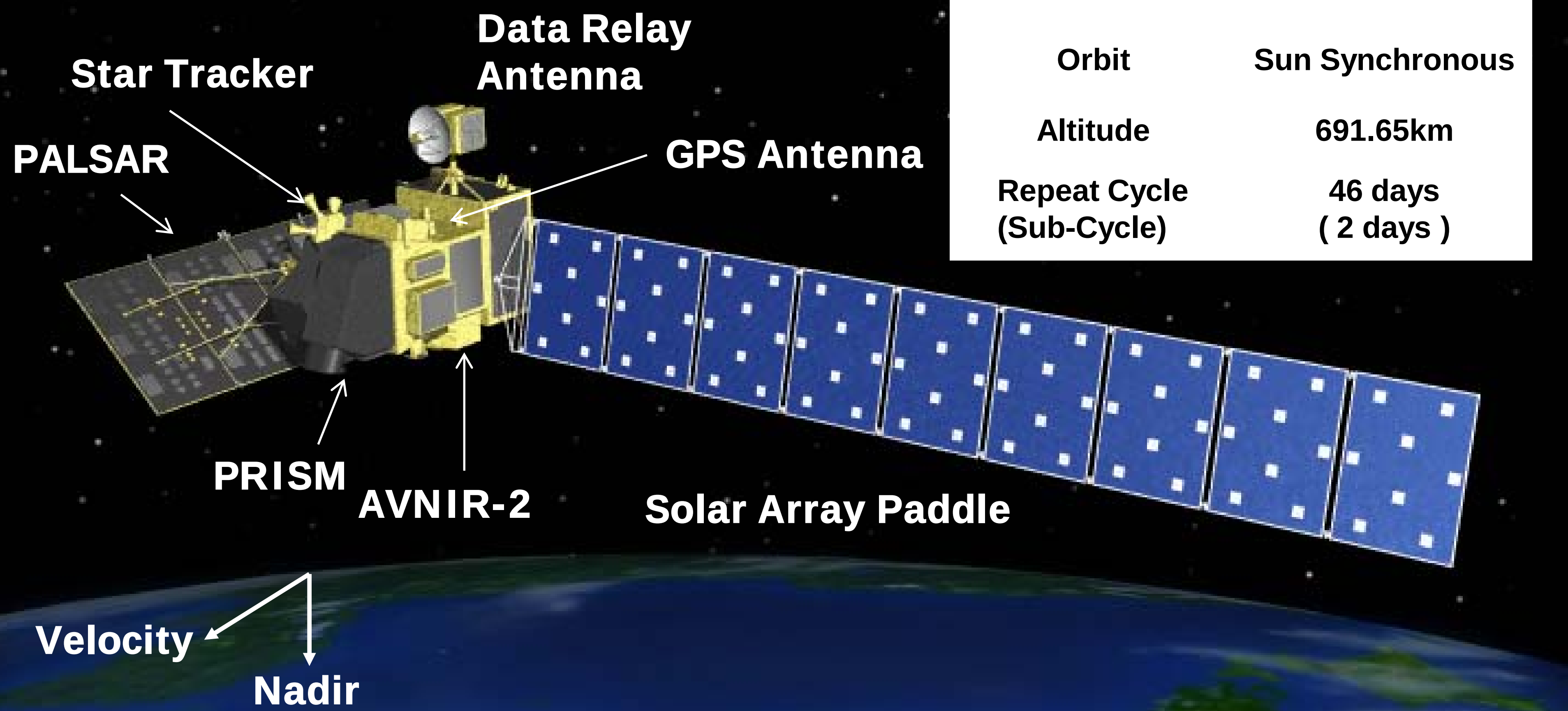
Contents of my talk

- ALOS and mission objectives
- CALVAL and features
- Data Acquisitions
- InSAR and Performance Evaluation
- Coherence vs. incidence angle
- Ionospheric perturbation
- ScanSAR InSAR
- ALOS-2
- Conclusion

ALOS Satellite System

Launch Date	Jan. 24 2006
Launch Vehicle	H-IIA
Spacecraft Mass	about 4,000kg
Generated Elec. Power	about 7kW at EOL
Orbit	Sun Synchronous
Altitude	691.65km
Repeat Cycle (Sub-Cycle)	46 days (2 days)



PRISM : Panchromatic Remote-sensing Instrument for Stereo Mapping
AVNIR-2: Advanced Visible and Near Infrared Radiometer type 2
PALSAR: Phased Array type L-band Synthetic Aperture Radar

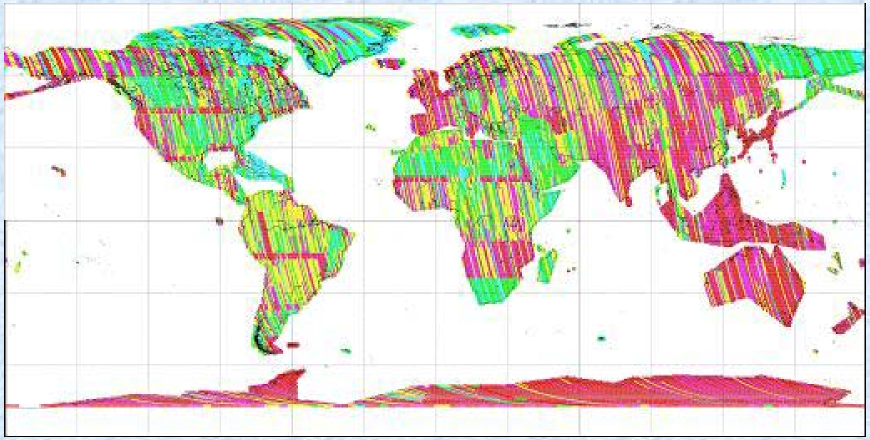
センサーと衛星の特性

- PALSAR (L-band SAR, 14/28MHz, STRIP(FBS, FBD, Pol), ScanSAR)
- AVNIR-2(4 band 光学)
- PRISM(Pan-DSM 光学)
- 正確な位置精度とラジオメトリ
- 高い安定性
- 長時間の観測 (~50 min./1軌道)
- 静止データ中継衛星を用いた全球観測
  DRTS + TDRS(650万シーン/ 1 PB / 5 年)
- 基本観測シナリオ

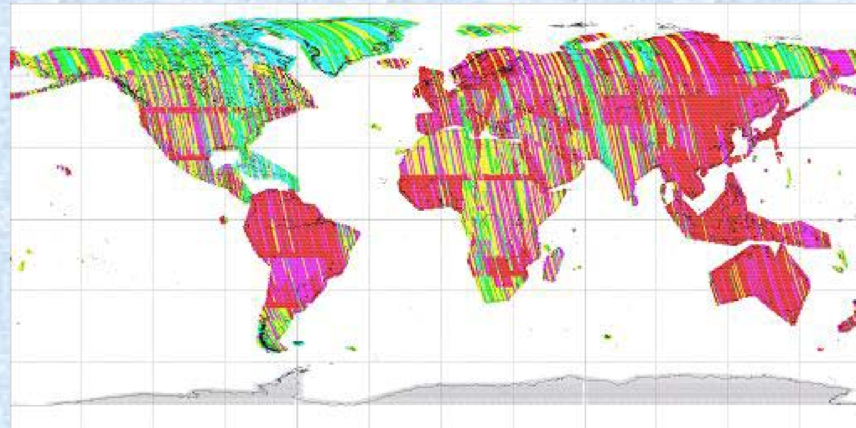
Applications（応用事例）

- **Oil Spill（海上油汚染）**
- **Fire scare（森林火災）**
- **Flooding （洪水）**
- **Land Slide (Flash water and Slow moving)（地滑り）**
- **Subsidence（地盤沈下）**
- **Volcano（火山）**
- **Earthquake（地震）**
- **Forest, REDD+, Wetland（森林監視）**
- **Polar Ice/Glaciers（極域氷河）**
- **Coastal Erosions（海岸浸食）**
- **Drift Ice monitoring（流氷）**
- **Change Detections（変化抽出）**
- **Rice Paddy Monitoring（作付け面積）**
- **Illegal Logging Monitoring（違法森林伐採監視）**
- **Ocean Wind Speed distribution（海上風速分布）**
- **DSM generation (PRISM, PALSAR by InSAR)（標高データ作成）**
- **Ionospheric Disturbances（電離層分布）**
- **Radio Frequency Interference（周波数干渉）**
- **Ortho-rectification（オルソ画像）**
- **Soil Moisture（土壌水分）**

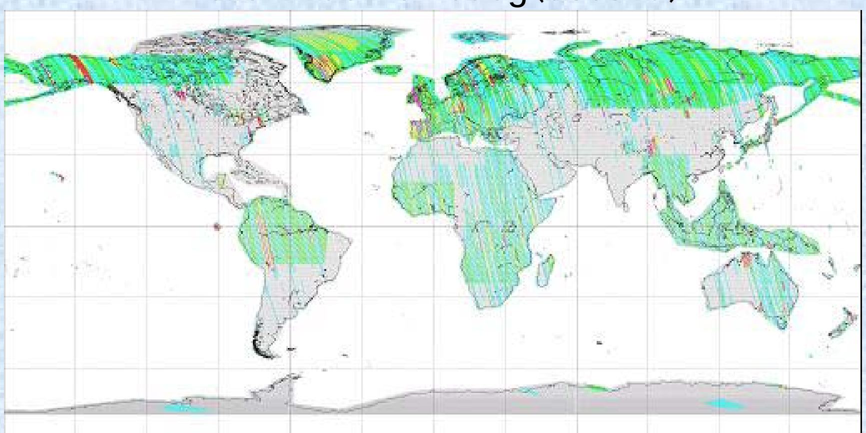
Global Data Acquisition and Basic Observation Scenario



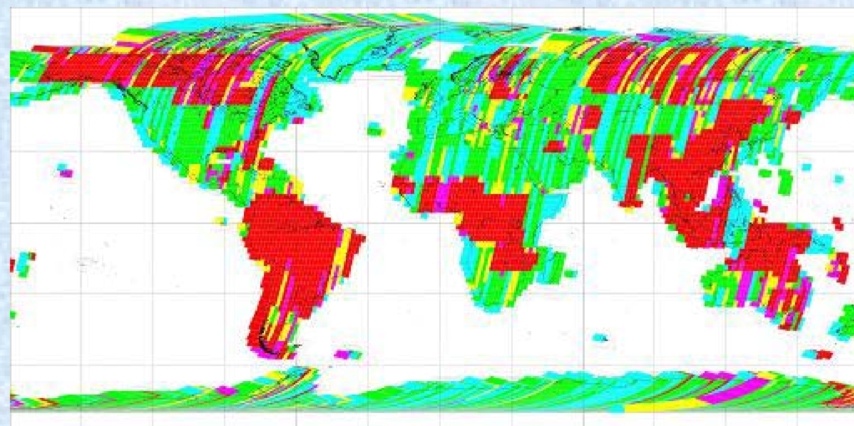
FBS Off-nadir:34.3deg（ascend）



FBD Off-nadir:34.3deg（ascend）



PLR Off-nadir:21.5deg（ascend）



WB1/WB2 Off-nadir:27.1deg（descend）

1 time
2 times
3 times
4 times
5 times
6 times
7 times
8 times
9 times
>10 times

Duration：2006年5月16日～ 2011年1月23日

PALSAR Data archives as of Jan. 23 2011

L-band SAR Characteristics

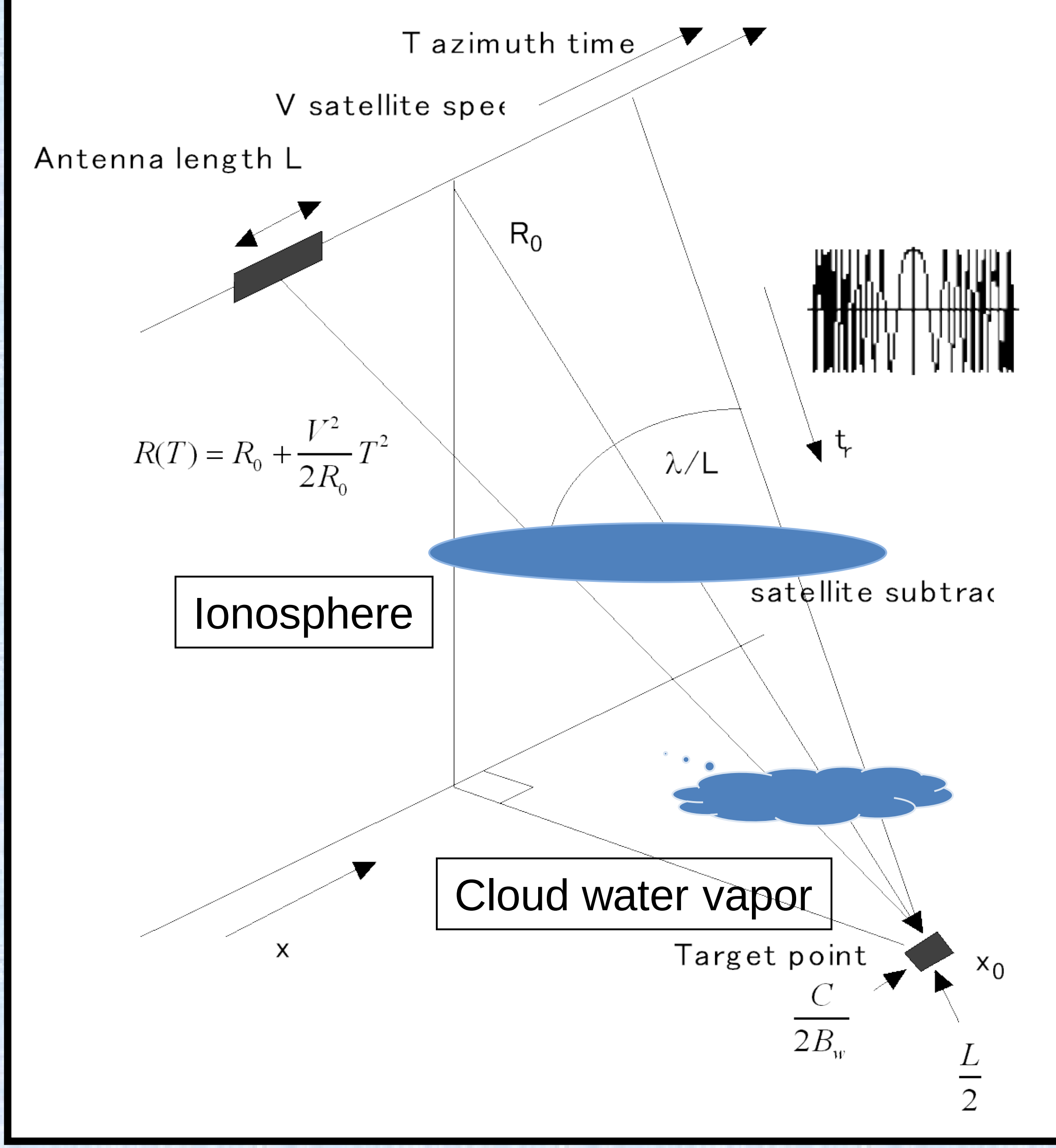
- Advantages (than higher frequency)
  - Higher Penetration through the vegetation covered targets
  - High InSAR coherence for the vegetation covered target
  - Lower backscatter from the lower vegetation

- Disadvantage (and advantage)
  - Higher sensitivity to the ionospheric disturbance

SAR imaging

High resolution SAR imaging is performed by two scale correlation processes, i.e., FM modulation in rage and Doppler modulation in azimuth.

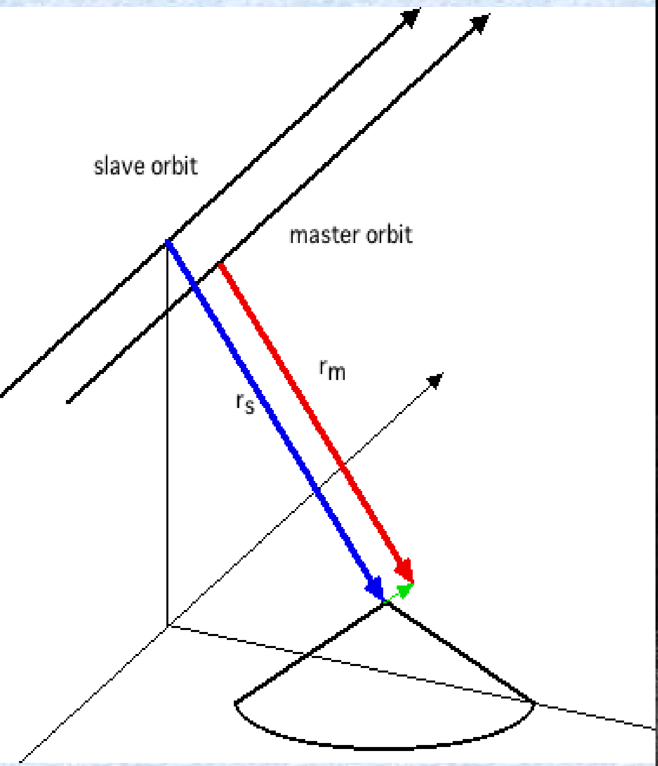
	Bw	L
JERS-1	15M	12m
PALSAR	28M	9m
PALSAR	14M	9m
Pi-SAR-L	50M	1.6m



$$S_{ra}(R,x) = A(R,x)\sin c\left(\frac{2\pi B_w(R-R_0)}{C}\right)\sin c\left(2\pi\left(\frac{x-x_0}{L}\right)\right)\exp\left(-\frac{4\pi R_0}{\lambda}j\right)$$

Differential SAR interferometry (1/2)

obtain the surface deformation map by differentiating two SAR images acquired at different times(master and slave), by correcting the distances between two orbits (1), and by correcting the surface topography (2).



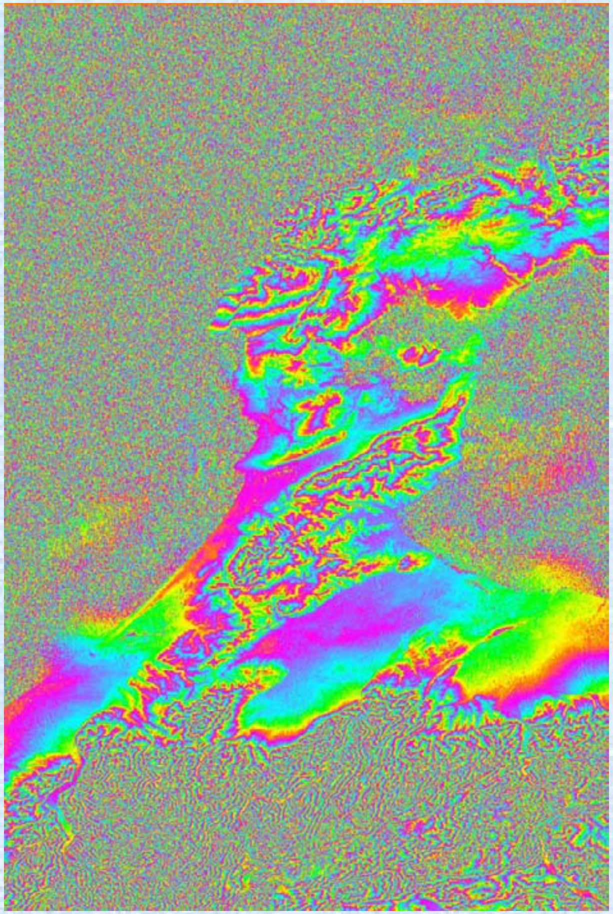
coordinate system

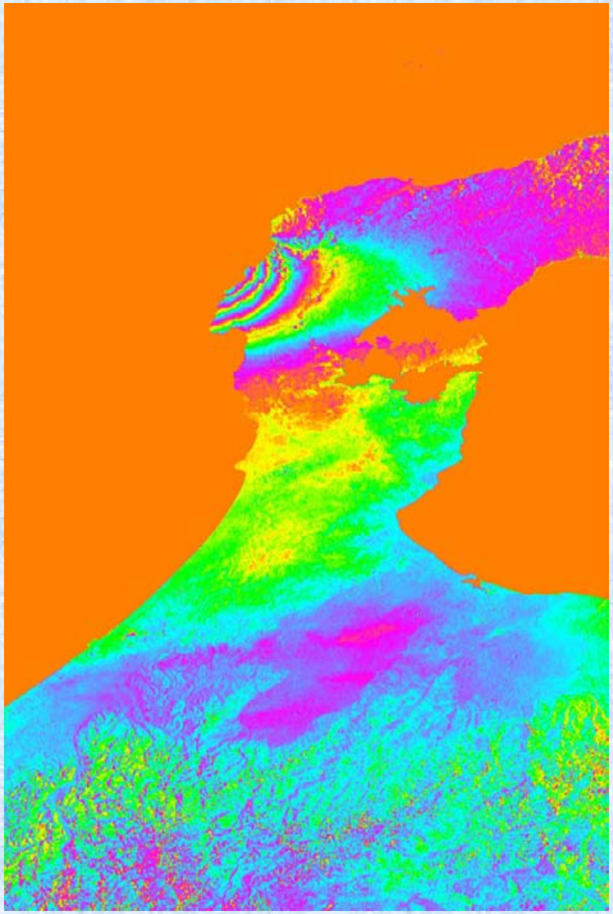
master(4/10/2007)

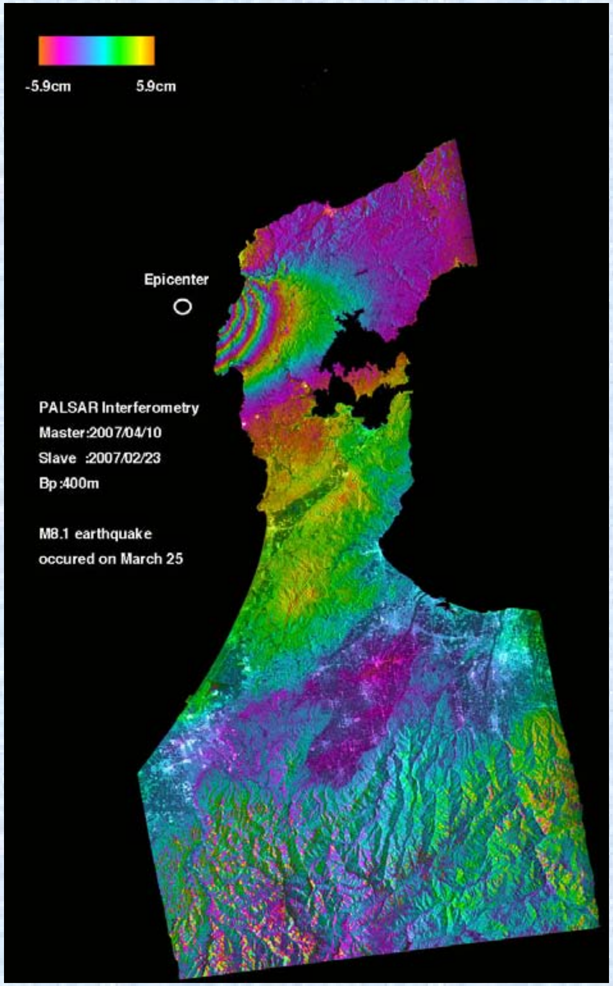
slave(2/23/2007)

Differential SAR interferometry (2/2)

Final result (3) is gained by ortho-rectification and the geocoding of the image (2)







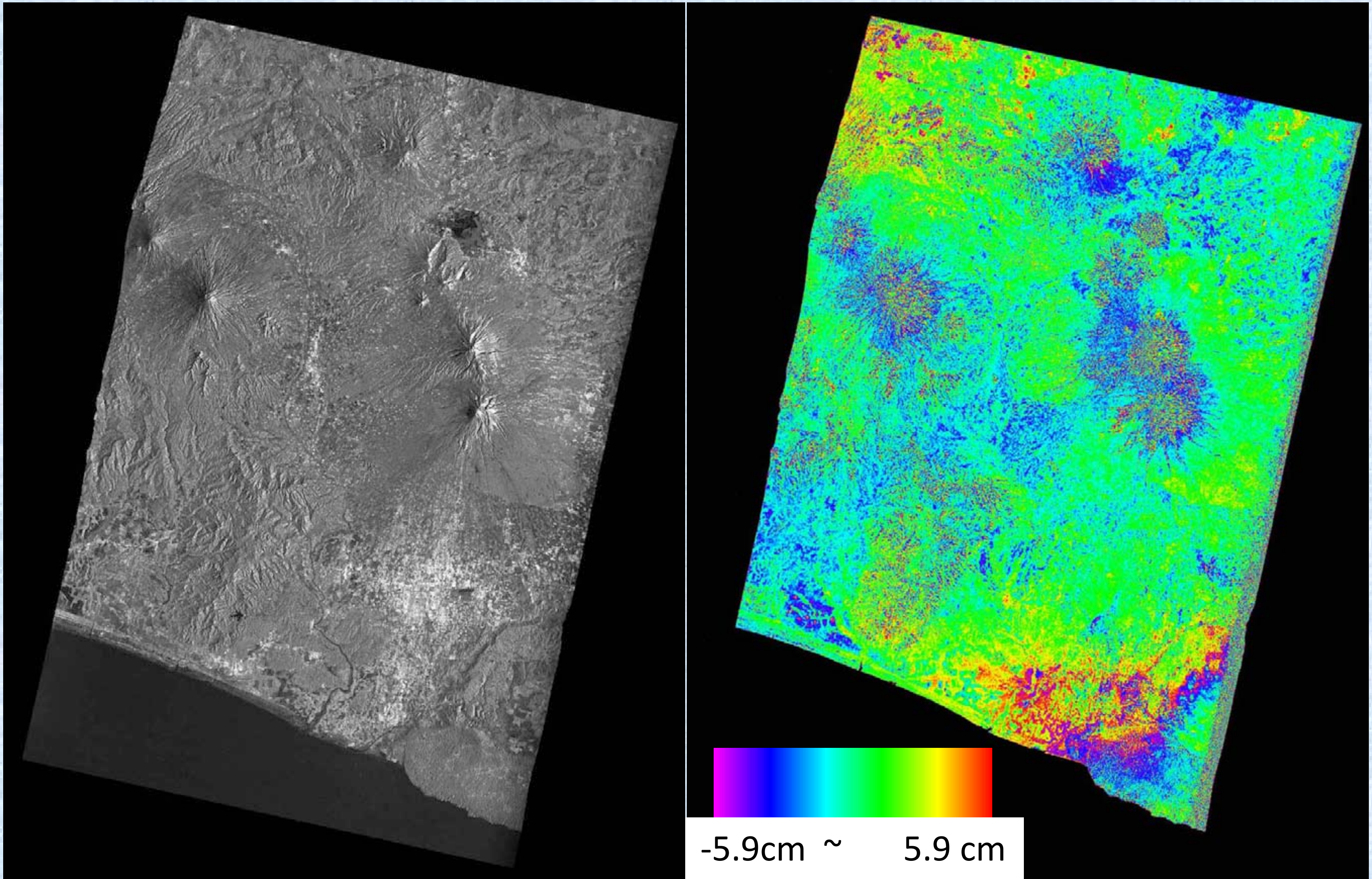
(1)orbit correction

(2)topography correction

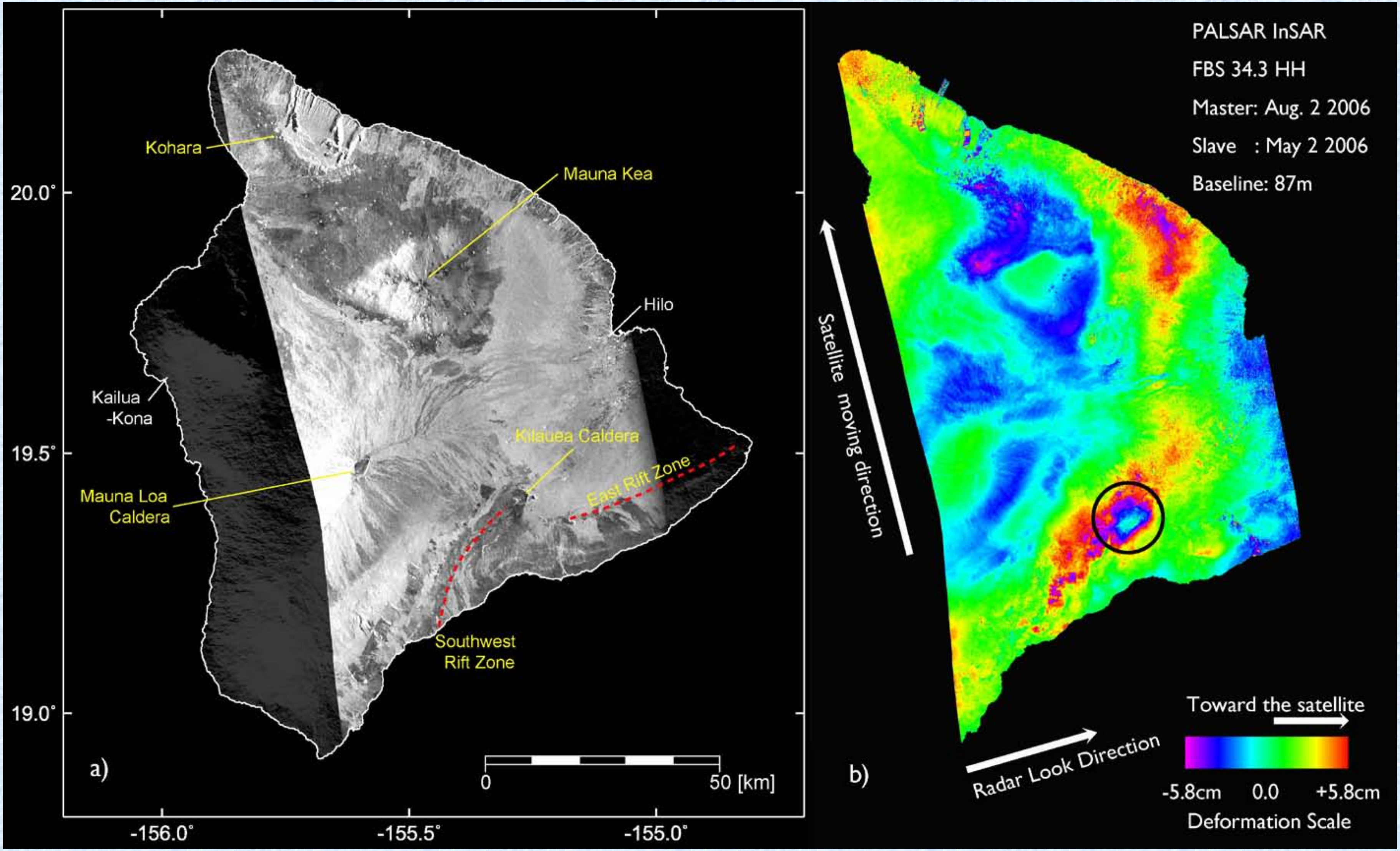
(3)final result

Yogjakarta- First detection

Indonesia, Earthquake triggered by Mt. Merapi Volcano, April 2006



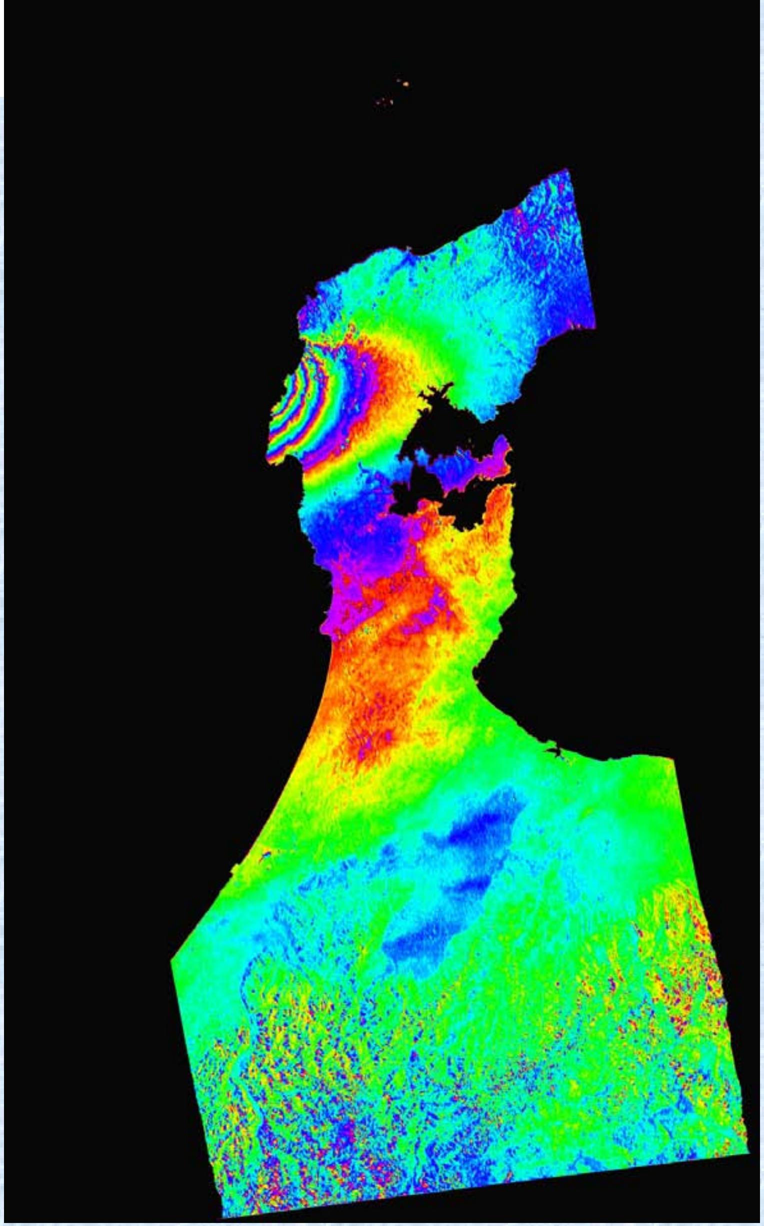
First DinSAR image detected by the PALSAR over Hawaii



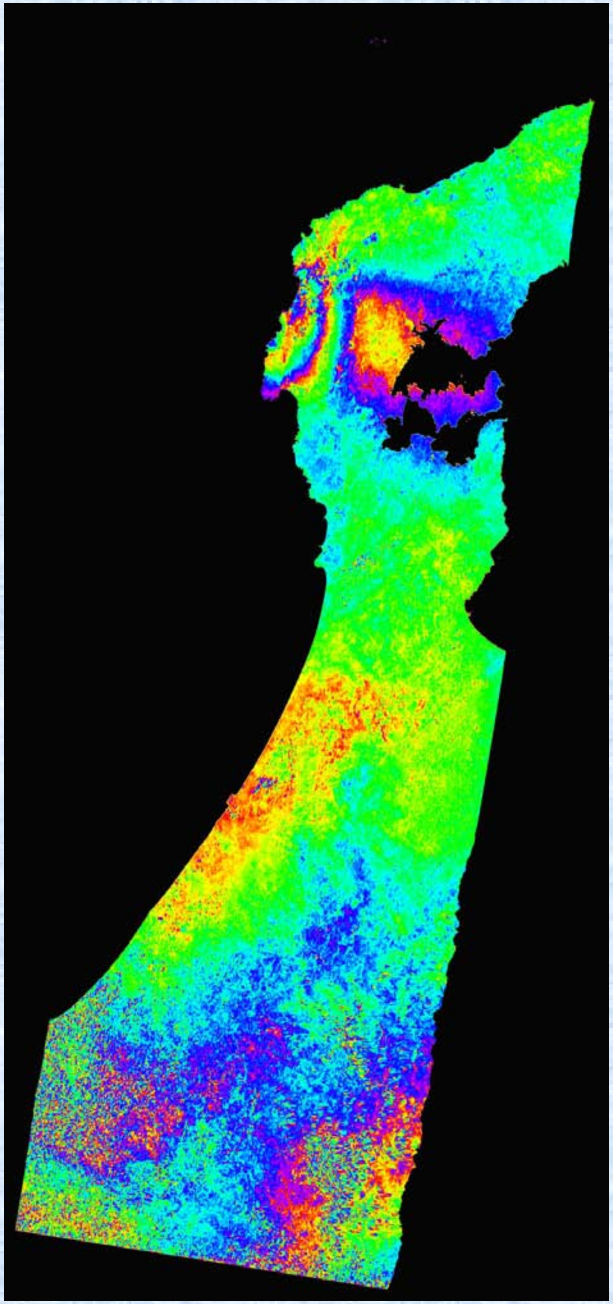
Noto Earthquake

Case 1
2007年04月10日
2007年02月23日
Yaw steer OFF
off=41.5

Case 2
2007年05月10日
2006年12月23日
Yaw steer ON
off=34.4

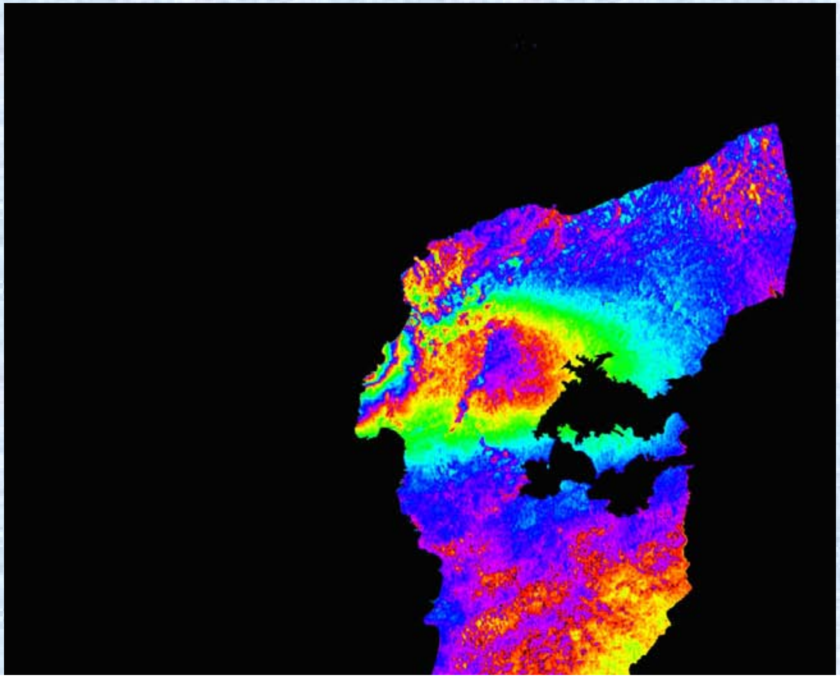


C1. Ascending Orbit

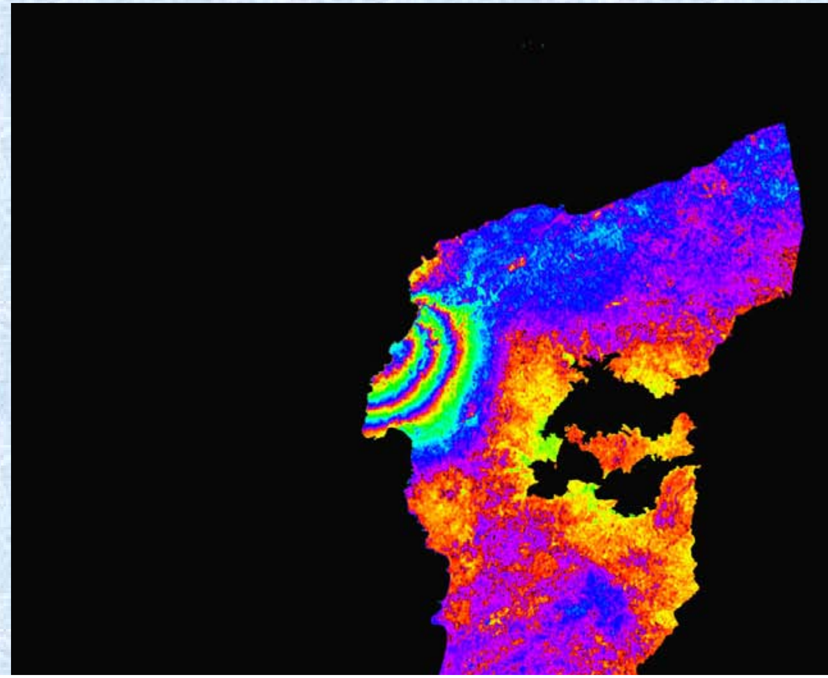


C2. Descending Orbit

水平方向変位

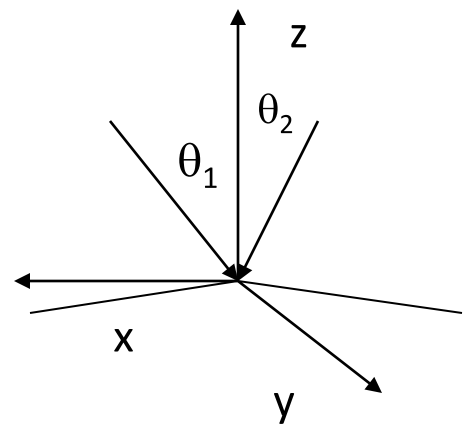


垂直方向変位



$$x = (d1 - z\cos\theta_1)/(\cos\phi\cos\theta_1)$$

$$z = (d_1 sin\theta_2 + d_2 sin\theta_1)/sin(\theta_1 + \theta_2)$$



変化はxとzのみと仮定

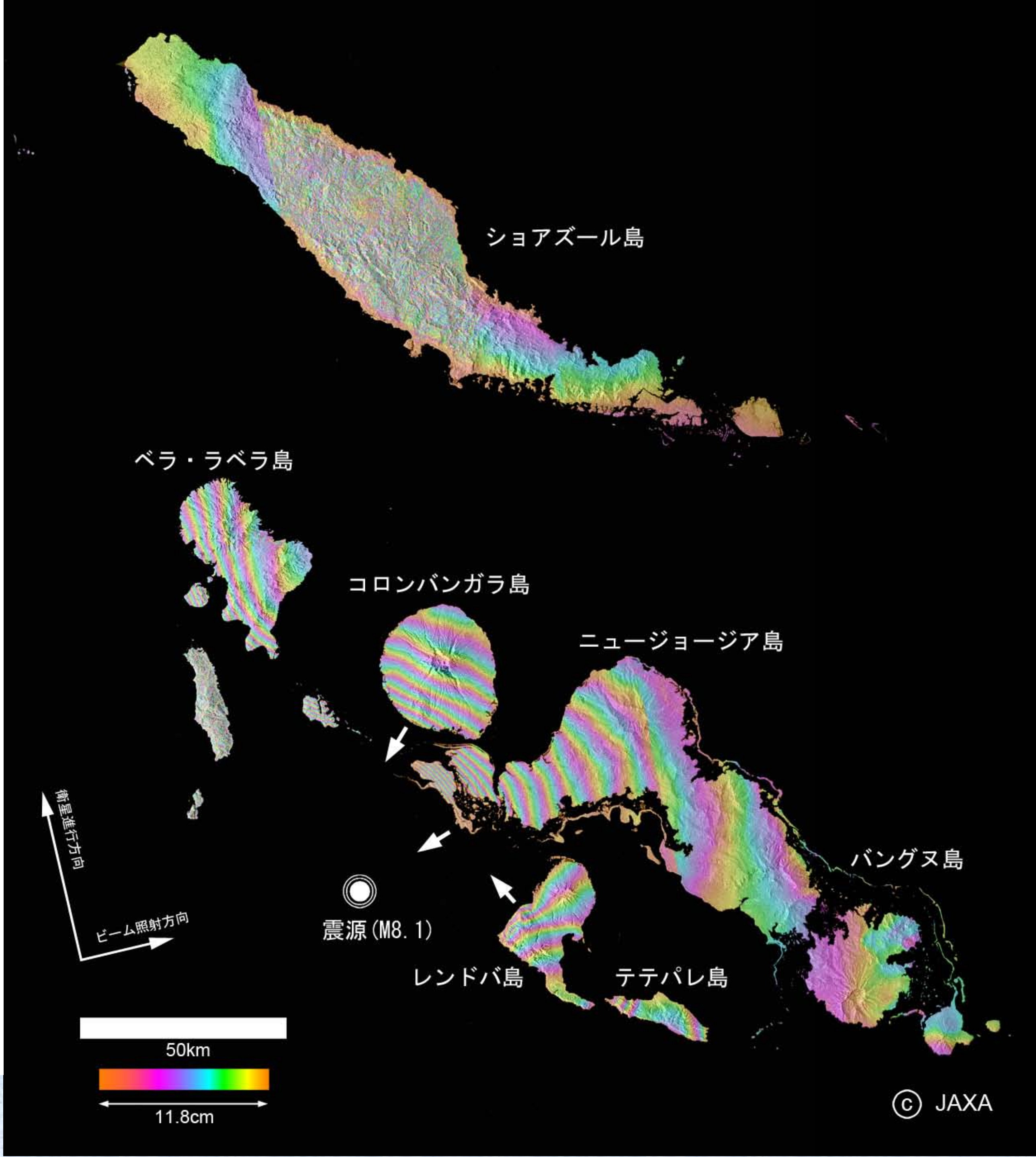
Solomon Island

M8.1
April 2 2007

Three DinSAR
344:4/10-2/23
345:5/3-1/31
343:5/10-2/12

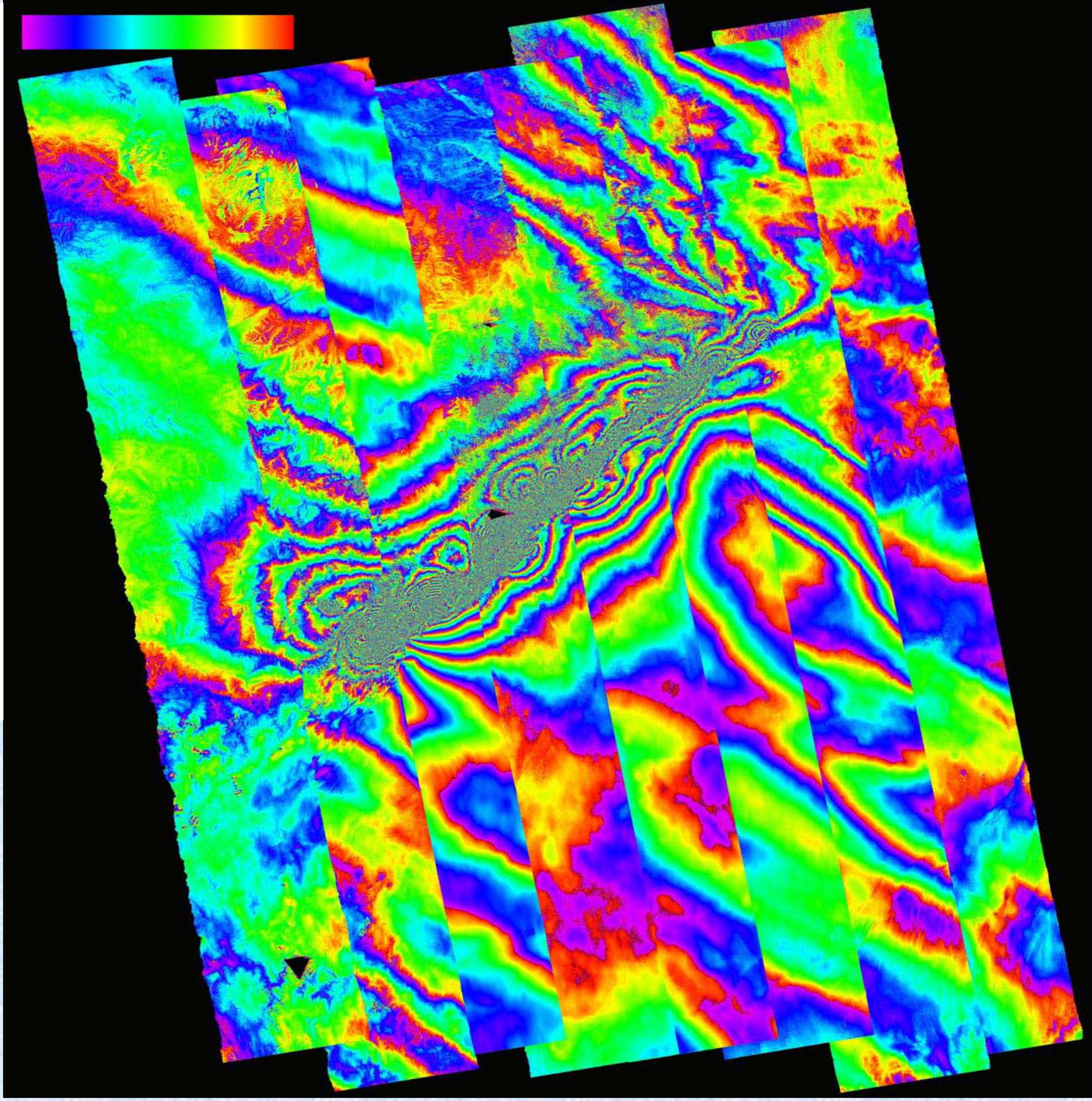
FBS343HH

- No orbit tuning.
- No further correction
- Three passes mosaic



May 12 2008
Wunshen
Earthquake
PALSAR data
8 pass mosaic

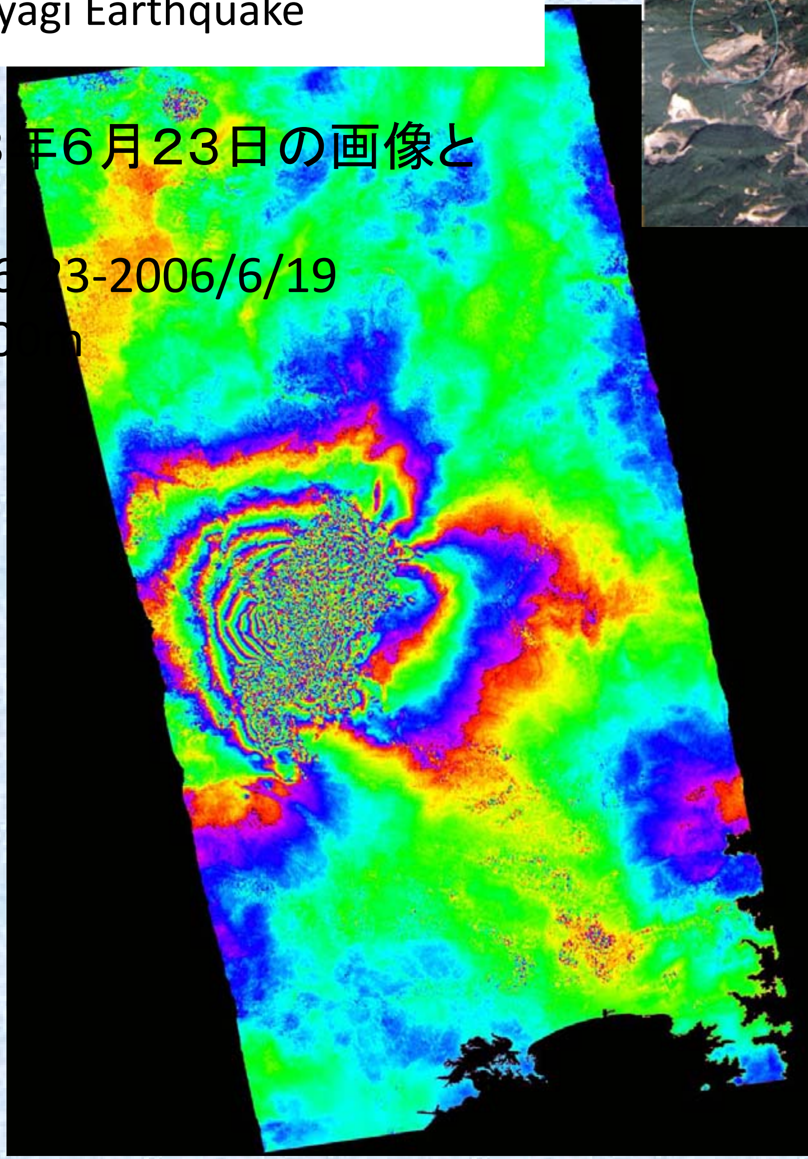
- First detection of the 290km faults
- All ascending passes
- Noisy patterns due to the ionosphere



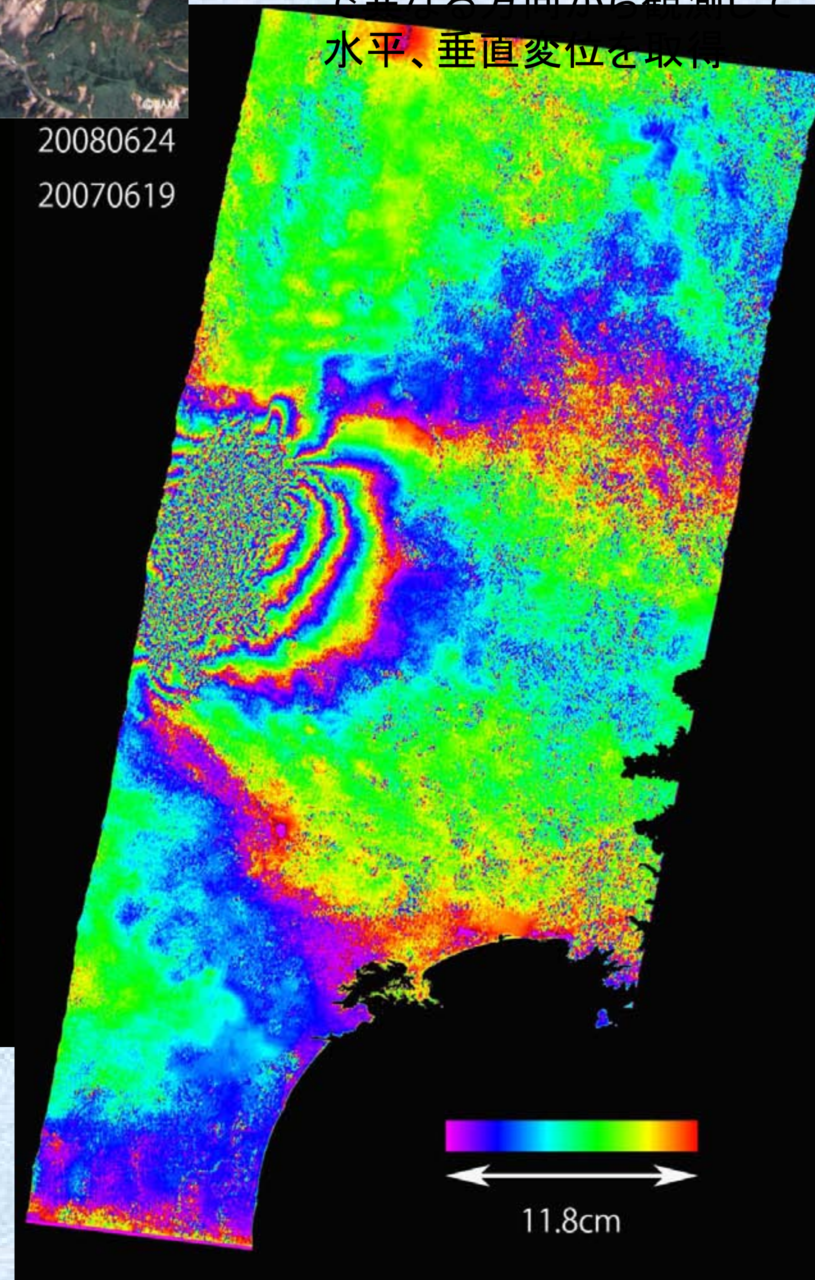
Iwate Miyagi Earthquake

2008年6月23日の画像と

2008/6/23-2006/6/19
Bp=-50[illegible]m



2008／6／24
2007／6／19
で異なる方向から観測して
水平、垂直変位を取得



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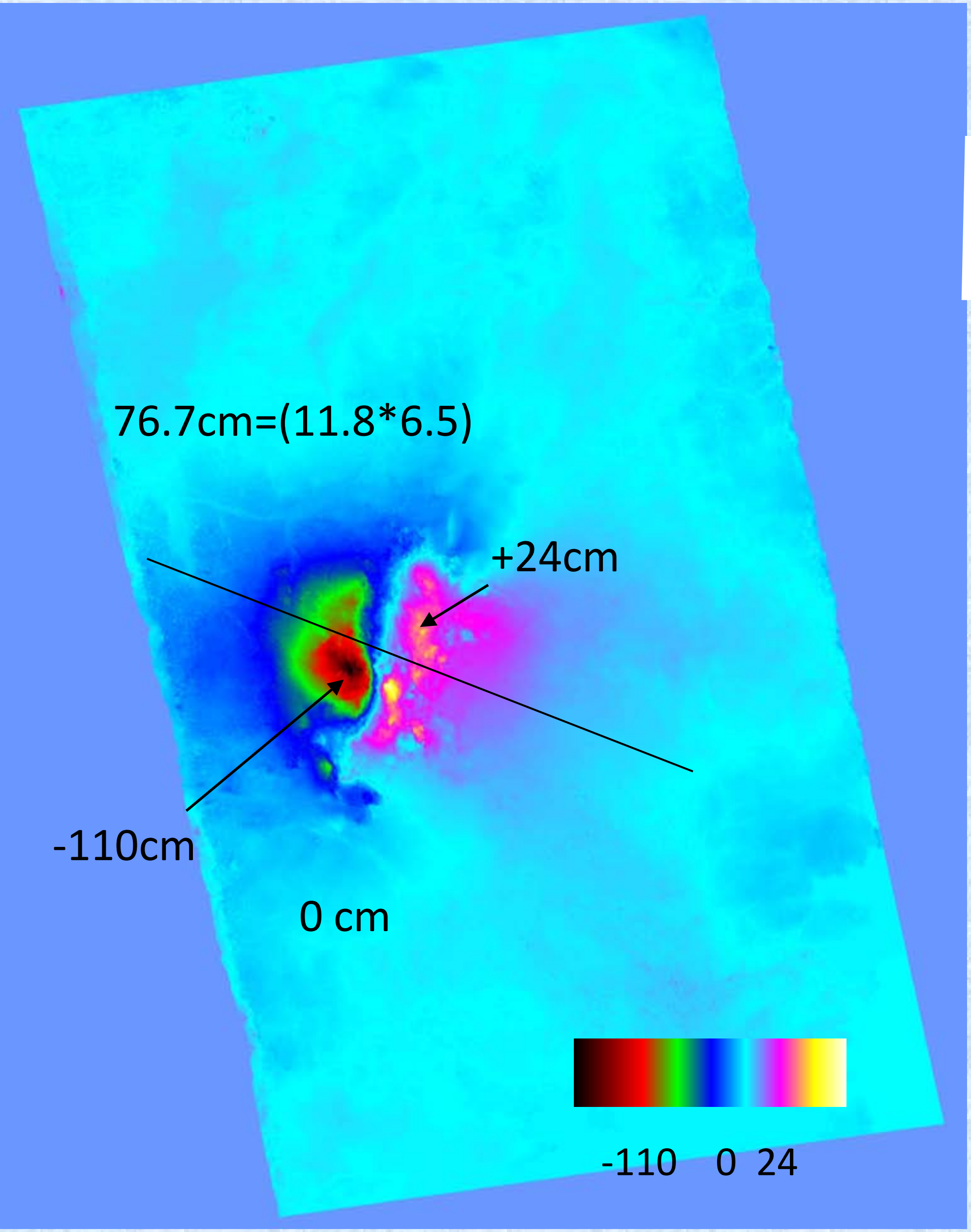
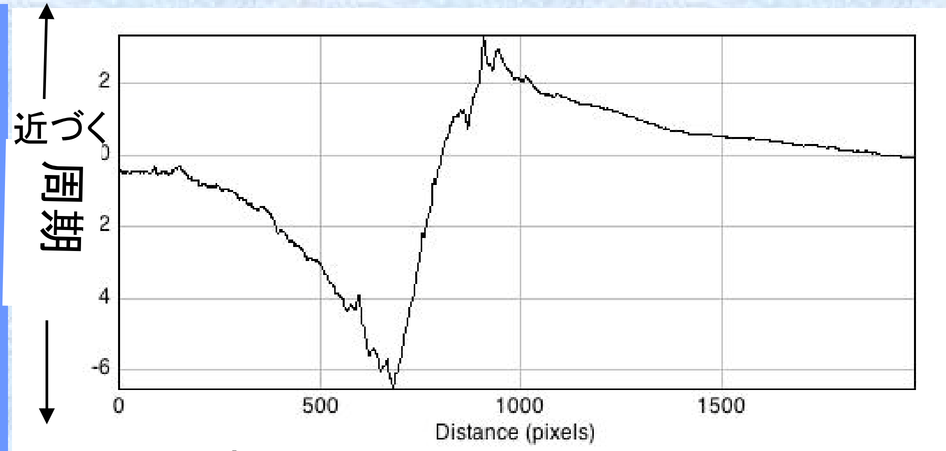
（Unwrapped data）

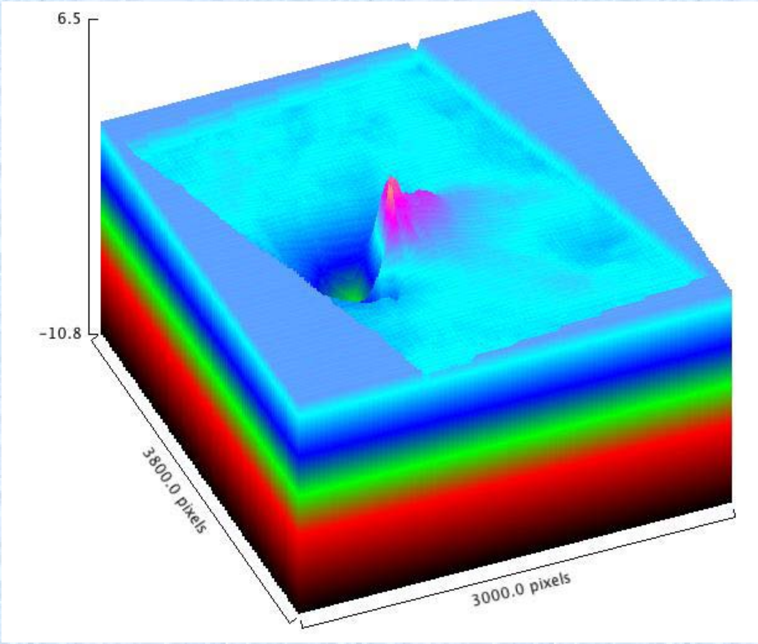


Unwrapped phase



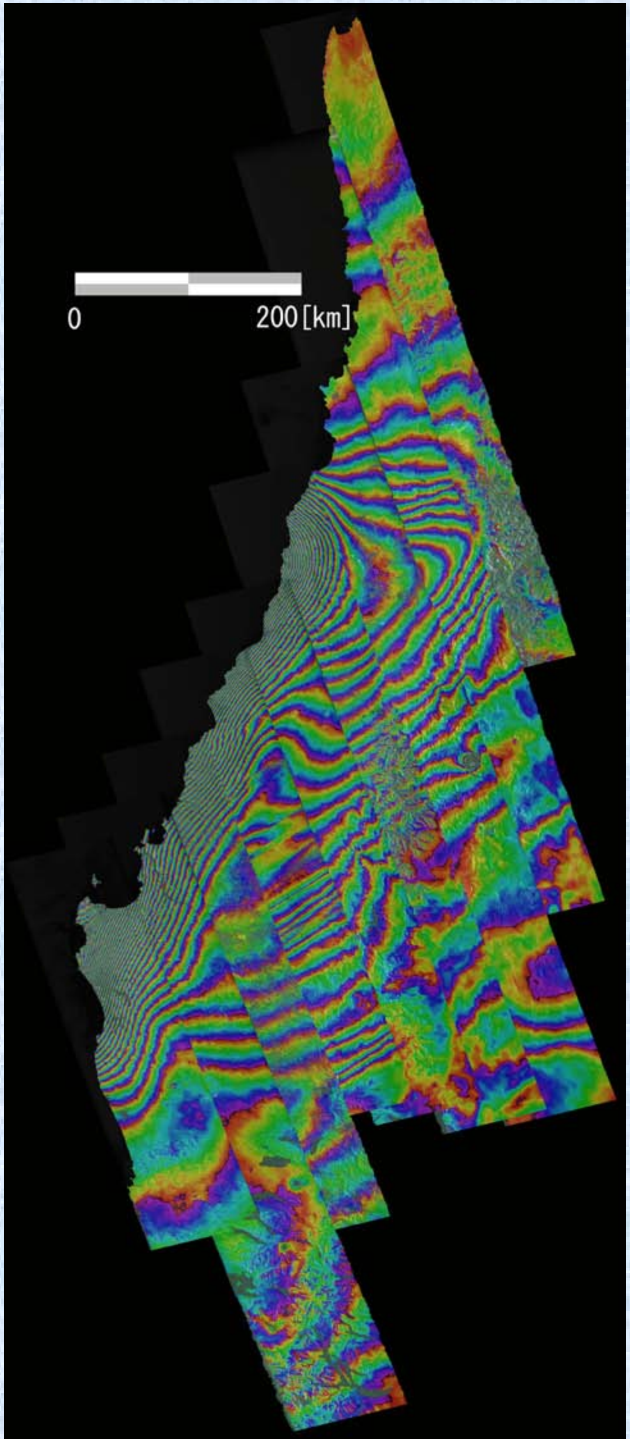
変動量の断面図/Cross section

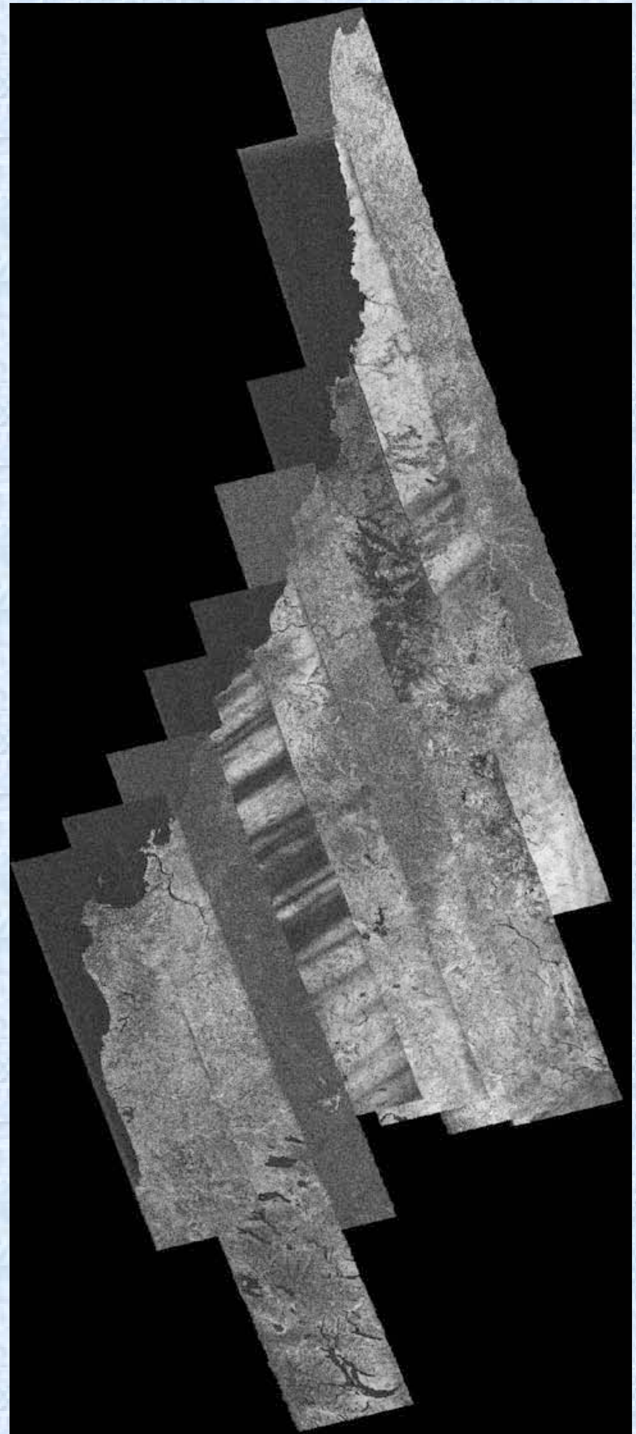
遠ざかる



変化量を積分したもの（3次元図）

Deformation monitoring for Chile Earthquake 2010

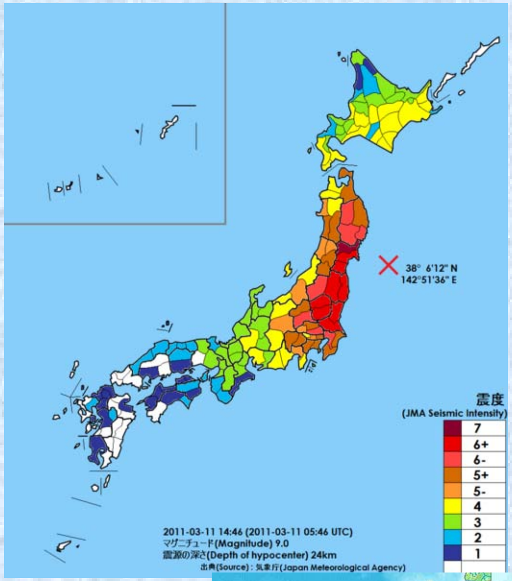




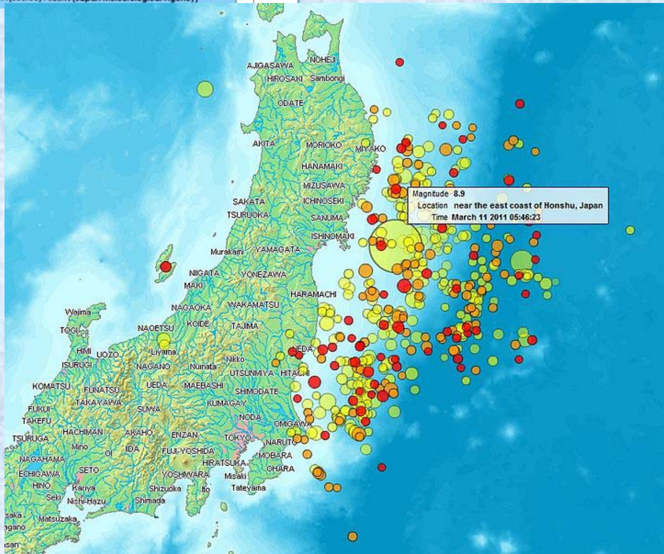
Tohoku-Oki Earthquake 2011

Occurred at 100 km off Sendai on 2:46PM 3.11 2011, M9.0, World 4th largest Earthquake

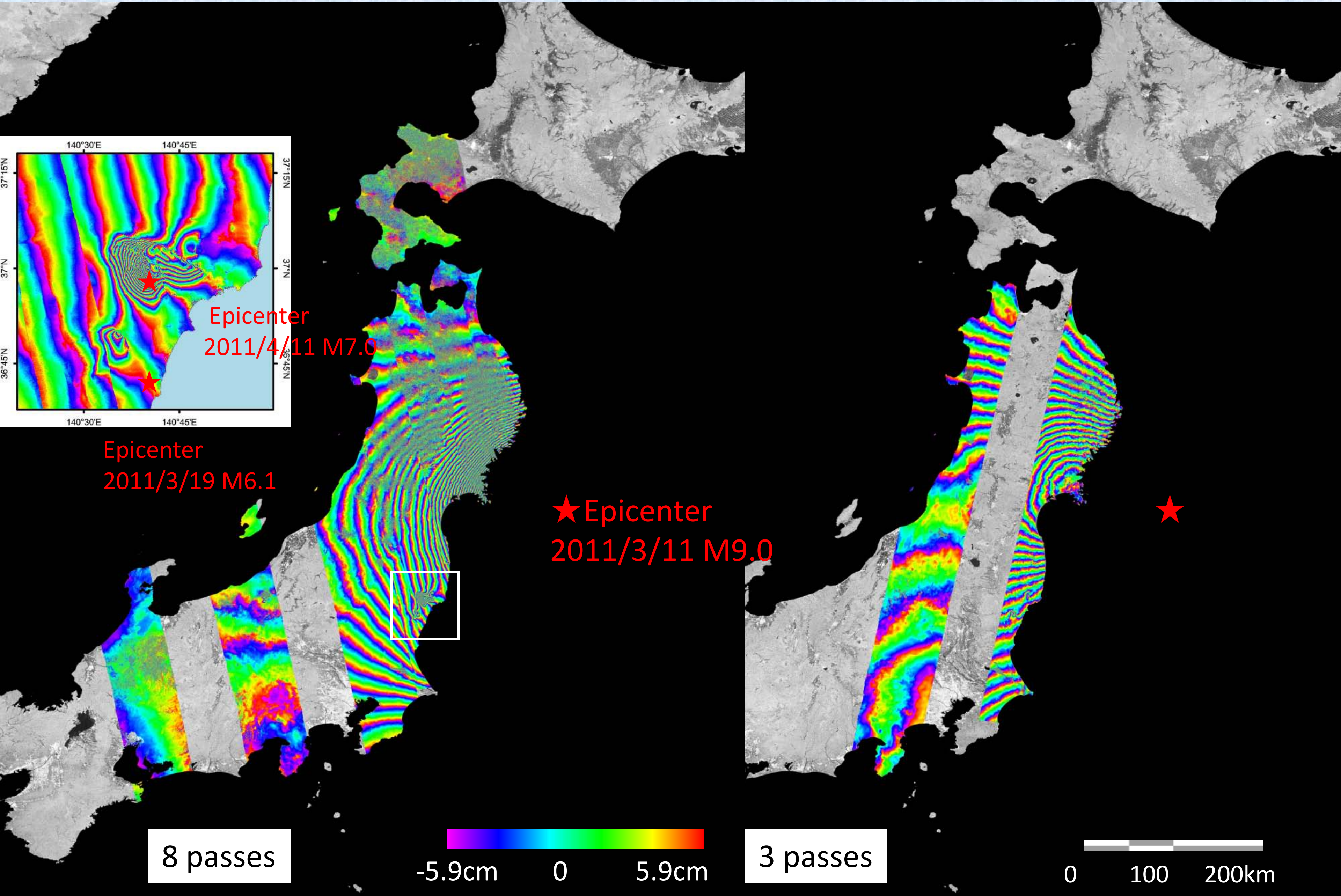
Dead: 15544
Missing: 5383
(July 10 2011)

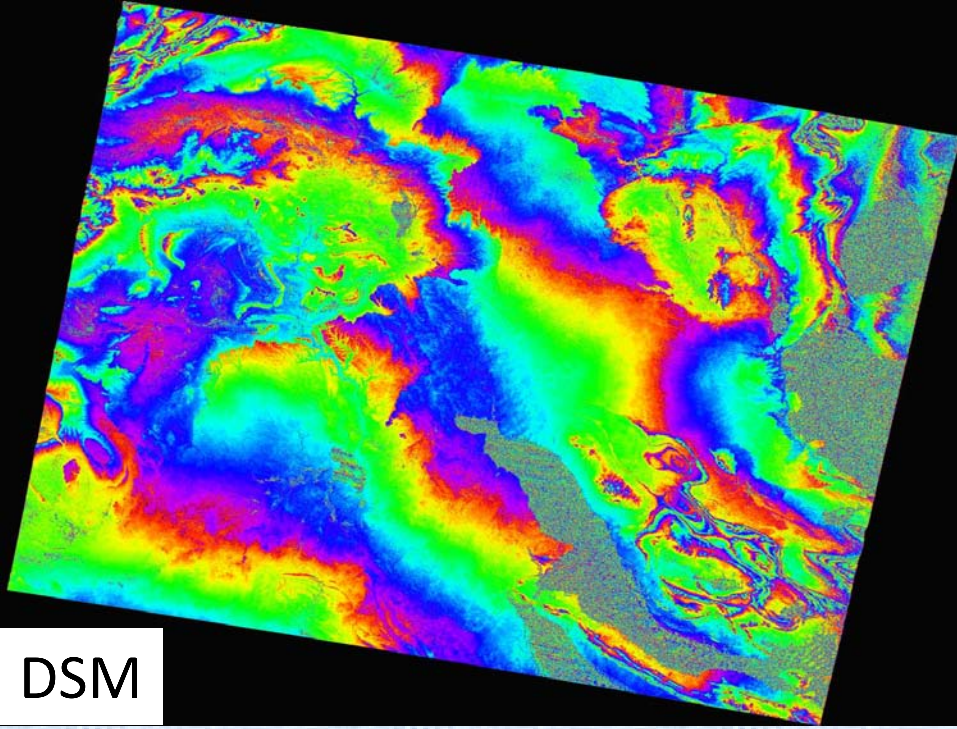


Seismic Intensity

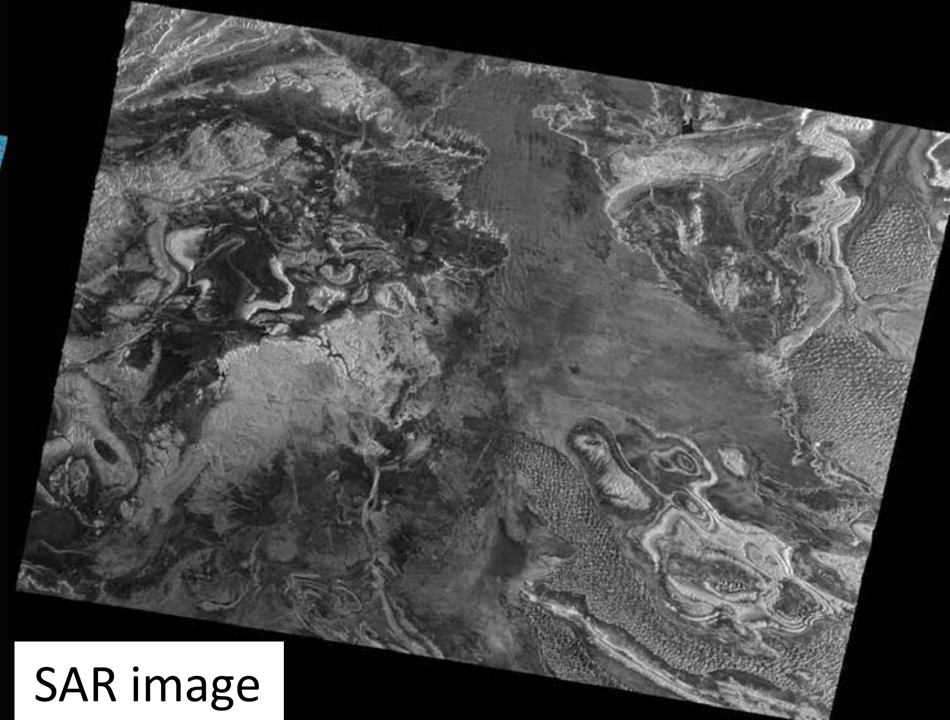


PALSAR DinSAR for Tohoku-Oki Earthquake





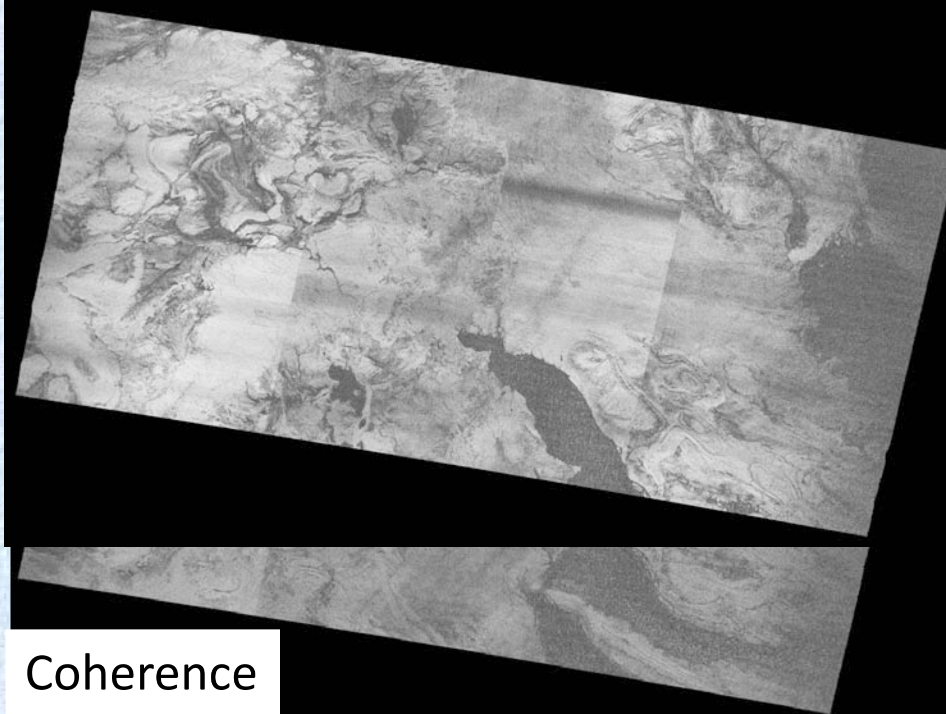
DSM



SAR image

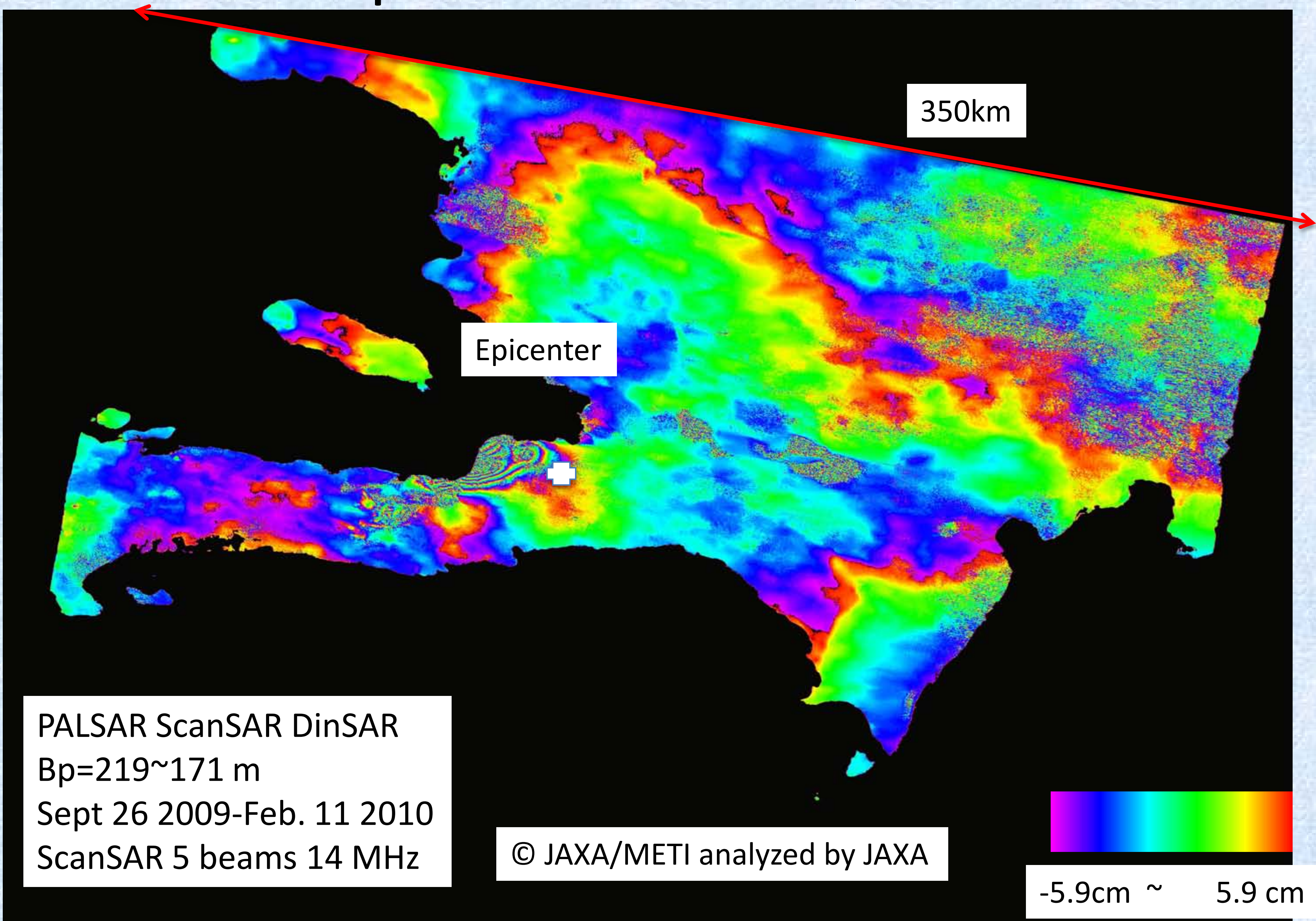
ScanSAR-ScanSAR Interferometry

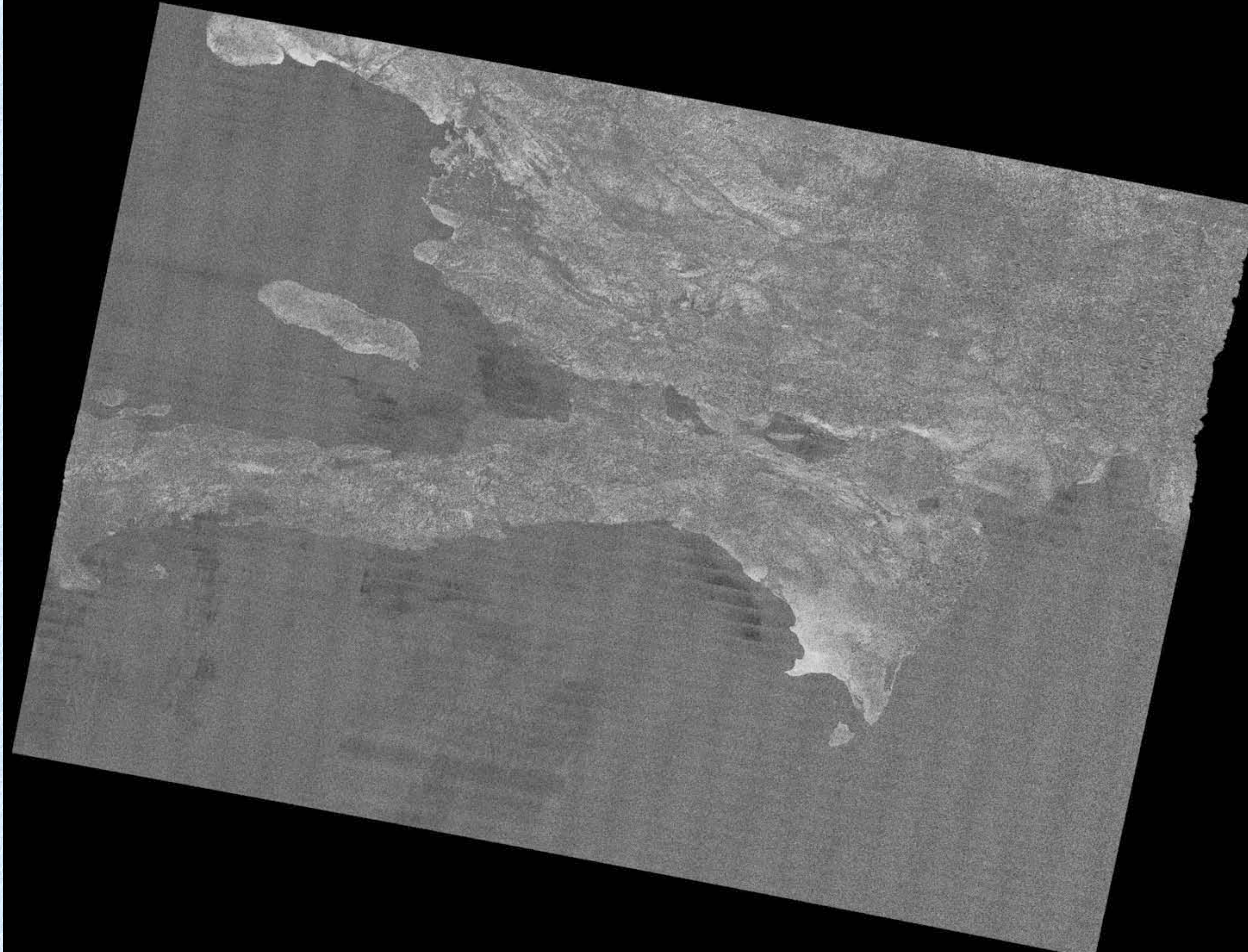
- High Coherence
- Wide image areas (350km)
- Saharan Dessert
- Bp~200m
- April 17 ~March 4, 2008



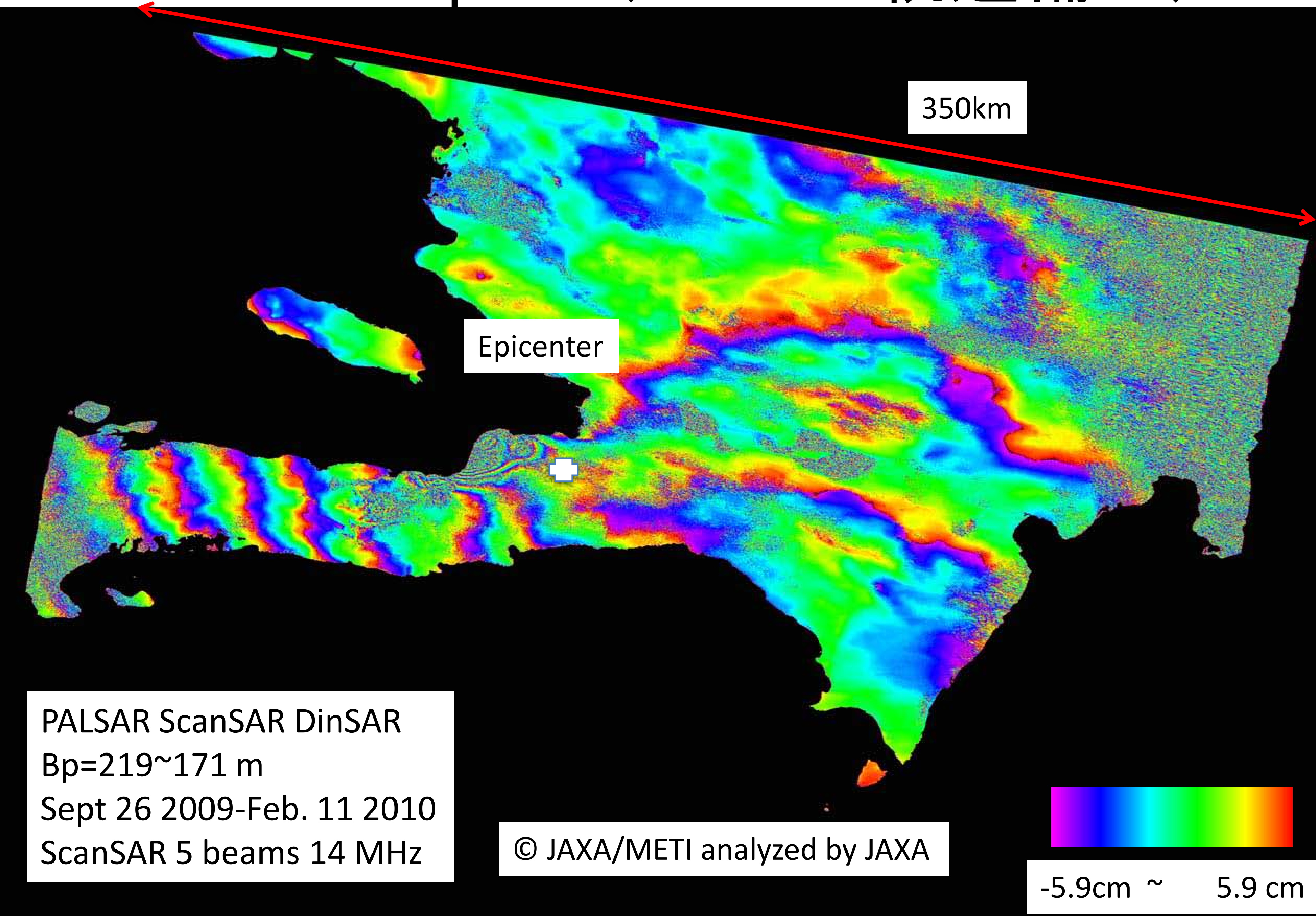
Coherence

Haiti Earthquake（ハイチ地震：精密軌道）





Haiti Earthquake（RARR＋軌道補正）

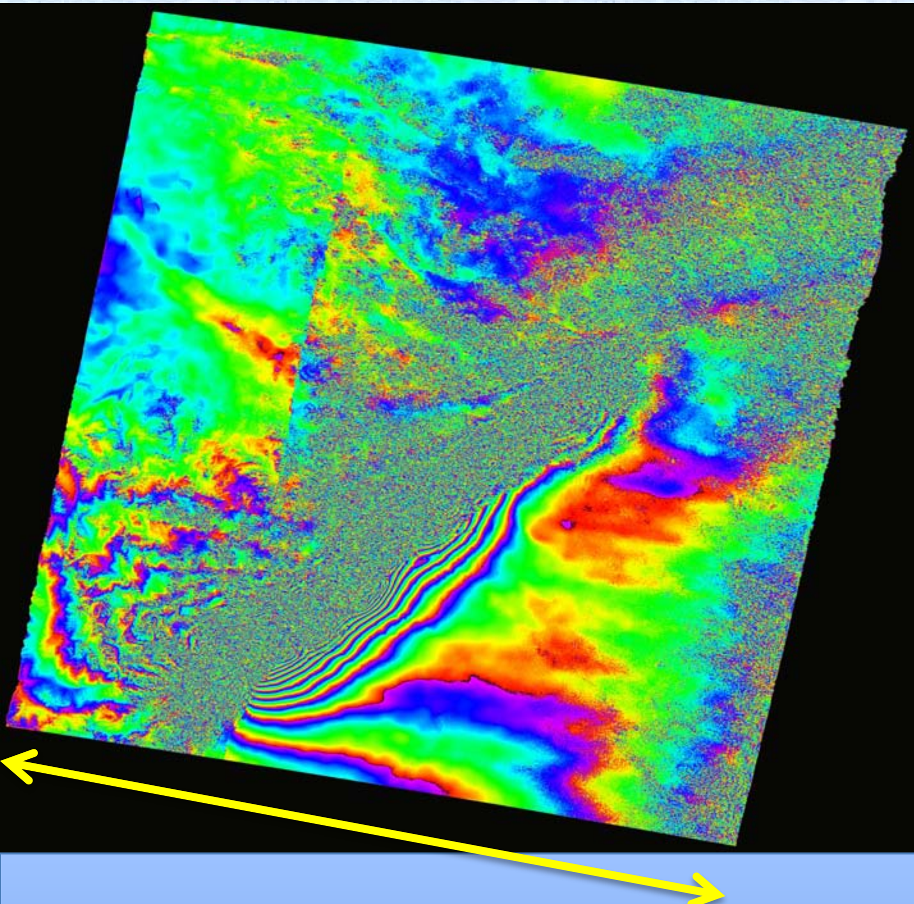


PALSAR ScanSAR DinSAR
Bp=219~171 m
Sept 26 2009-Feb. 11 2010
ScanSAR 5 beams 14 MHz

© JAXA/METI analyzed by JAXA

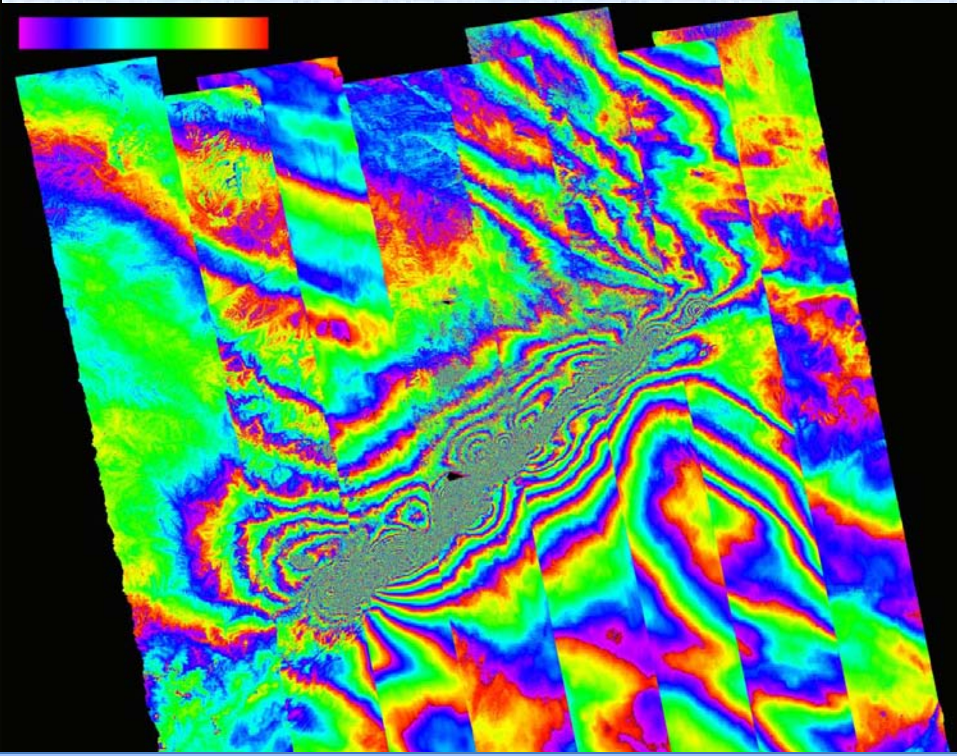
四川省大地震、2008年5月12日

ScanInSAR

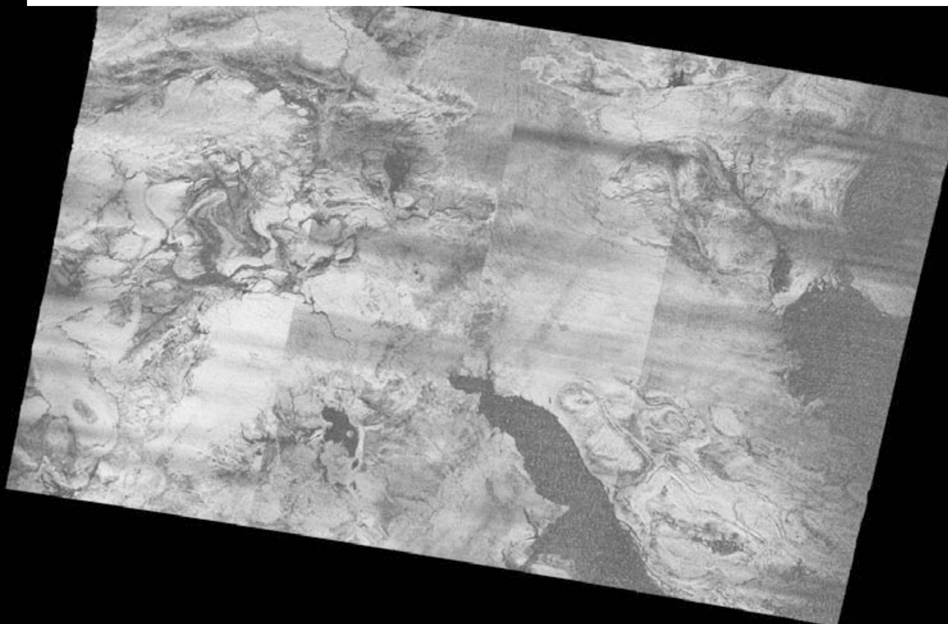


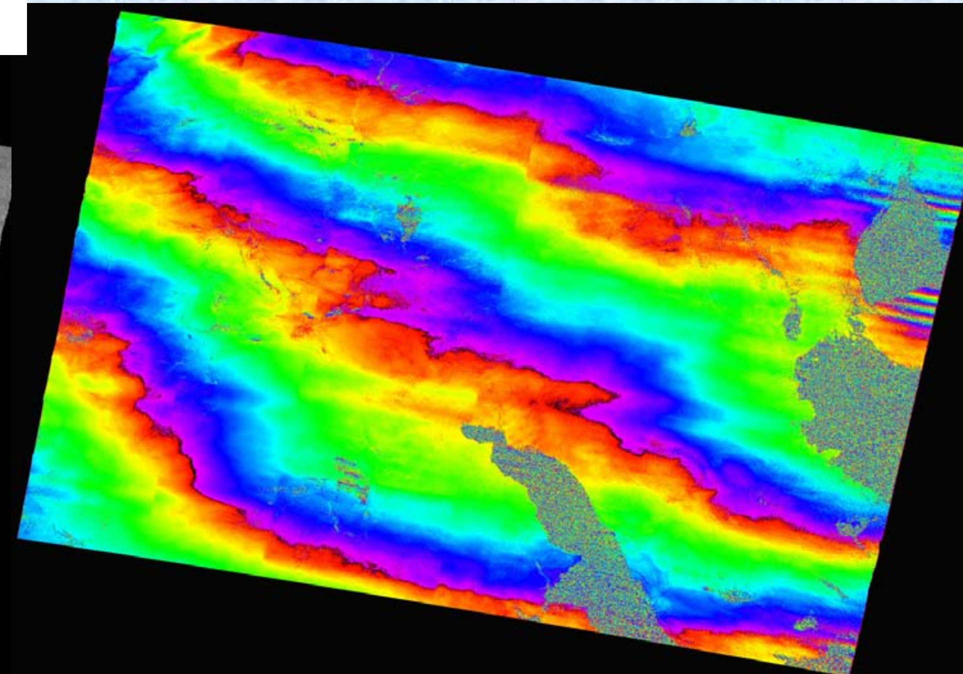
350km

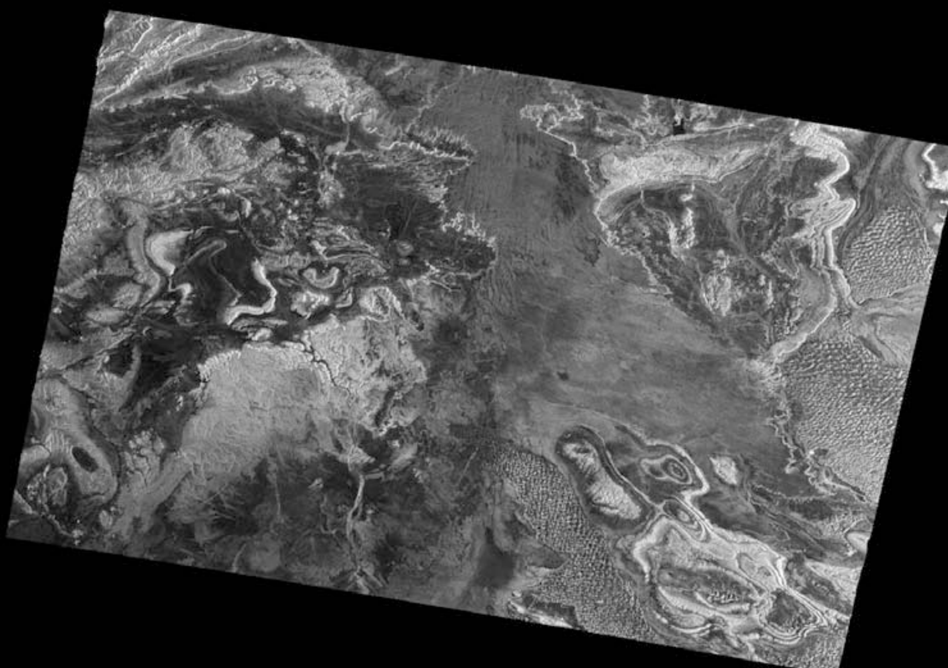
Strip SAR x 8

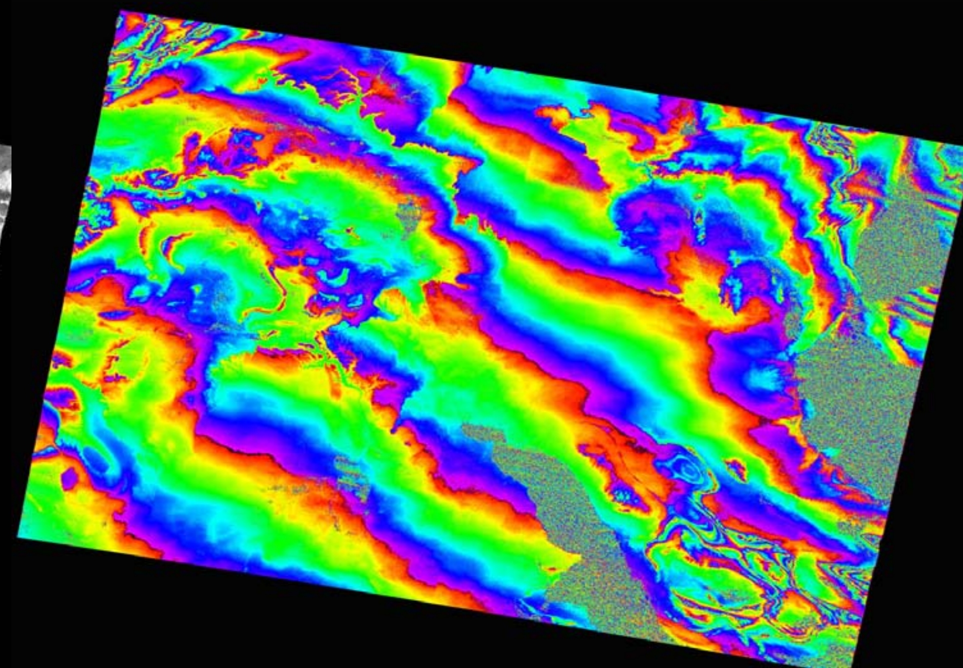


タンザニア:コヒーレンス最大化処理を実施

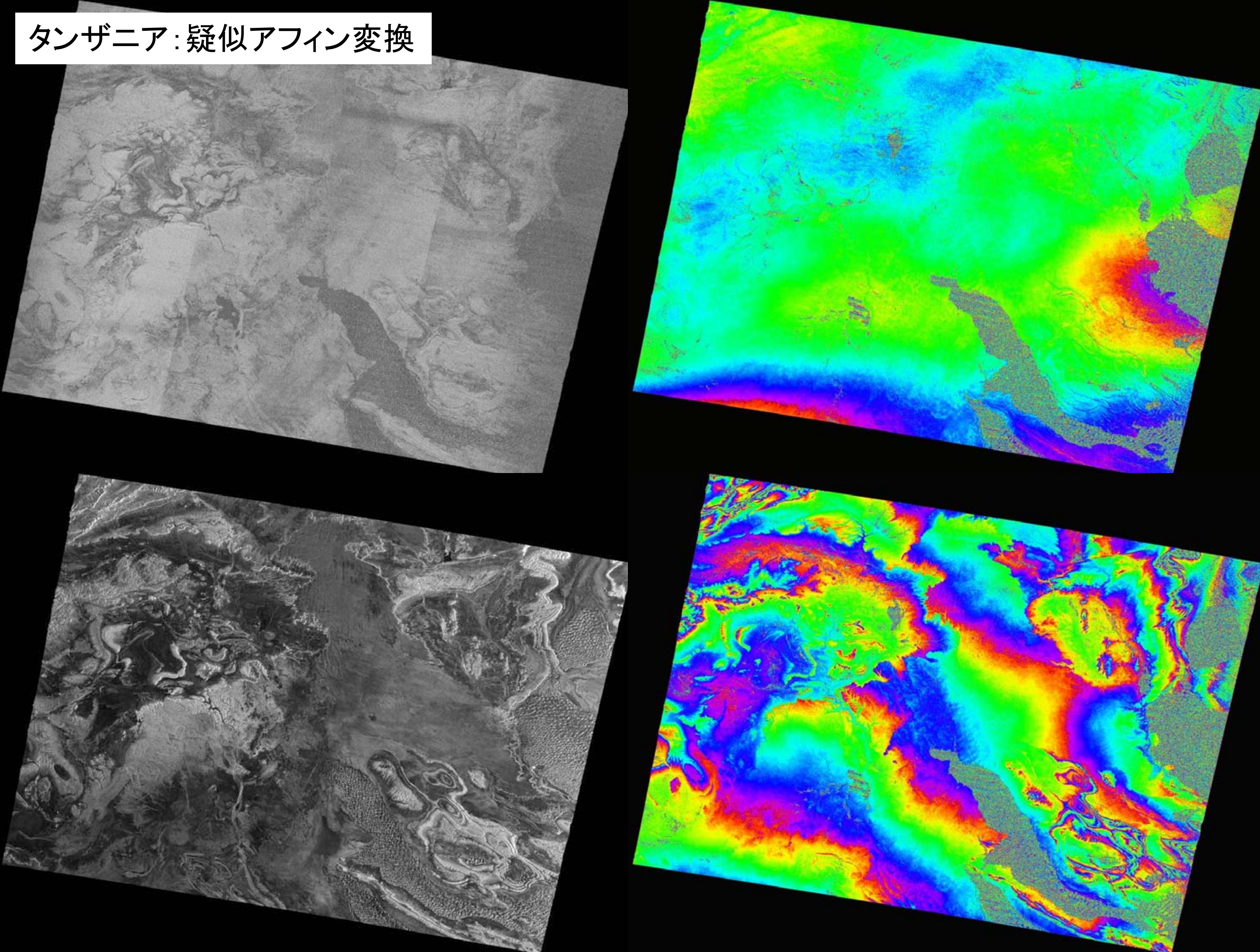








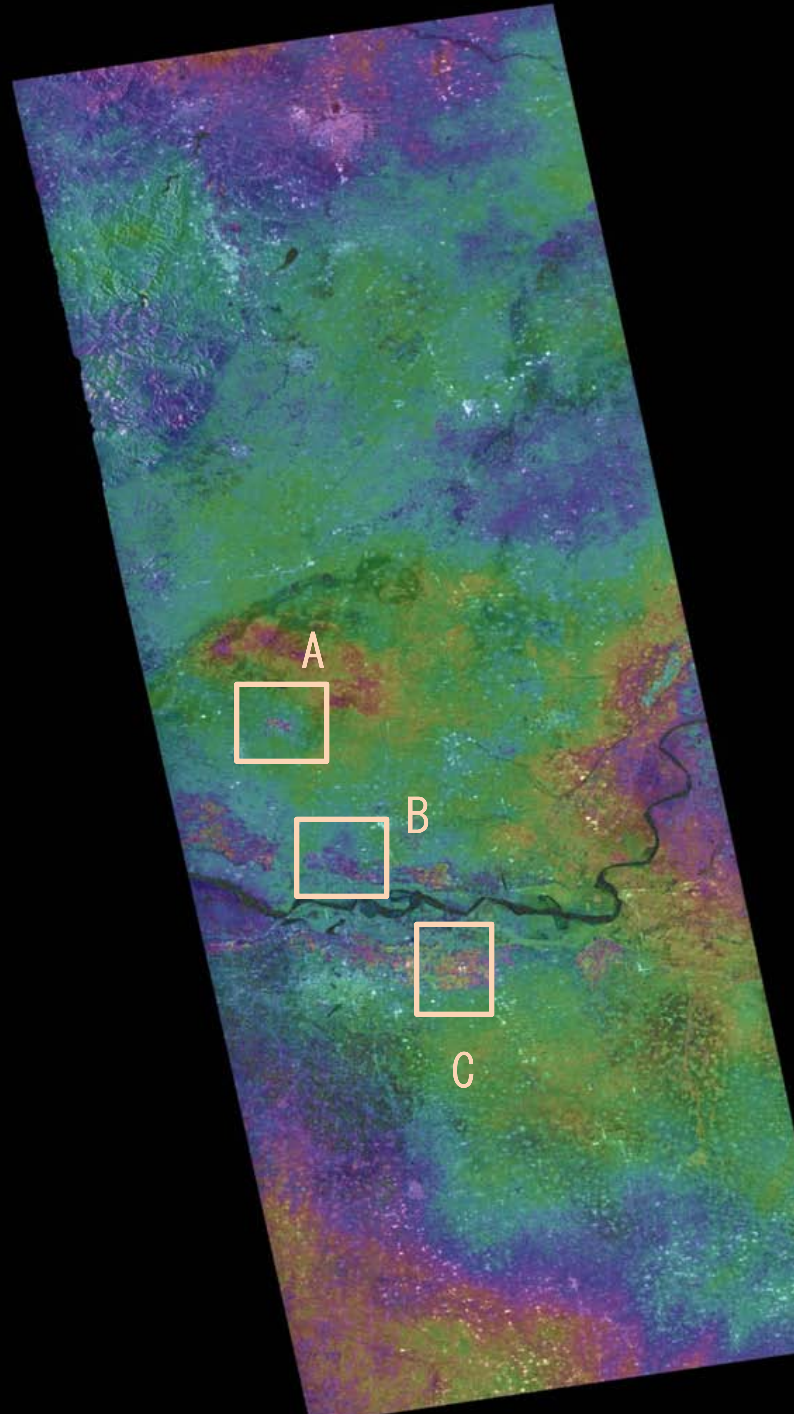
タンザニア:疑似アフィン変換

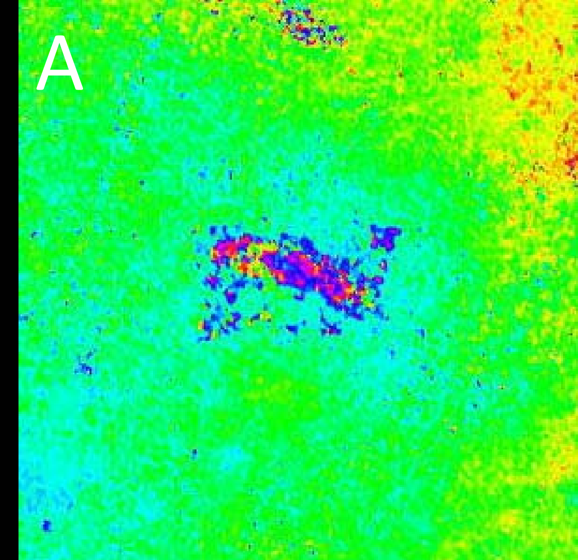


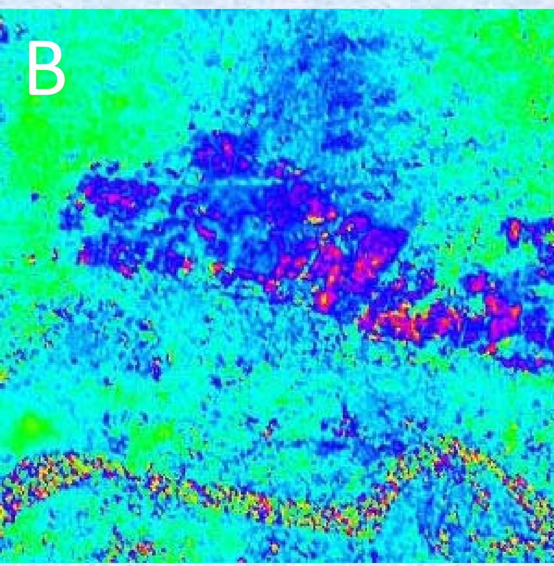
Drought and related subsidence around Yellow river, China

Master: FBS343H
2007/09/14
Slave : FBD343H
2007/07/30

Orb Distance: 110m

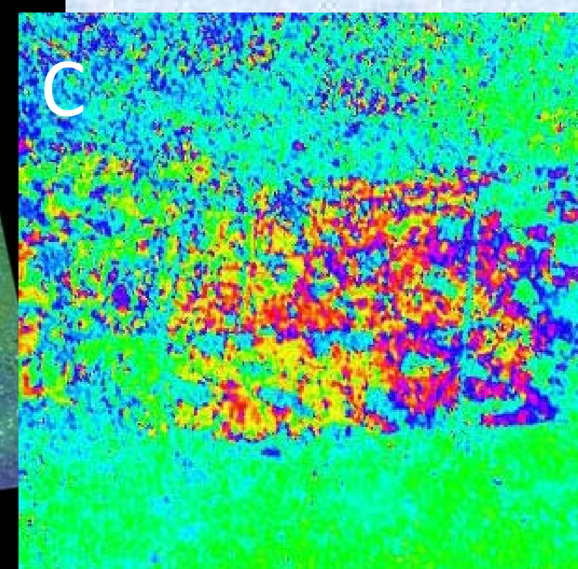




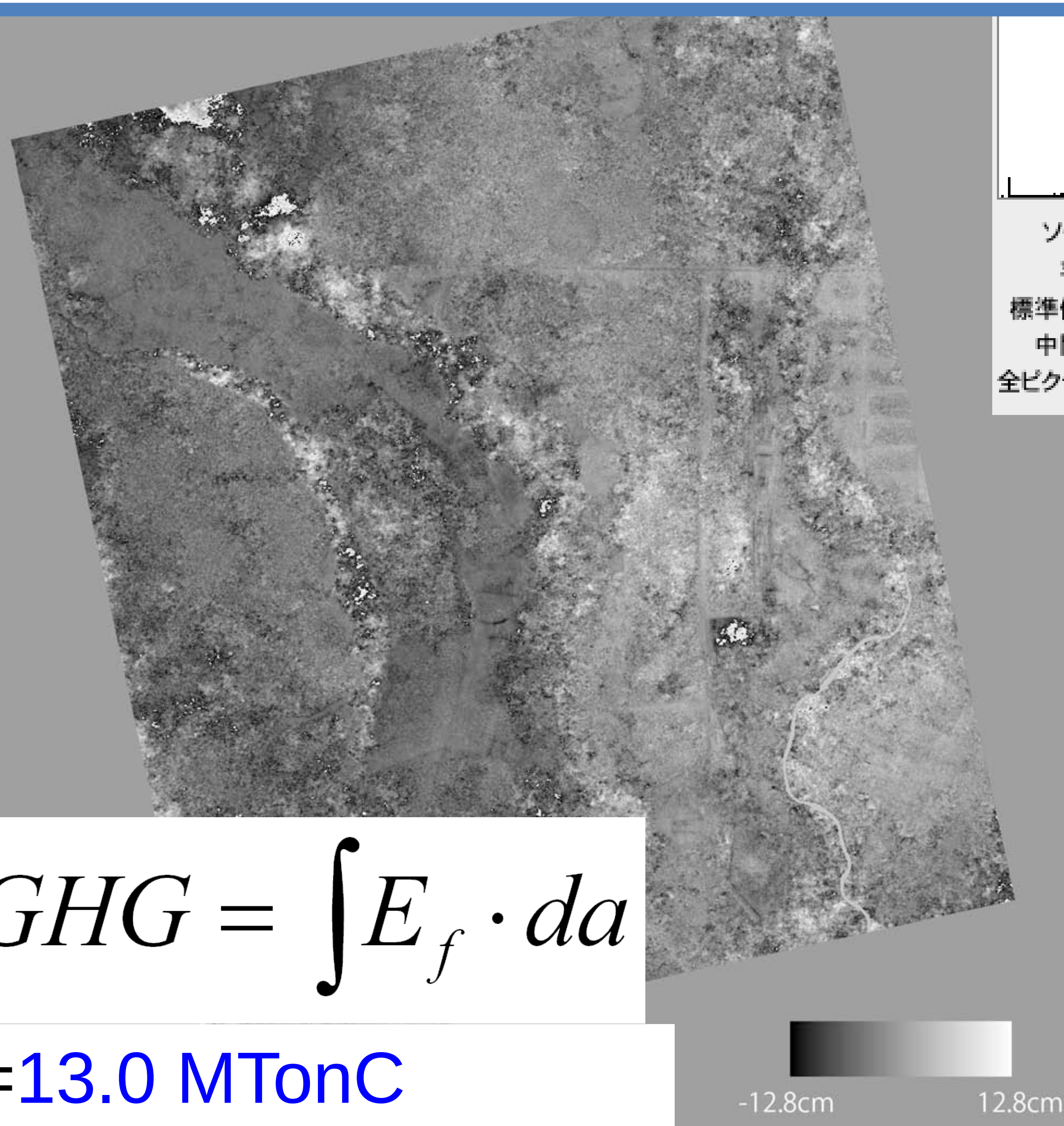


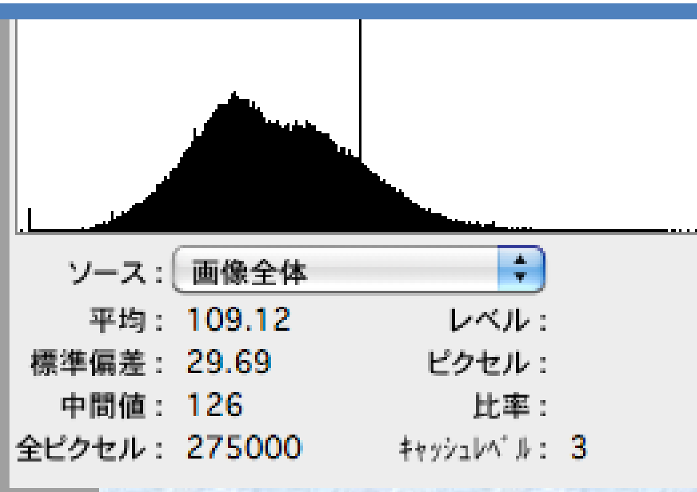
Subside

-5.9cm 5.9cm

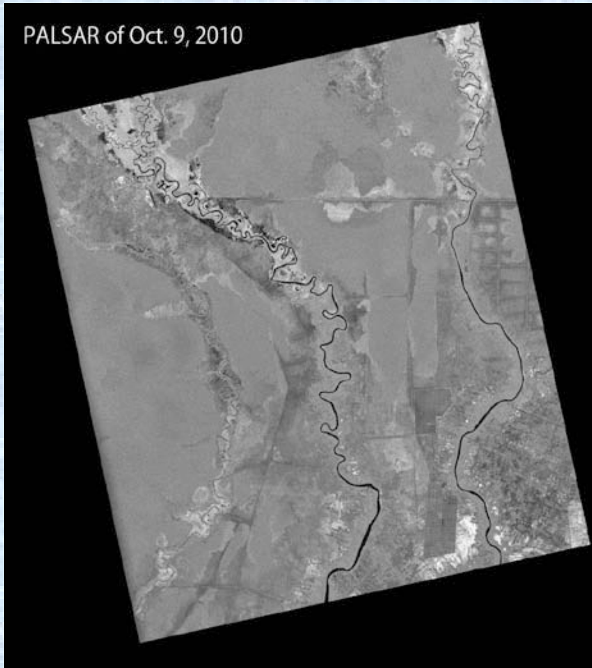


Subsidence and GHG emission at Central Kalimantan





mean-subsidence=
-3.030946e+00 cm/year

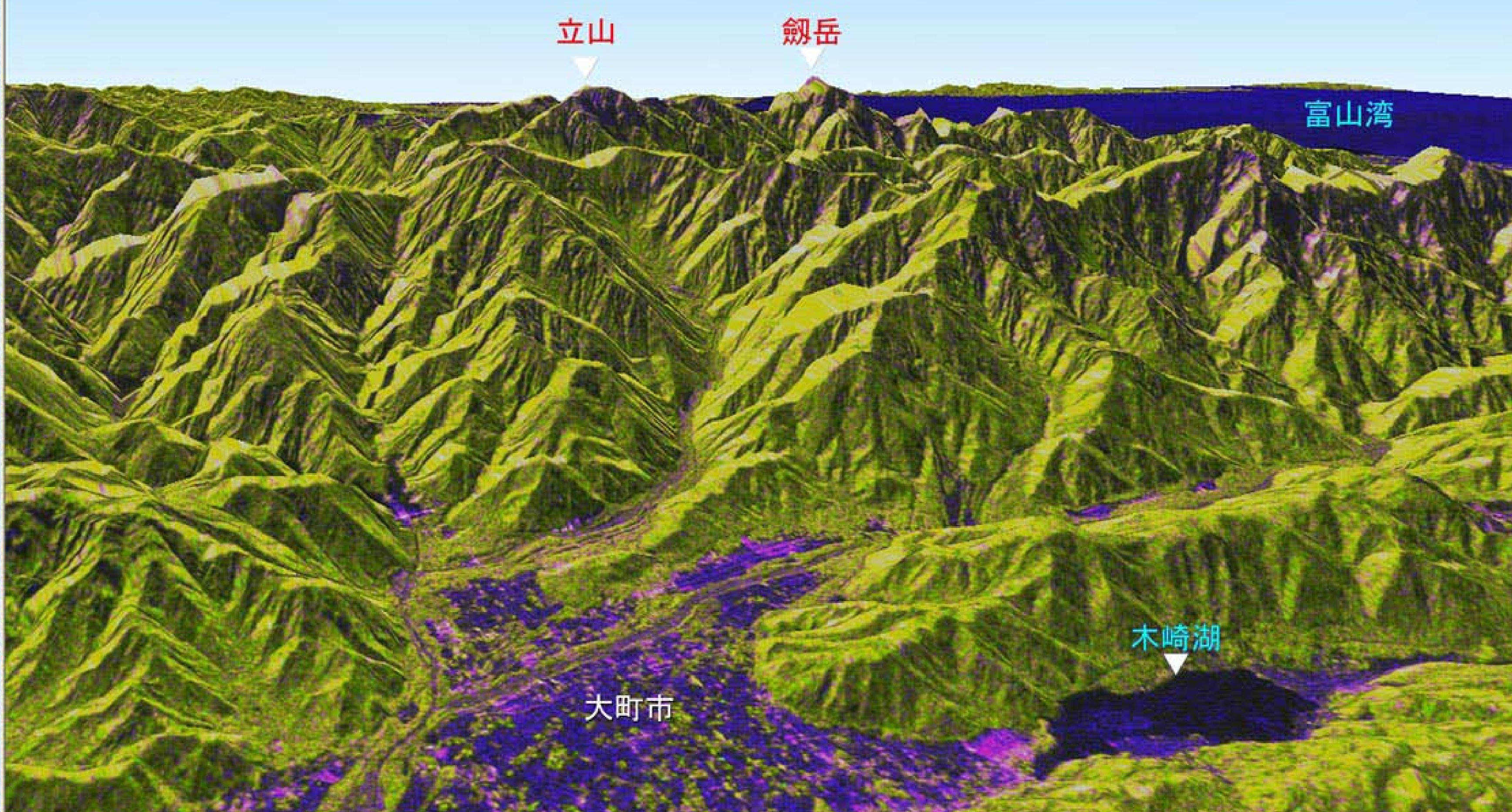


$$GHG = \int E_f \cdot da$$

=13.0 MTonC

PALSAR InSAR DEM

干渉SAR DEMの作成に関しては、46日以上の繰り返し干渉のために気象の影響を受ける。そのために、5ペア以上を相加平均して、誤差を小さくする。大山で評価して、30m以内の精度を確認した。本例は、富山県剣岳周辺のDEMを作成し、FBD画像を重ねあわせ、立体視したものである。2007年の生産数は5。4シーン／日であり、仕様を満足している。



InSAR Sensitivity – L band

- Incidence angle dependence
- Seasonality
- Ionosphere (TID and Plasma Bubble)
- Orbit Accuracy and Statistics
- Multi Frequency Comparison
- Comparison between JERS-1 and PALSAR

Coherence analysis: Temporal correlation

$$\gamma_{total} = \frac{\left|\langle a \cdot b^* \rangle\right|}{\sqrt{\langle a \cdot a^* \rangle \langle b \cdot b^* \rangle}}$$

$$= \gamma_{temp} \cdot \gamma_{space} \cdot \gamma_{SNR} \cdot \gamma_{vol}$$

$$\gamma_{temp} = \frac{\gamma_{total}}{\gamma_{SNR} \cdot \gamma_{space} \cdot \gamma_{vol}}$$

$$\gamma_{vol} \leq \mathrm{sinc}\left(k_z h_v / 2\right)$$

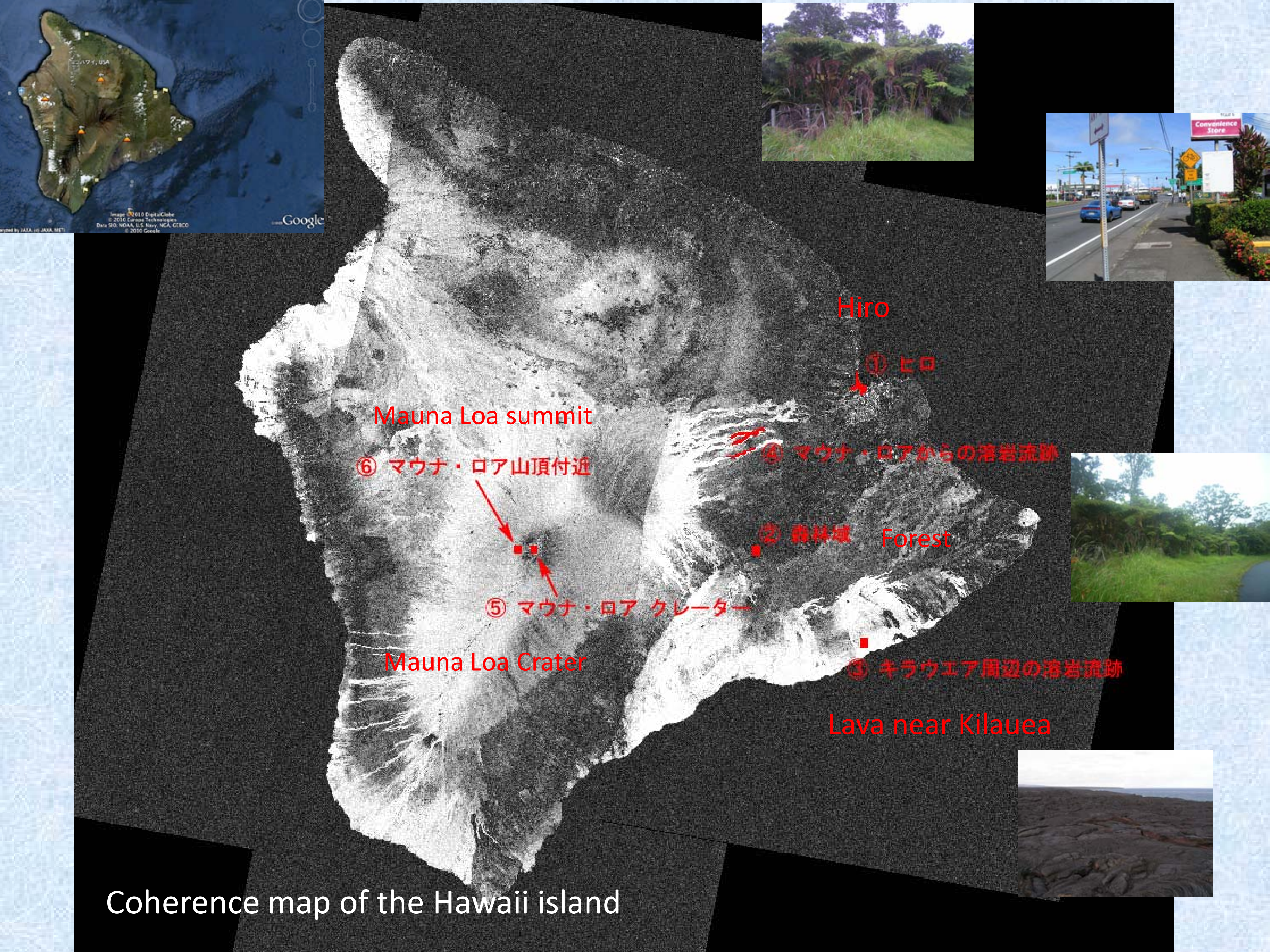
kz: the sensitivity of interferometric phase to height, hv: ambiguous volume height

$$\gamma_{space} \approx 1 - \frac{2|B|\cos^2\theta}{\lambda r} \frac{c}{B_w \sin\theta}$$

θ: incidence angle, Bw: Band width
r: slant range, B: baseline

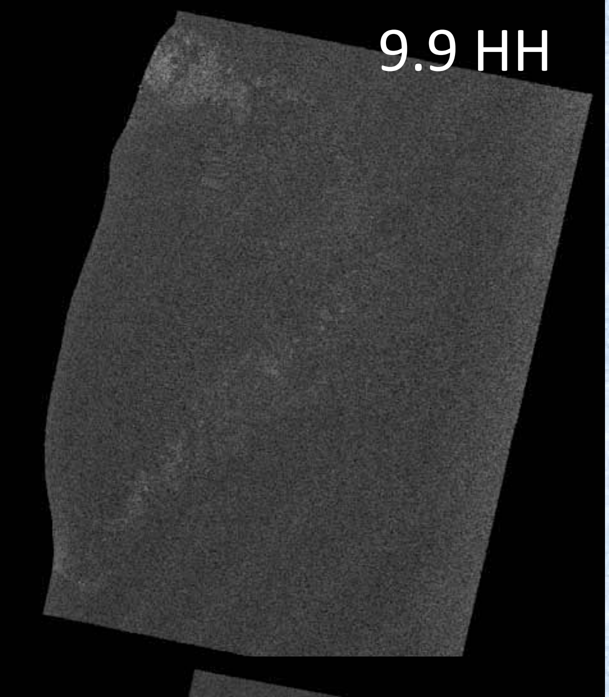
$$\gamma_{SNR} = \frac{1}{1 + SNR^{-1}}$$

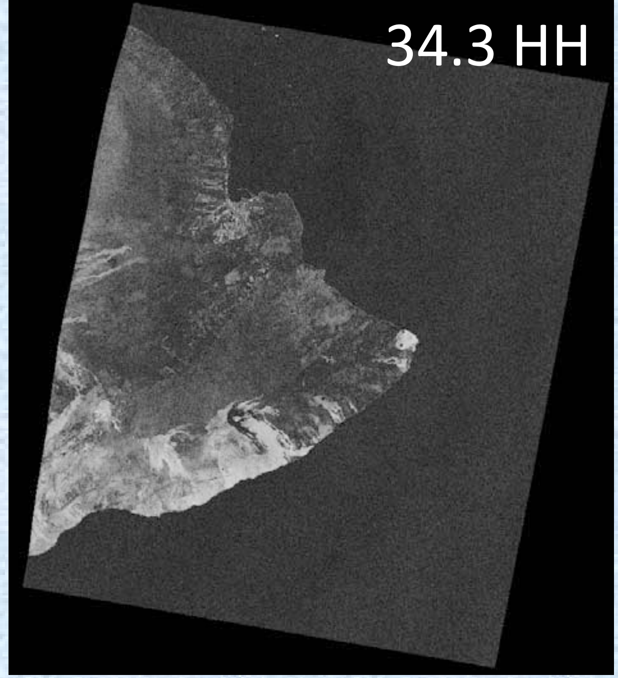
γ_{SNR}	σ^0	σ^0_{NE}	sensor
~0.9	-5~-10 dB	-18 dB	JERS-1
1.0	-8 ~ -15 dB	-25 dB	PI-SAR
1.0	-8~-15dB	-27~-34dB	PALSAR

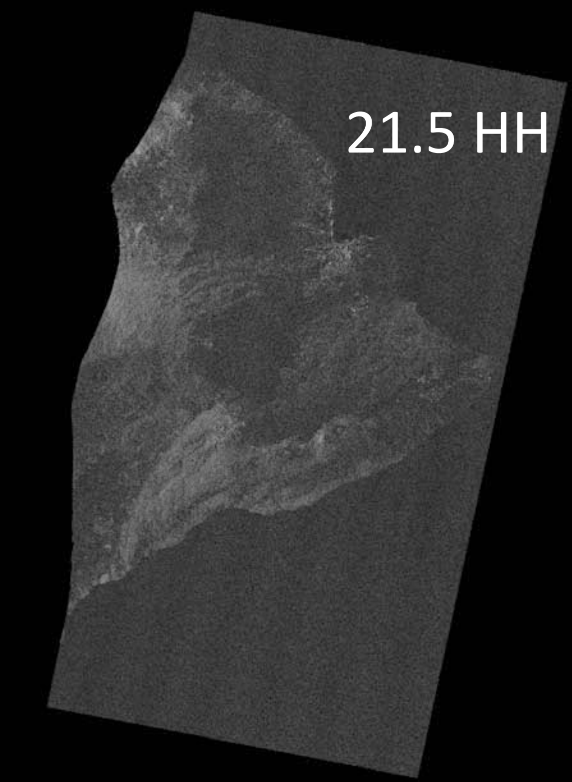


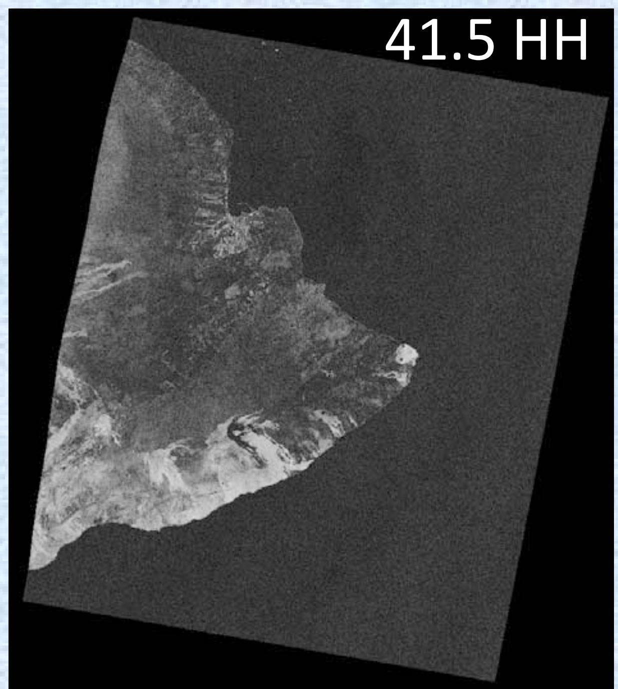
Coherence map of the Hawaii island

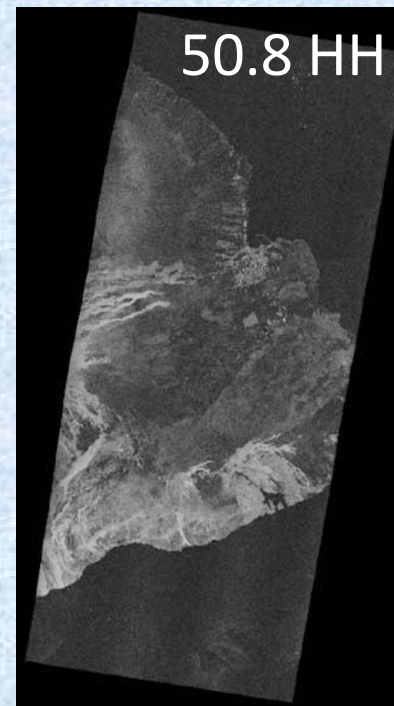
Comparison of coherence WRT off-nadir angle



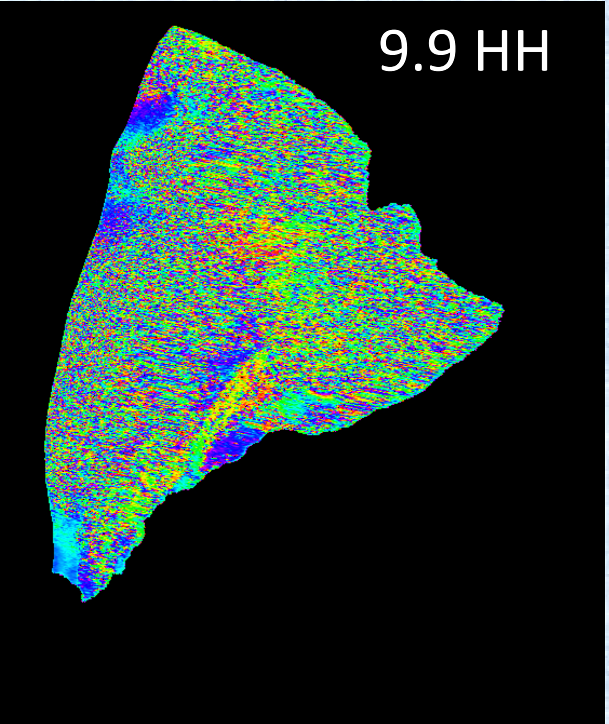


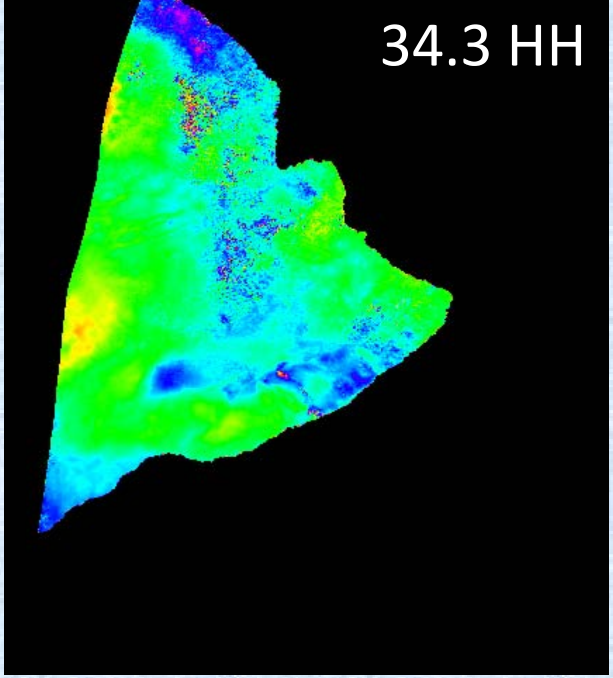


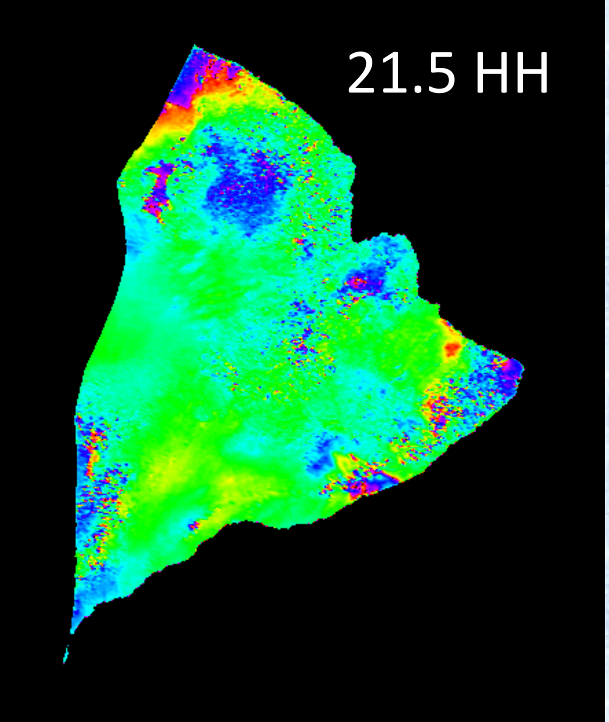


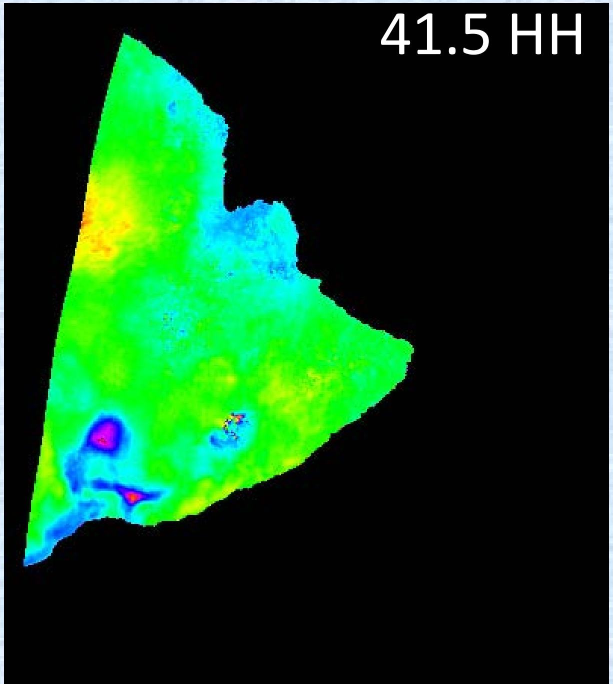


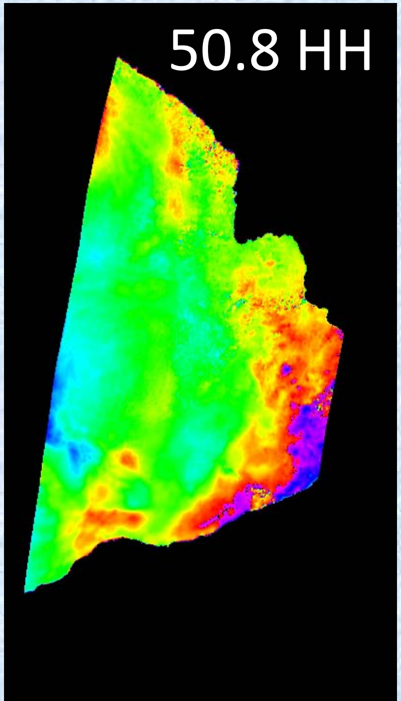
Comparison of DinSAR WRT off-nadir angle





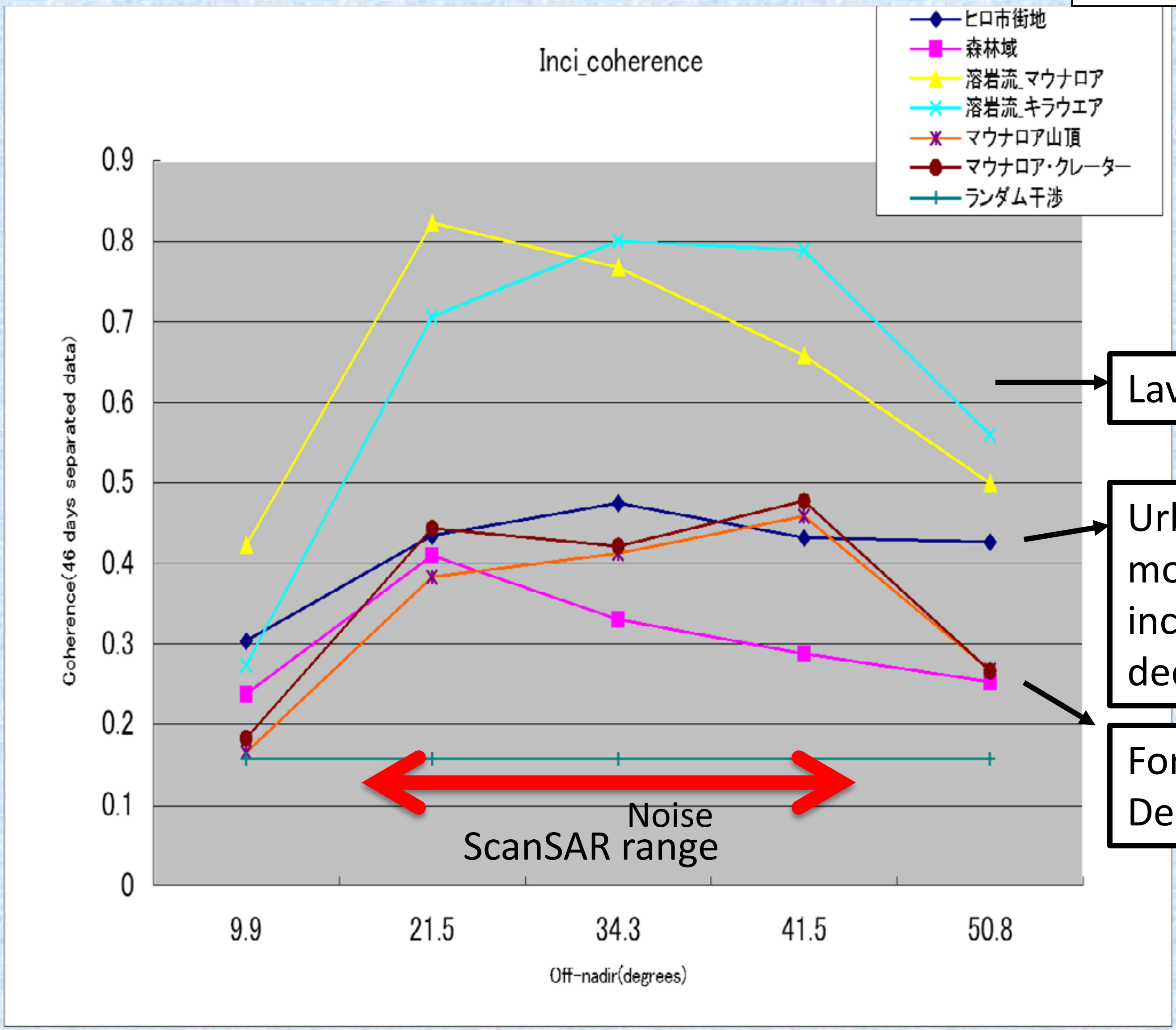






Incidence angle dependence of coherence

Condition:
Only 46 days separated data used.
No-temporal correlation corrected
Bp:~200m
No. of data ~ 2,3.



Lava: shows high coherence

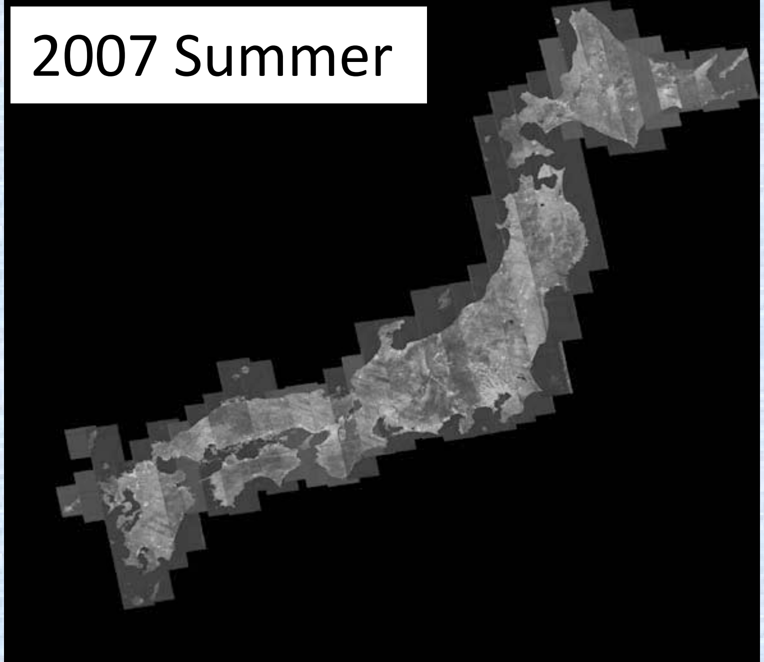
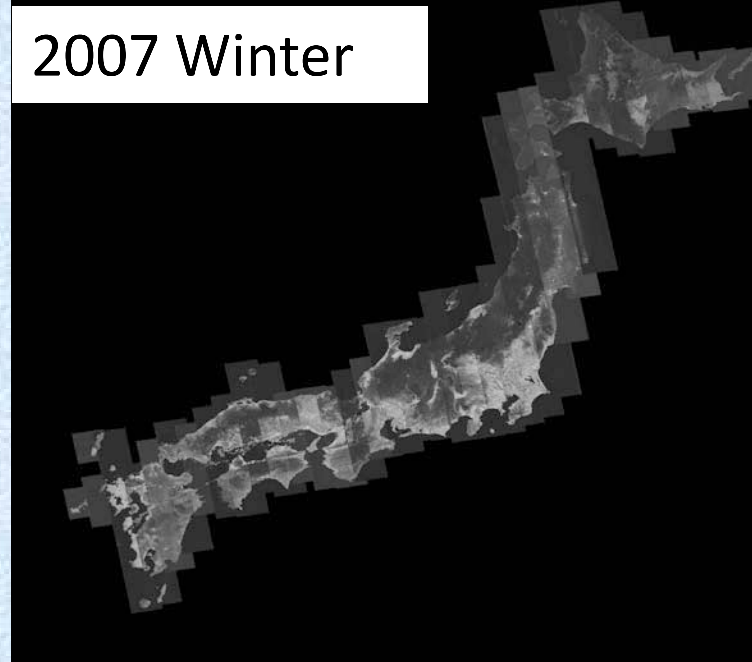
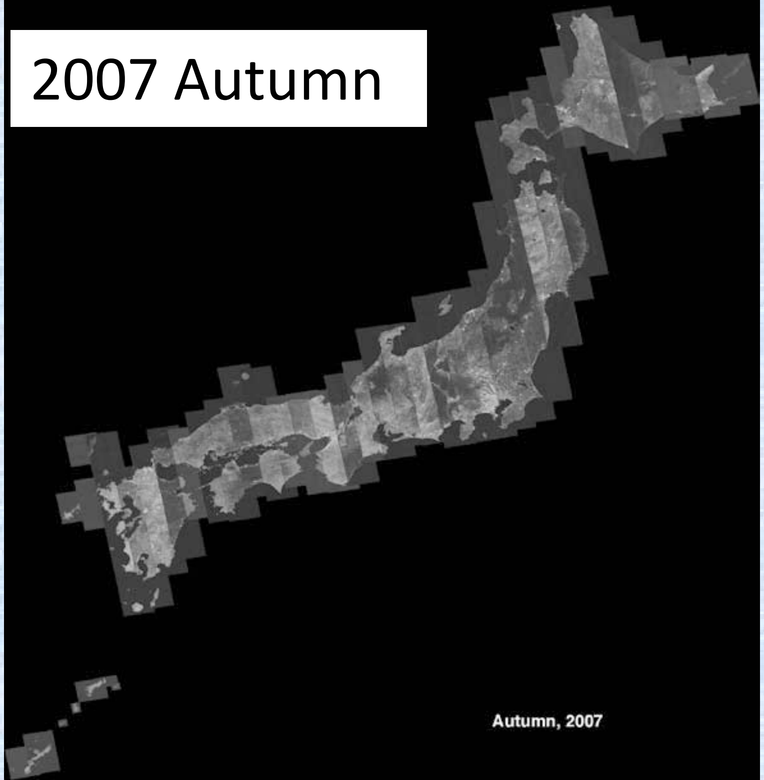
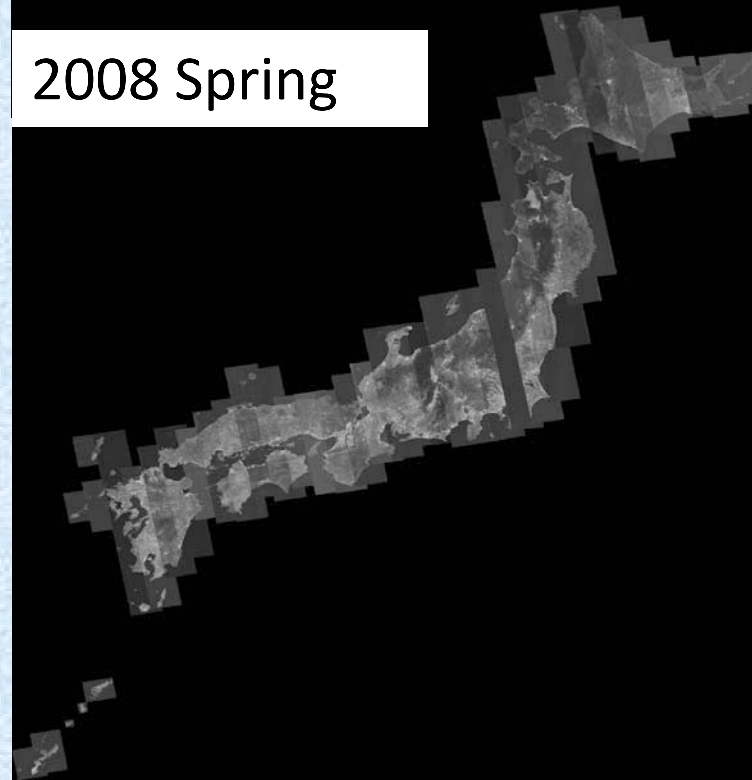
Urban and volcanic mountain :increase with the incidence angle by41.5, then decreases.

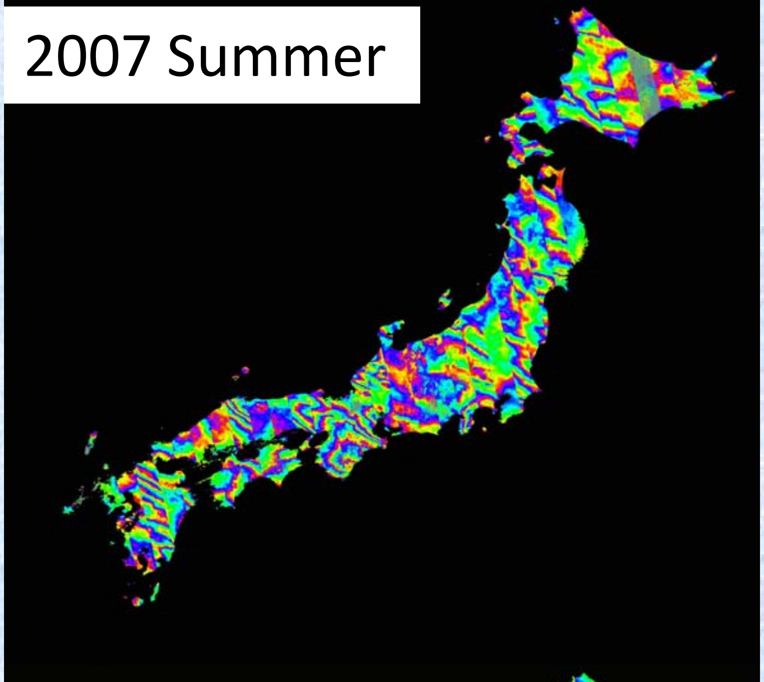
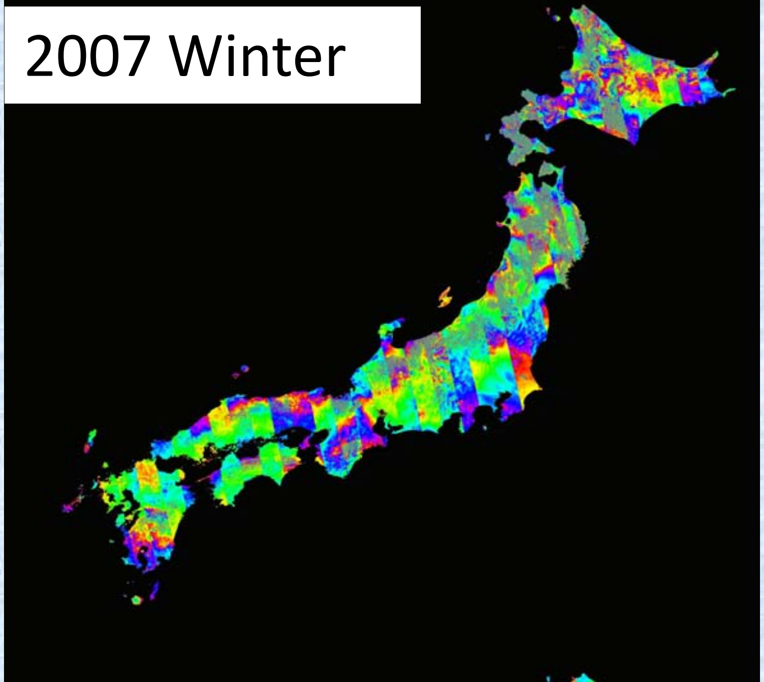
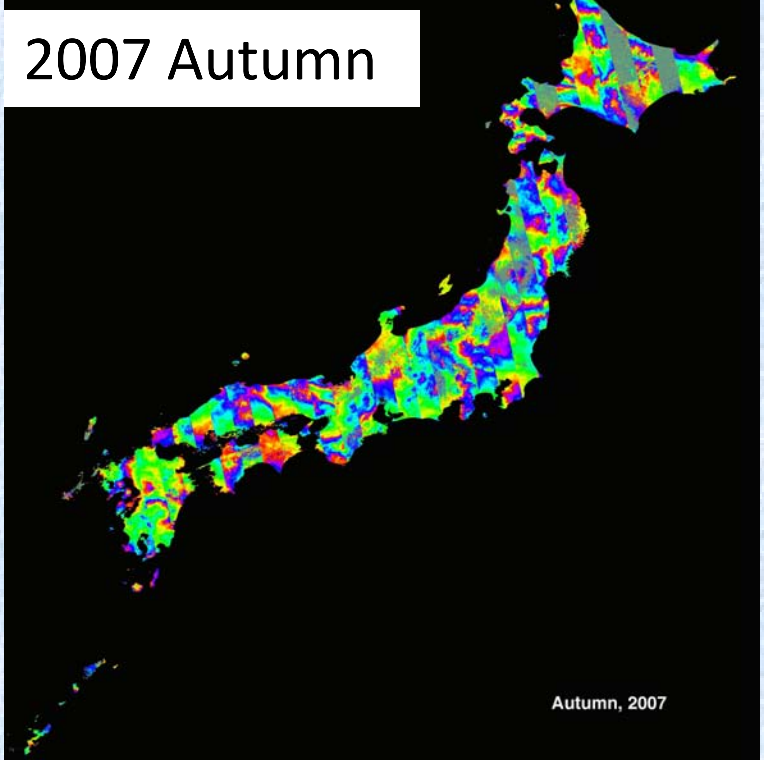
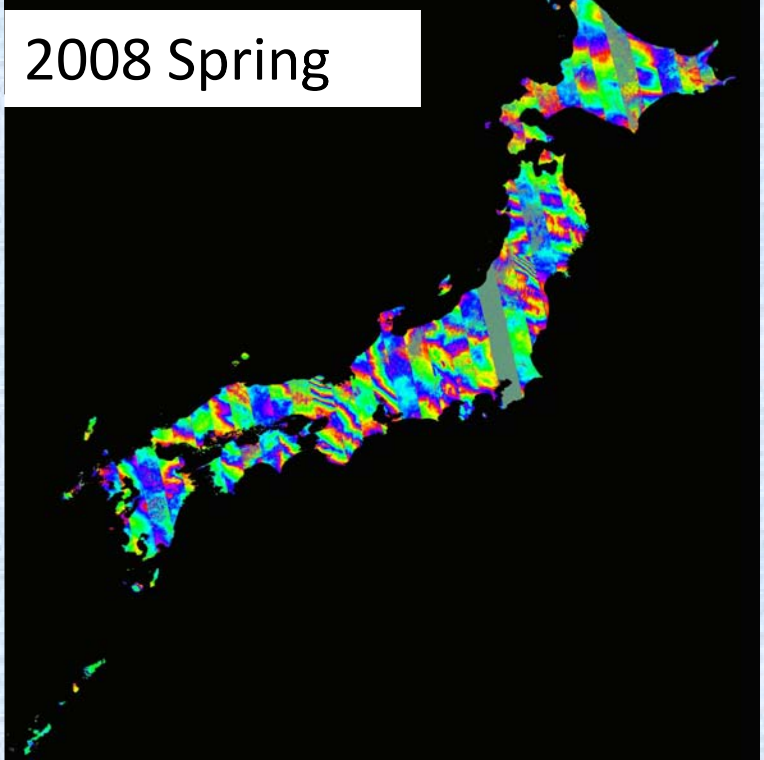
Forest: maximized at 21.5. Decreased after the angle.

Type A: Others
Type B: Forest

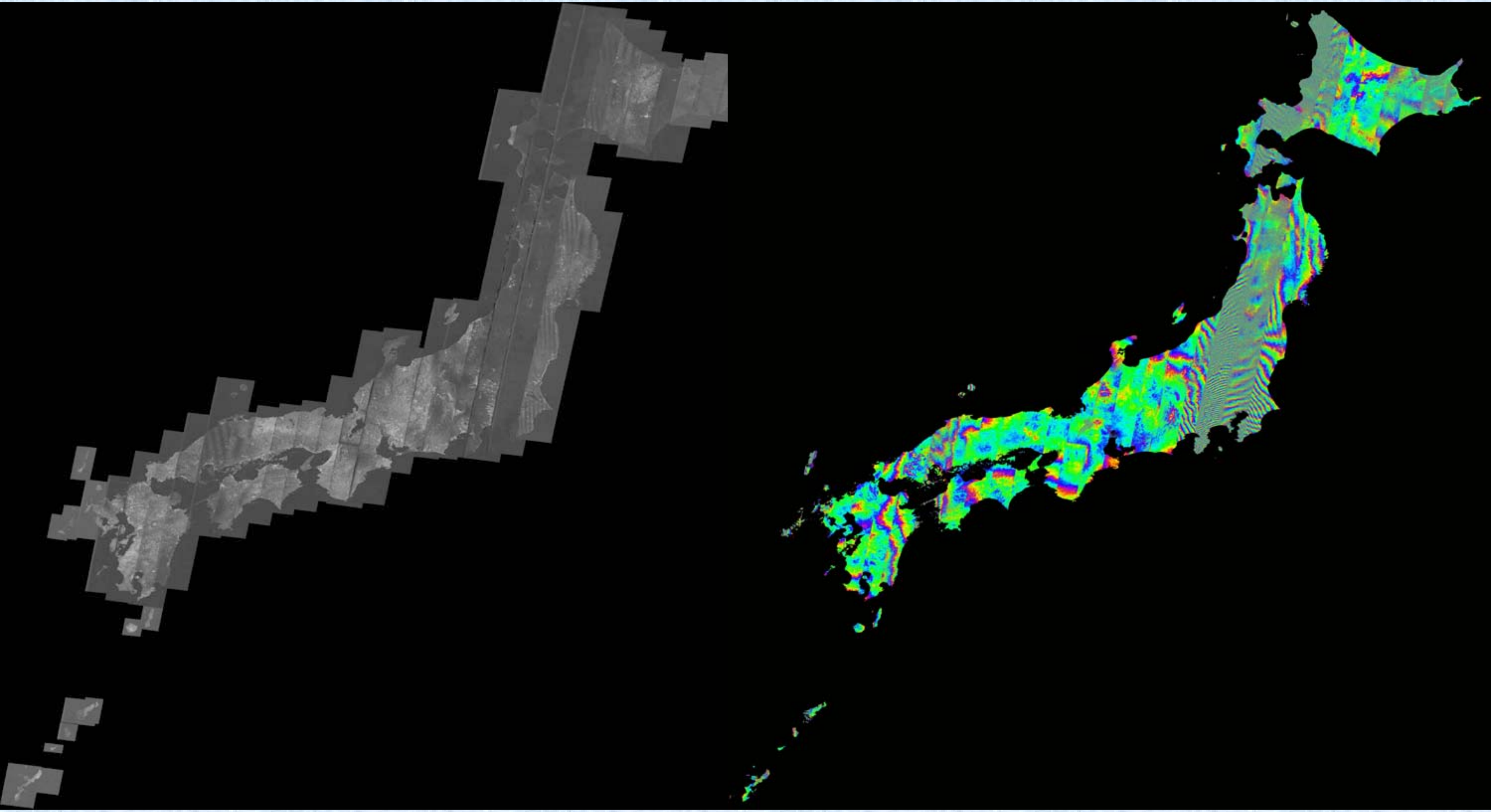
PALSAR InSAR coherence WRT Season

- SAR Processor: SIGMA-SAR
- Total Data：500GB：Two sets of 41 passes covering Japan (2007 summer, 2007 autumn, 2007 winter, and 2008 spring)
- Precise Orbit: (40 cm: 3 sigma)
- Evaluation Items
  - Coherence vs. season
  - Deformation Uniformity vs. season
  - Perpendicular Baseline Characteristics


2007 Summer

2007 Winter

2007 Autumn
Autumn, 2007

2008 Spring


2007 Summer

2007 Winter

2007 Autumn
Autumn, 2007

2008 Spring

JERS-1 SAR data



Summary

- Coherence:
- Summer > Winter (Mountain area lower values)
- Mountain area: lower than flat (larger band width)

- Phase deformation: Winter is more uniform than Summer
- Descending orbit is better than Ascending orbit

- Best selection: Winter and descending orbits

- Select a bit larger off-nadir for better coherence(ScanSAR beam selection)

Orbit determination

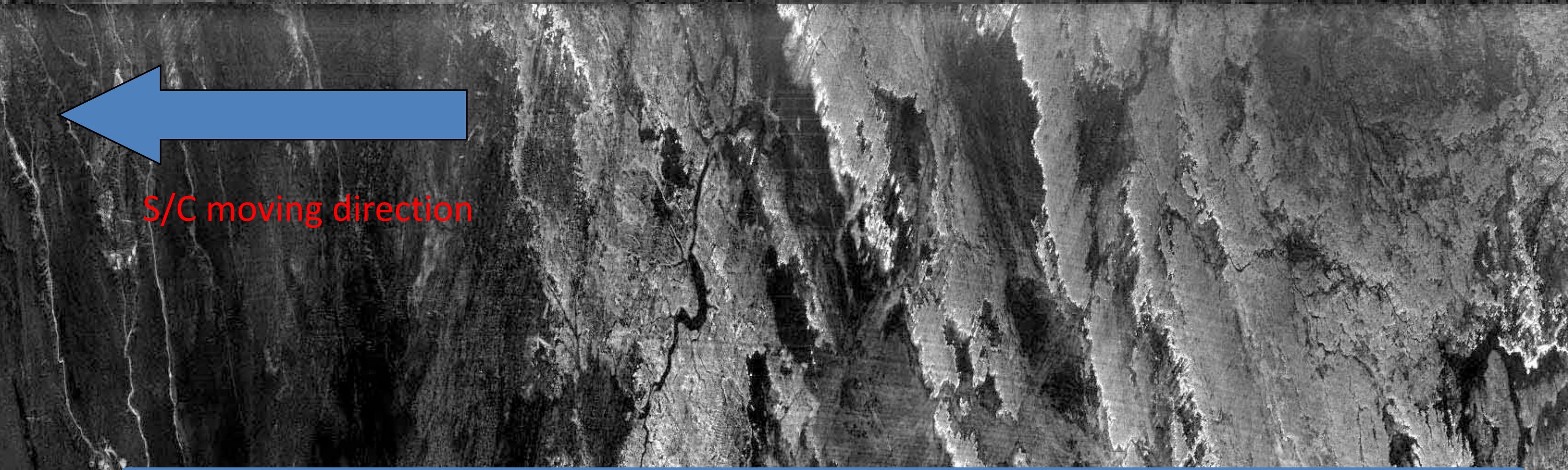
Orbit determination	Spec.	Measurements (* is after May 16 2006)		
Onboard determination (<95%) Quick distribution	< 200 m	35m	Random	23m (X: 8m, Y: 8m, Z: 20m, all 2σ)
			bias	12m (2σ)
GUTS-offline determination(3σ) Three days for distribution after observation	< 1m	0.40 m*	random	0.21m* (3σ) (Overlap method)
			bias	0.18m (3σ) (SLR ranging of Aug.)

Type of orbits

- Range and range rate(Estimated)
- Range and range rate(post processed)
- Onboard data
- GUTS-off line data (Most accurate)

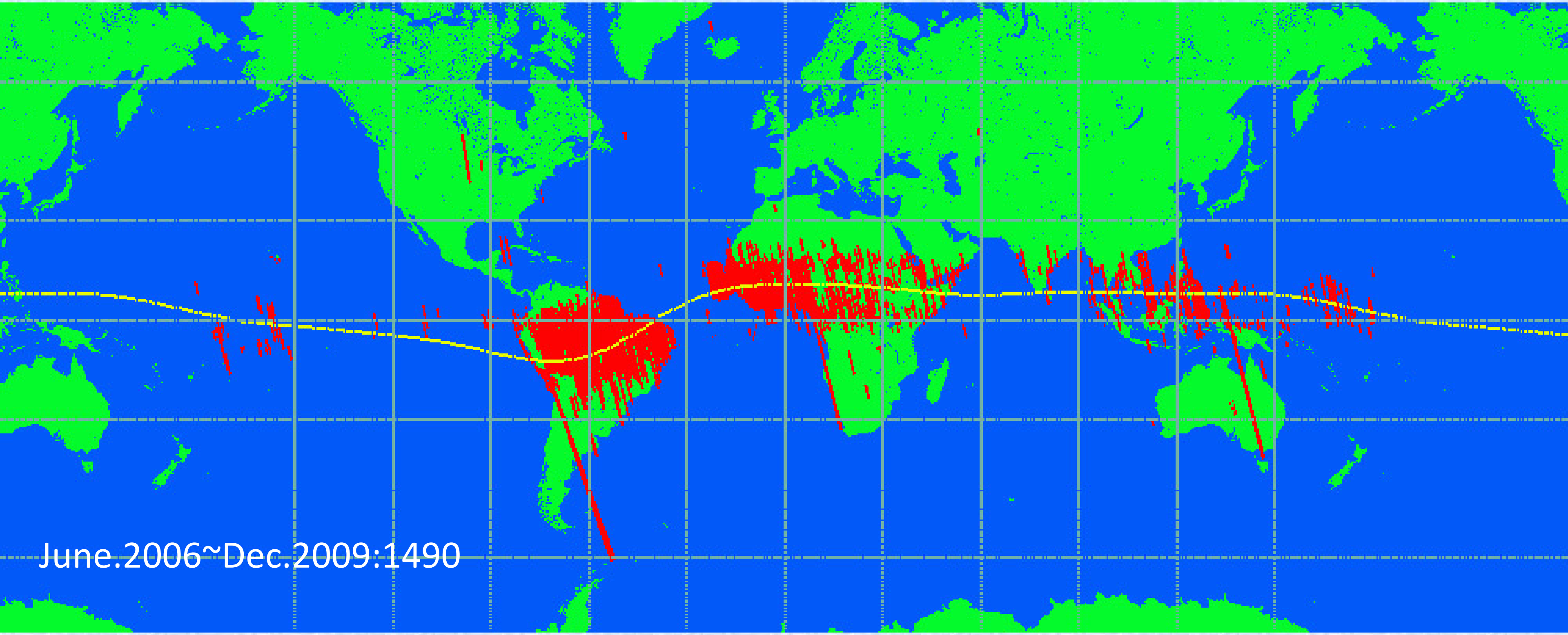
ECR(Earth Centered Rotational)

recommended



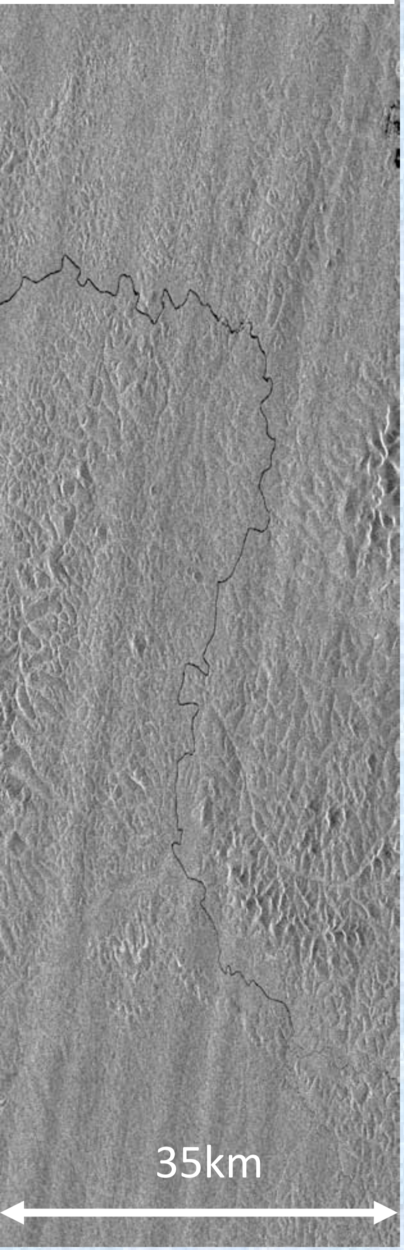
Plasma Bubble and the related PALSAR Images

PALSAR Streaks Appearance

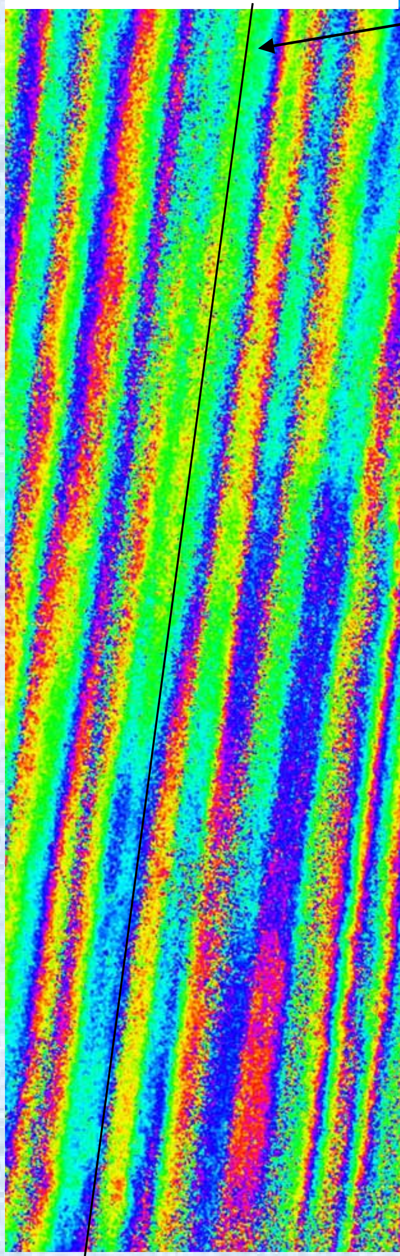


Total number of appearance : 1490 : June 2006~Dec. 2

Amplitude image (hh polarization) 2006/11/05



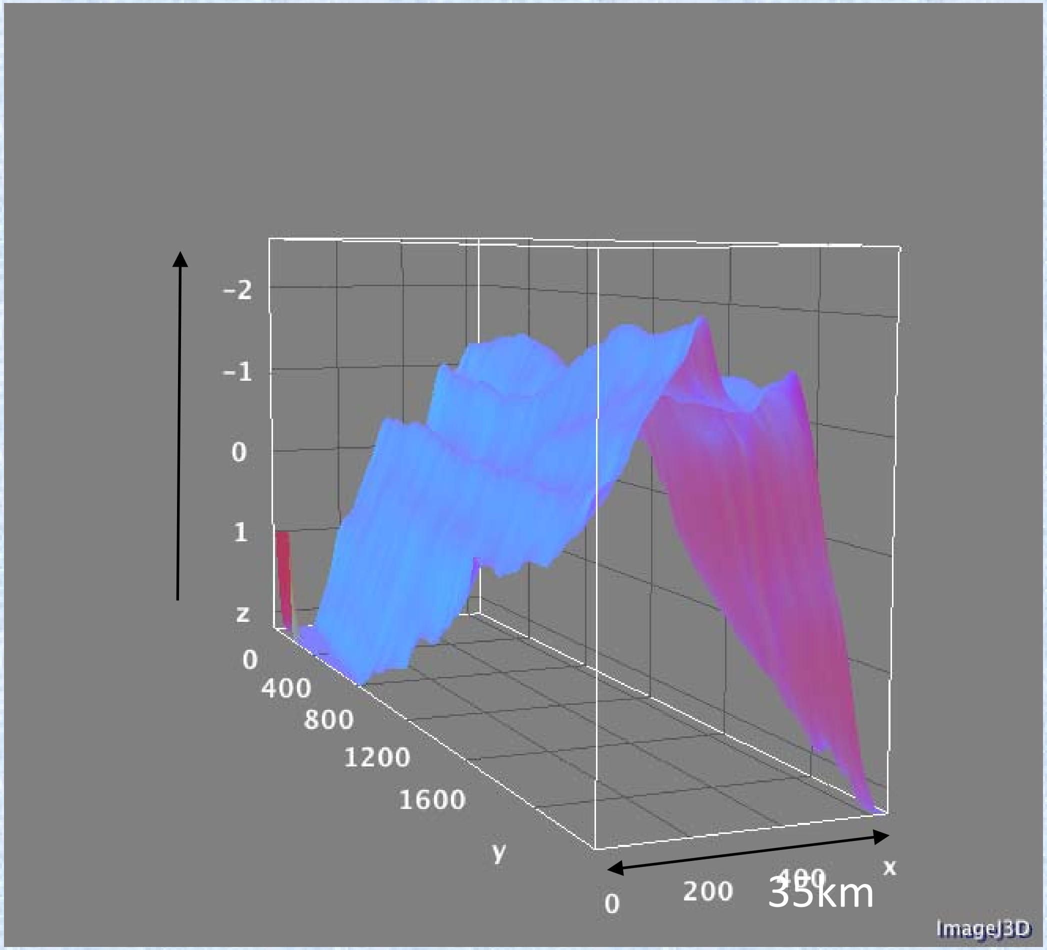
Phase (orbit and terrain corrected phase)



One example of lower latitude case in Brazil

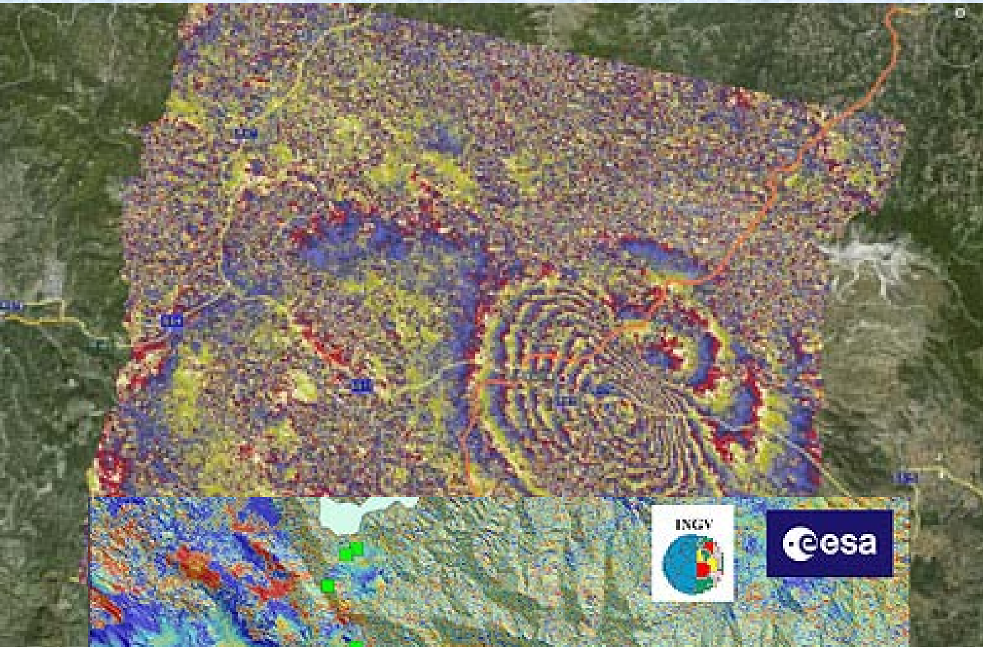
Direction of the line – parallel to the geomagnetic line

20060920-20061105:RSP072:Brazil



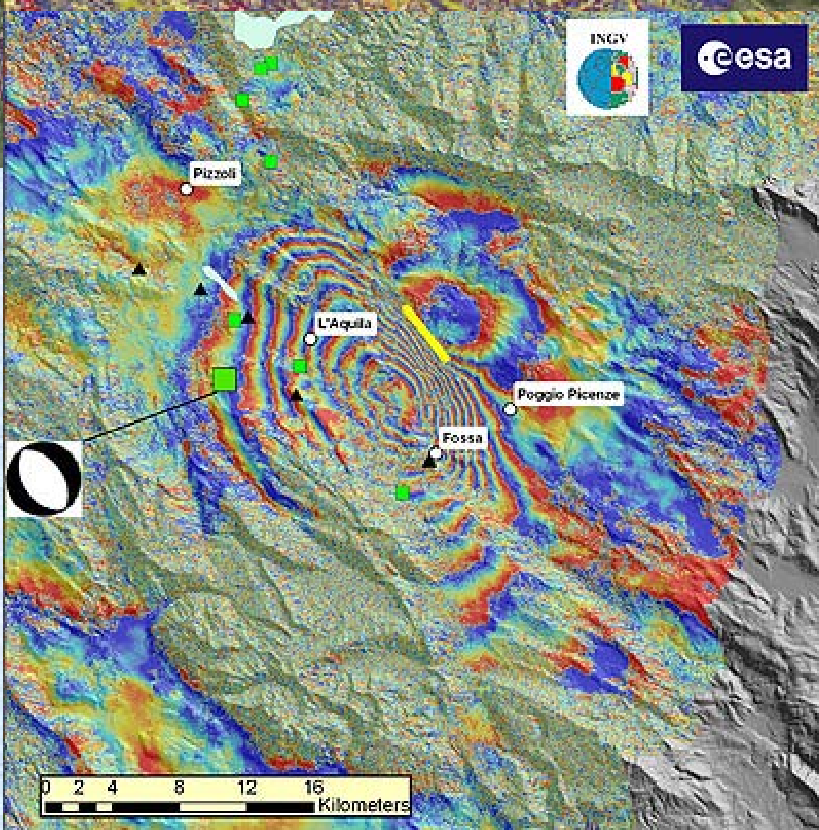
Unwrapped phase

Three Frequency SAR for L’Aquila Earthquake

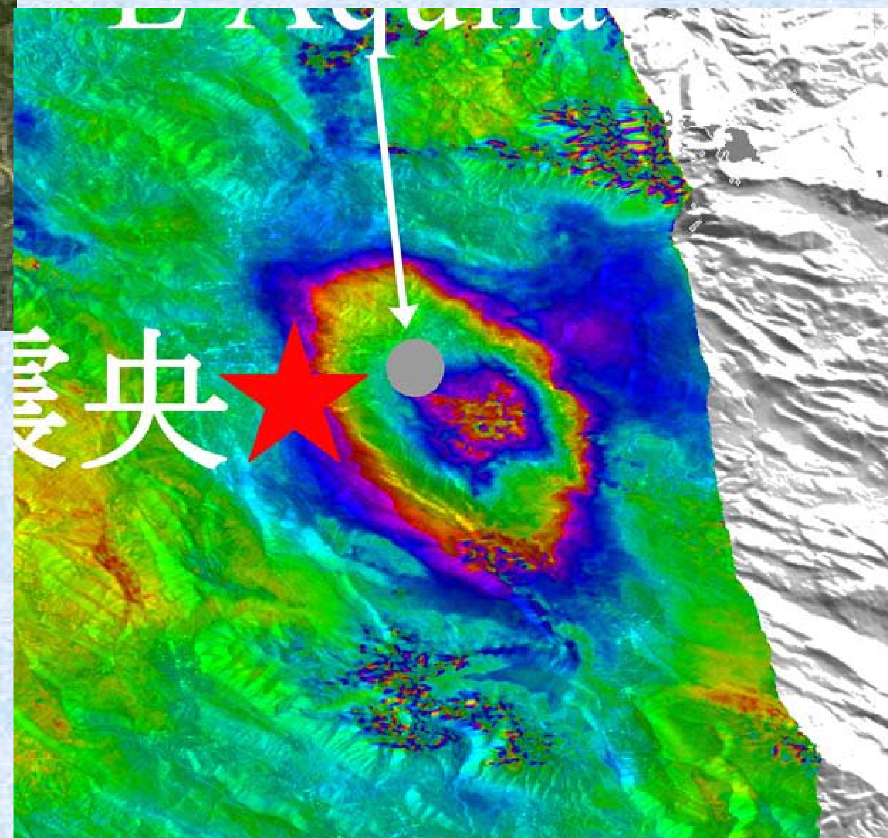


X

イタリア地震

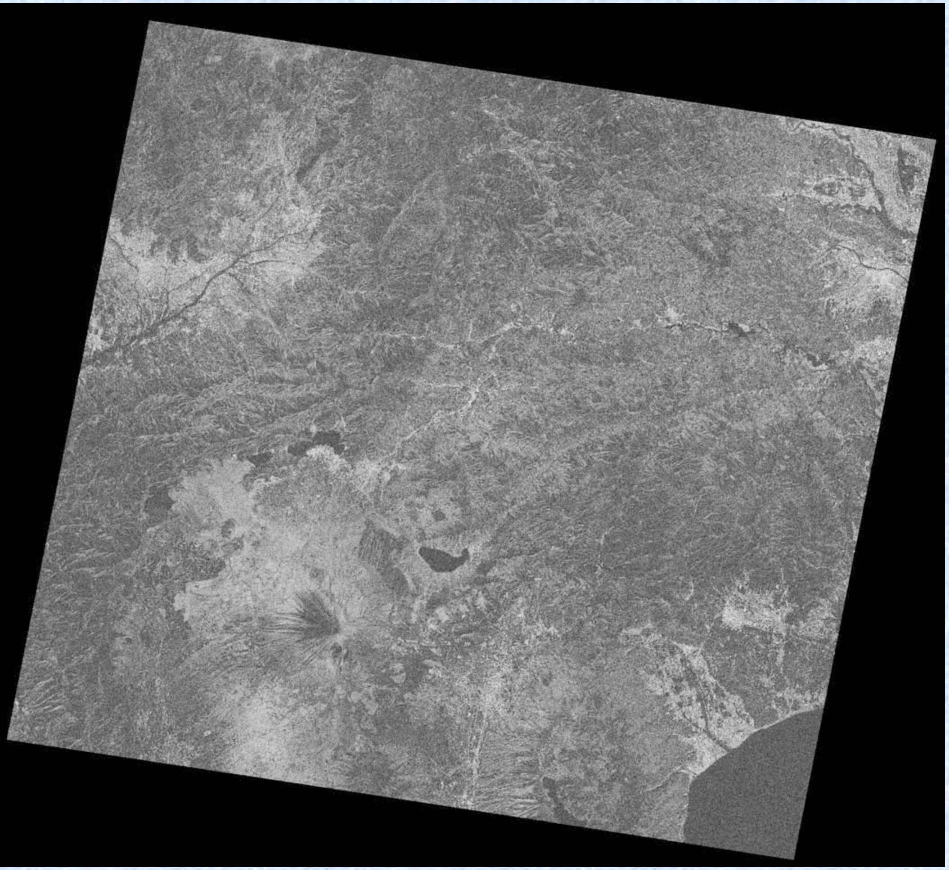


C

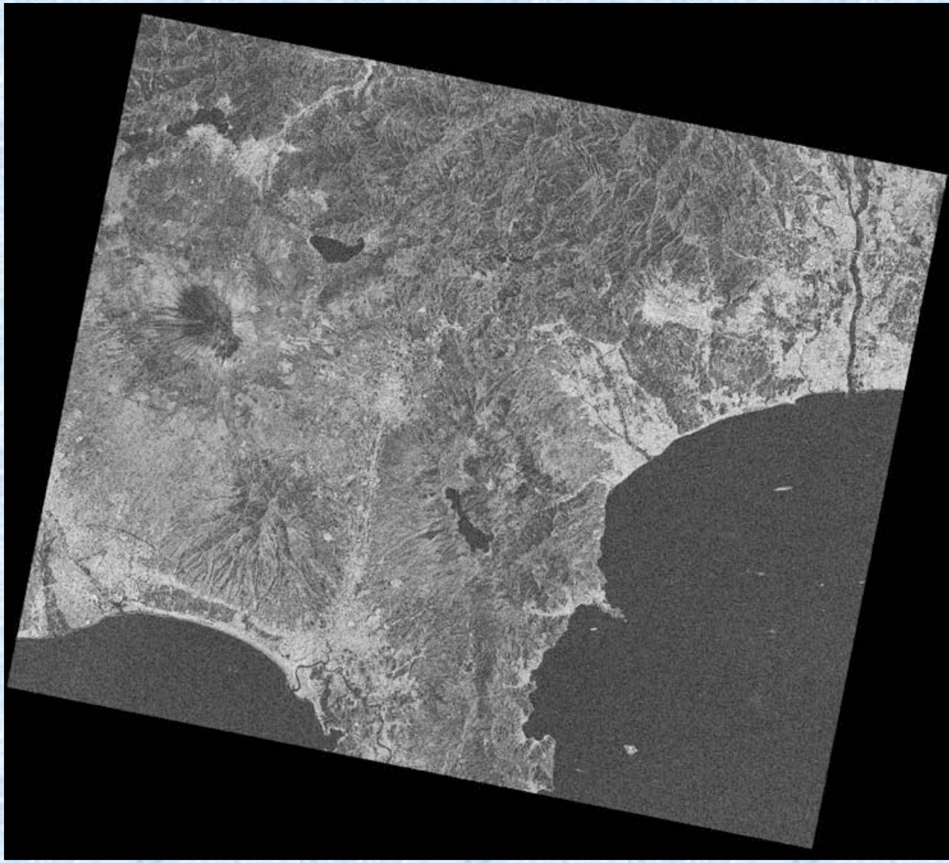


L

Comparison of JERS-1 SAR + PALSAR(34.3) in coherence



JERS-1 SAR
Oct. 21 and Sept. 7, 1995.

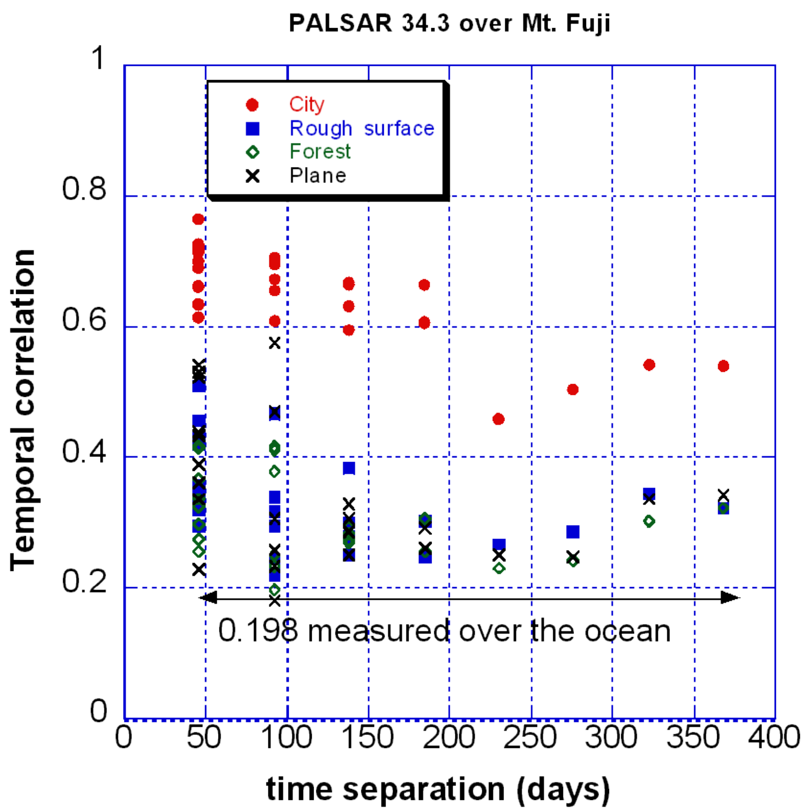


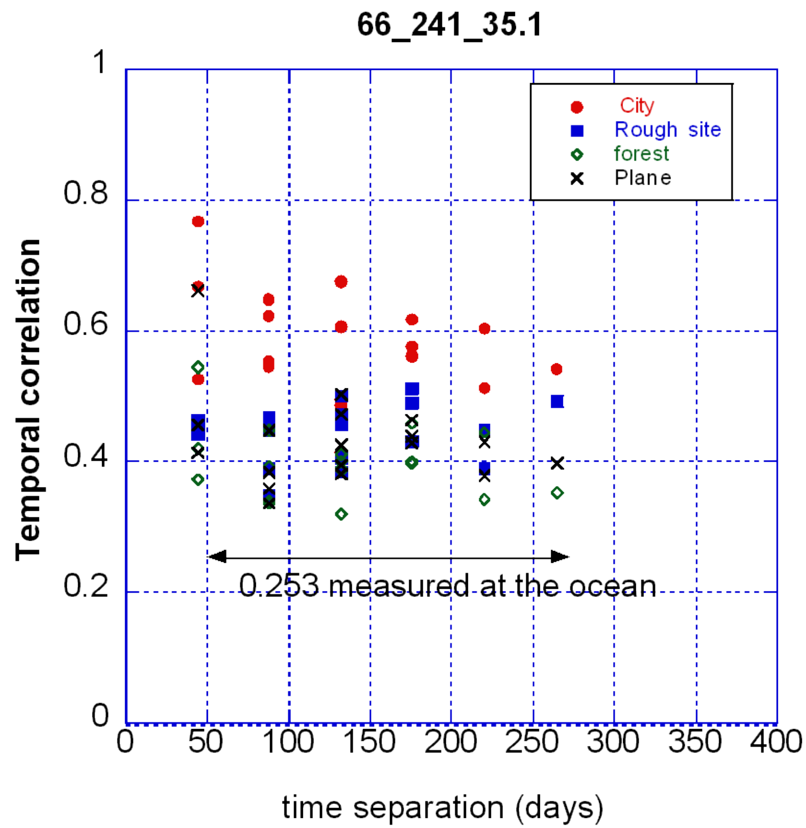
PALSAR

JERS-1 SAR/PALSAR Coherence Comparison

PALSAR

JERS-1 SAR

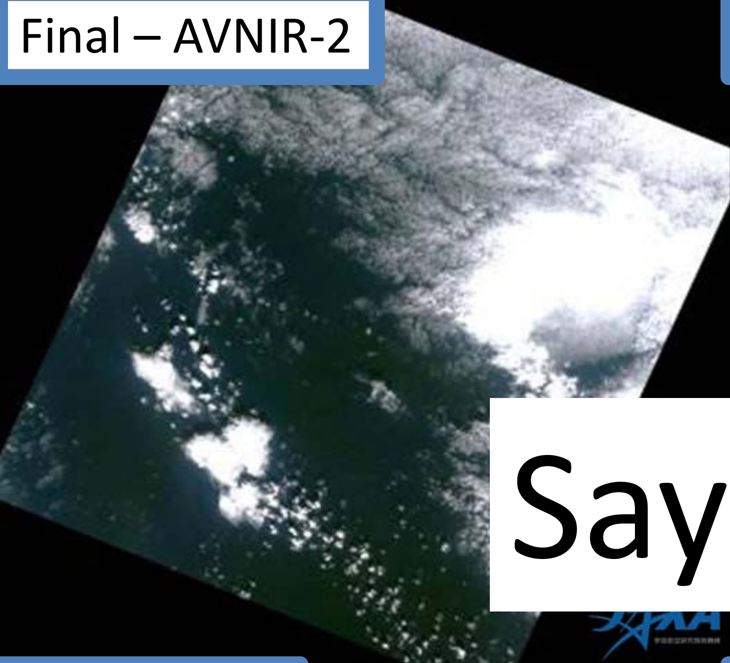




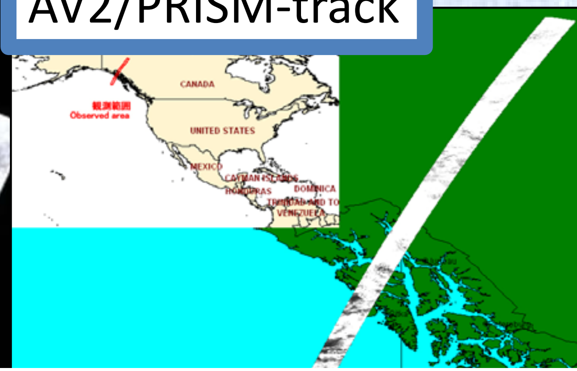
Noise level: higher in JERS-1
Dynamic range: smaller in JERS-1

Sayonara-ALOS

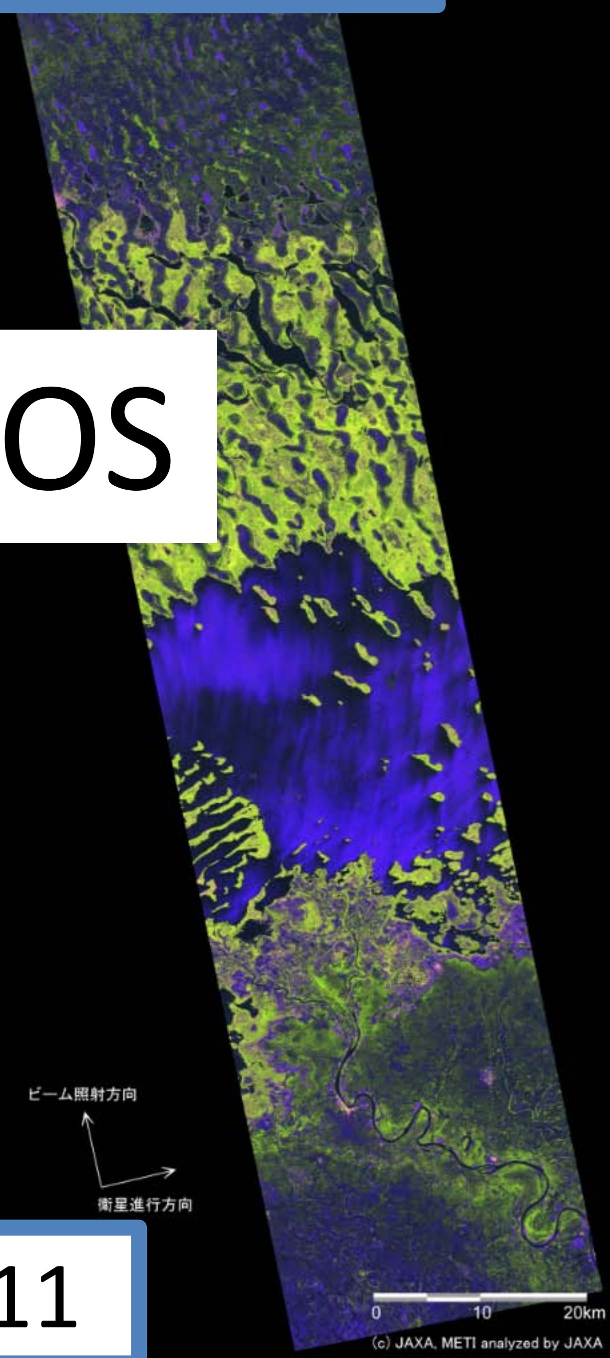
Final – AVNIR-2



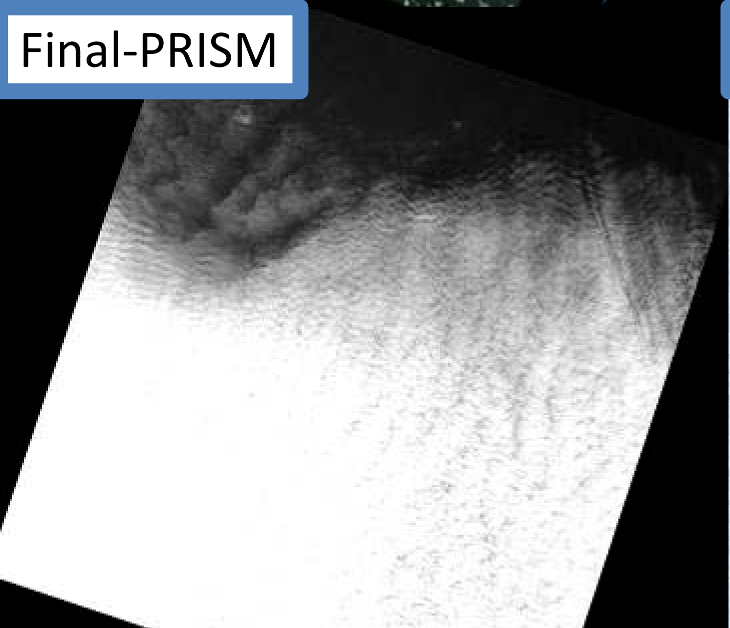
AV2/PRISM-track



PALSAR - FULLPOL



Final-PRISM



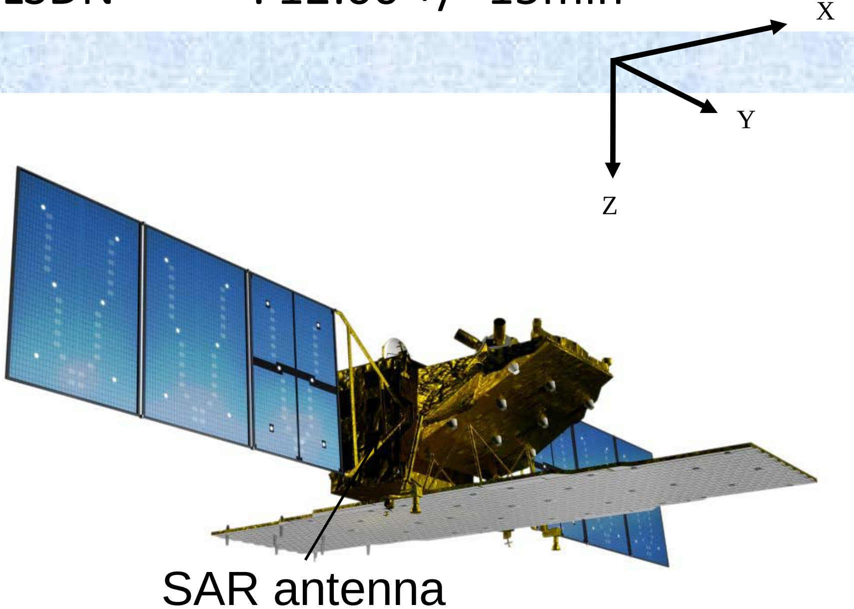
PALSAR-track

Final ALOS Images of April 22, 2011

The ALOS-2

ALOS-2 satellite

- Orbit type : Sun-synchronous
- Launch : 2013
- Altitude : 628km +/- 500m(for reference orbit)
- Revisit time : 14days
- LSDN : 12:00 +/- 15min



PALSAR-2

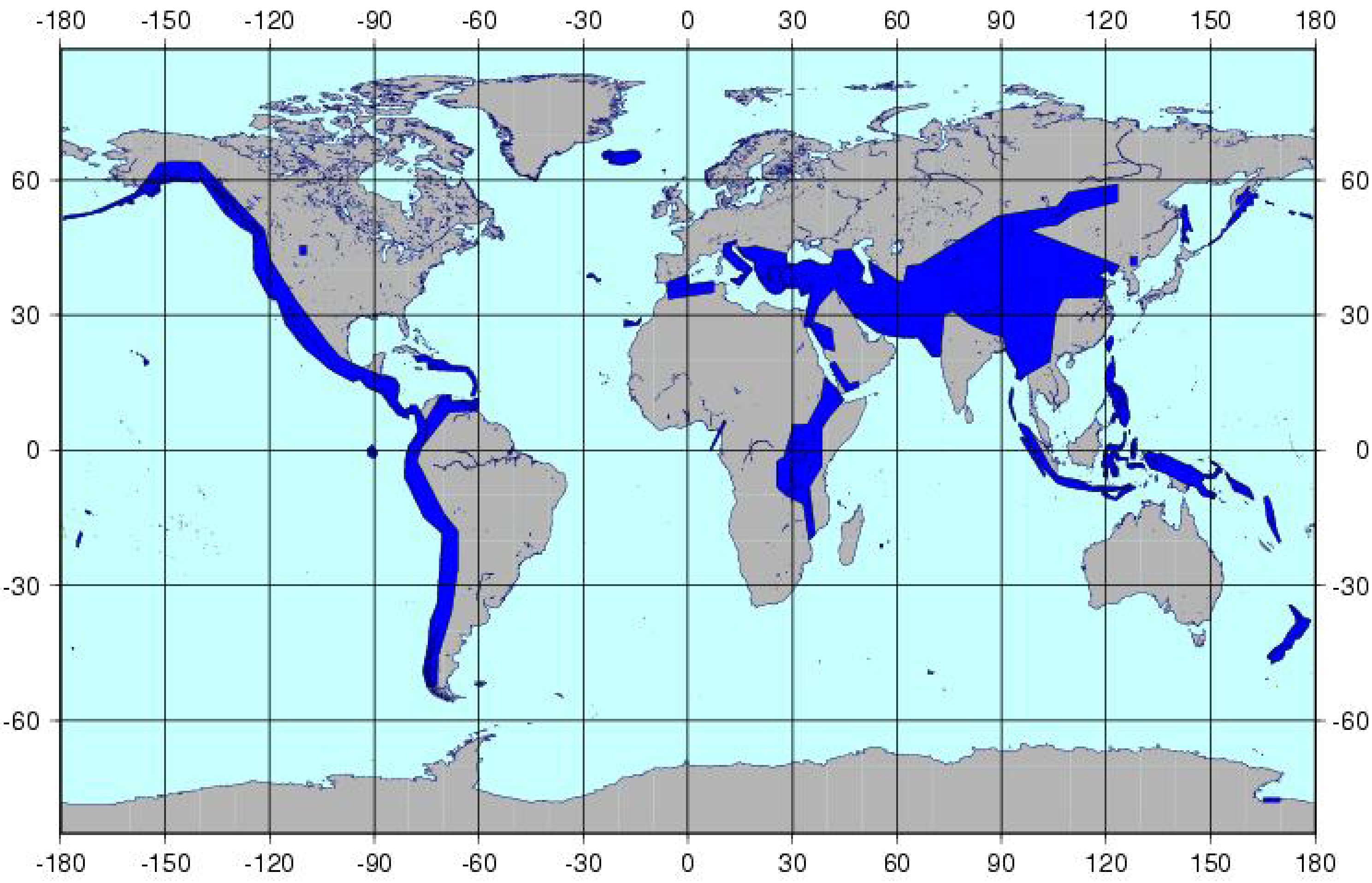
- L-band Synthetic Aperture Radar
- Active Phased Array Antenna type
  two dimensions scan (range and azimuth)
- Antenna size : 3m(El) x 10m(Az)
- Bandwidth : 14 to 84MHz
- Peak transmit Power : 5100W
- Observation swath : 25km to 490km
- Resolution : Range 3m to 100m
  Azimuth 1m to 100m

RA: July 2012

Observation Region for deformation 1/2

FBD【10m】, 28MHz

エリア
Eurasia
Algeria
Itary
Baekdu
Sakhalin
Kuril
KurilVolc
NewZealand
Iceland
Timor
Sumatra
SumatraWest
Andaman
Celebes
Talaud
Moluccas
Seram
NewGuinea
Vanuatu
Philippine
Taiwan
Alaska
NorthAmerica
SouthAmerica
Yellow
Venezuela
Cuba
SaudiVolc
YemenVolc
G_RiftValley
CameroonVolc
Comoros
AleutianWest1
AleutianWest2
AleutianEast
Galapagos
Hawaii
Tonga
Samoa
SolomonIslands
KanaryIslands
Azores
Reunion
Erebus



●高分解能[10m]モード

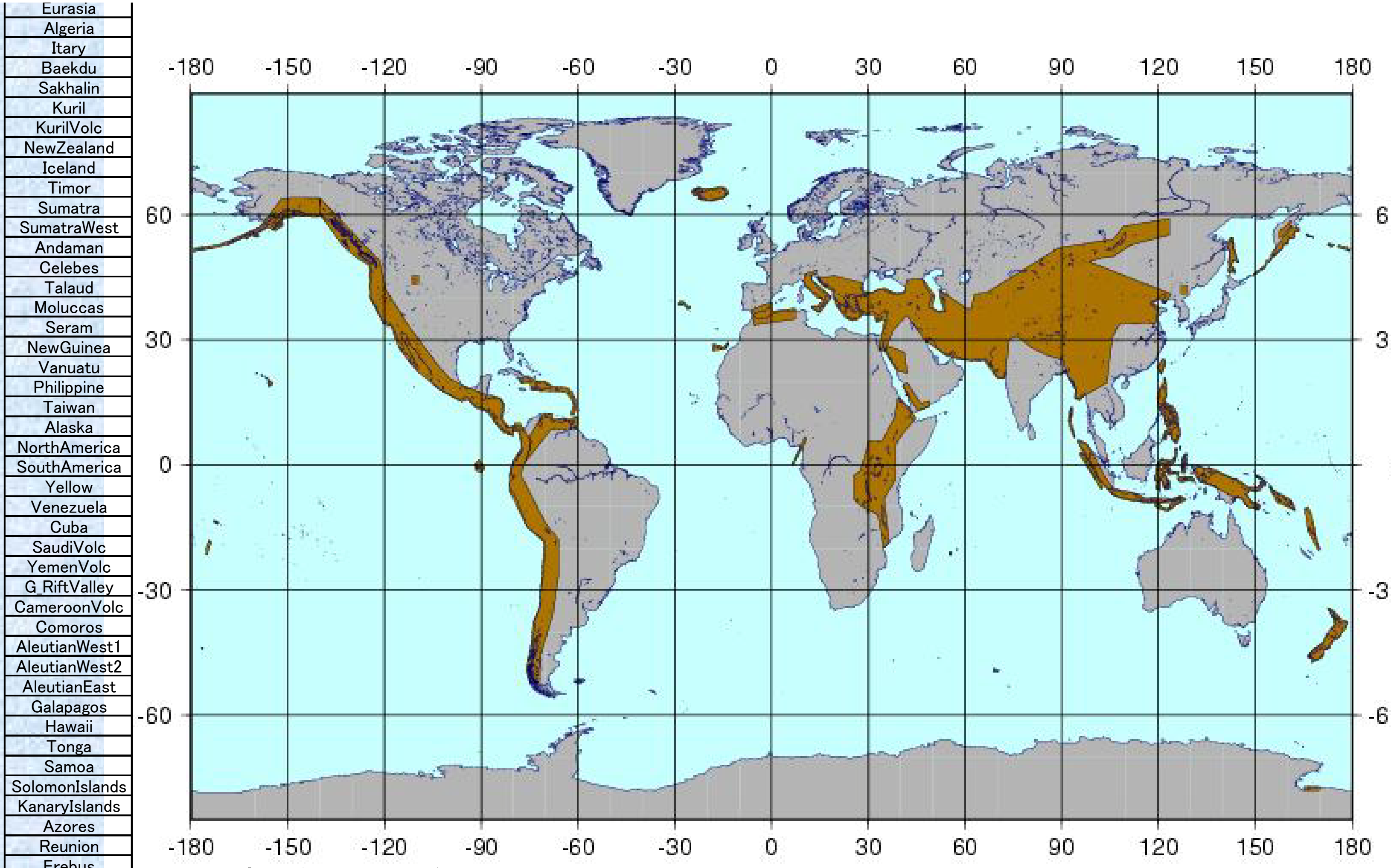
●入射角：30度～45度

●降交軌道左右方向で年1回観測　（火山活動が活発な時期は年2回観測する。）

・Left/right tilting of satellite is a demanding manoeuver, I would suggest instead acquisitions in ascending and descending passes.
・10mモード　HH+HV

Observation Region for deformation 1/2

ScanSAR 14 MHz Dual



●広域観測モード、14MHzで年1回

●入射角:30度～45度

●降交軌道左右方向で年1回観測　（火山活動が活発な時期は年2回観測する。）

基本観測計画

1）変化抽出：異なる入射角から要求後最短時間で観測：ベースマップの作成とアップデート
2）地殻変動：同じ入射角から要求後最短時間で観測：ベースマップの作成：二つの要求が運用を困難に：D+R+Lに固執すると、観測頻度が極端に減少、広帯域の良好な特性が時間劣化を補償出来ない。Scan-InSARとStrip-InSARのバランス。
森林観測：定期的な観測、ScanSAR+Dualと10mFBDがコア

現在、シミューレーションはスタート、２月末に一回目の結果を得る。同時並行に観測計画（戦略）をたてる。

Summary

ALOS observed the Earth repeatedly using L-band SAR, PALSAR, for five years and showed the L-band based repeat-pass interferometry performance on deformation, subsidence, volcanic monitoring.

ALOS-2, 2013, considers the InSAR in a way that

1. **Orbit tube is +- 500m (orbital maintenance every 3~4 months)**
2. **Scan-InSAR will be globally used.**
3. **(Right+Left looking in descending will be used for deformation monitoring.)**
4. **Ascending for Forest monitoring**