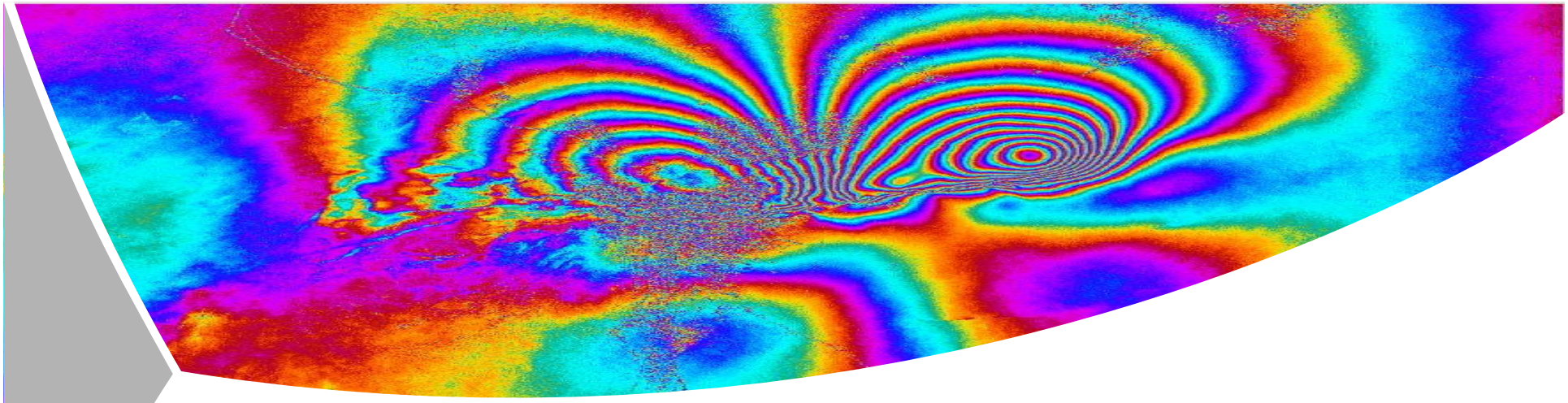


Surface Deformation Measurements
Scientific Requirements & Challenges

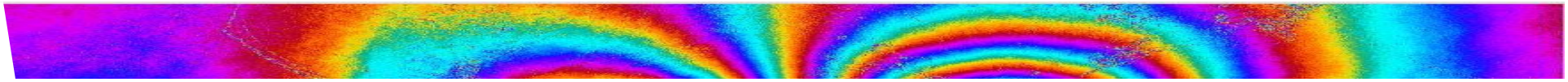
1st Science and Application Workshop

for Germany-Japan Next-Generation SAR

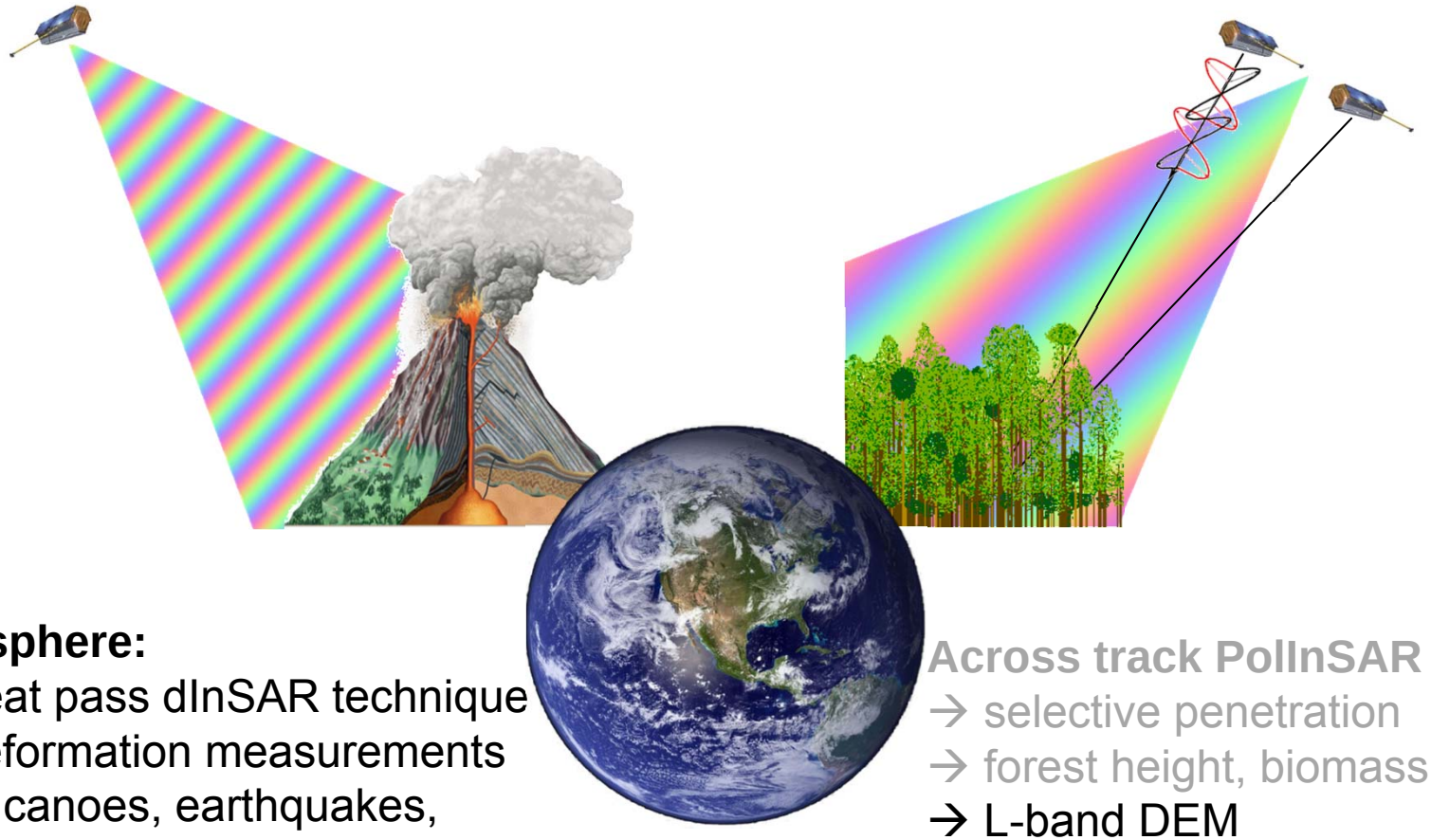
M. Eineder, C. Minet, A. Parizzi

Tokyo, 27.6.2013

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

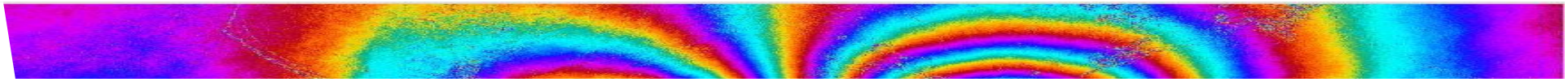


Tandem-L Mission: Two Operation Modes

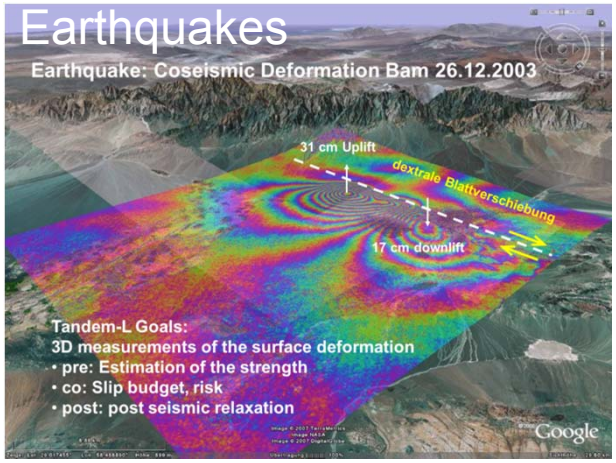


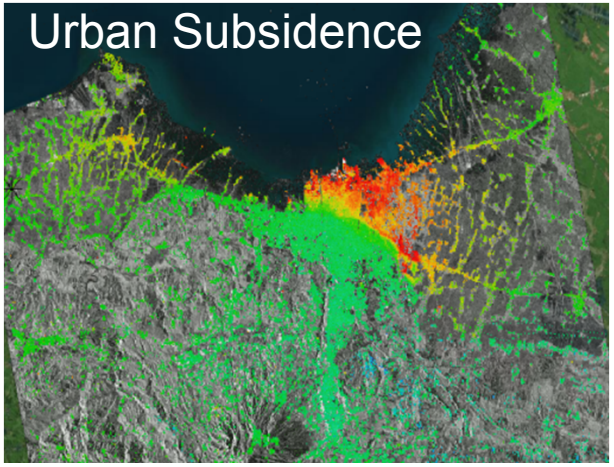
Geosphere:
Repeat pass dInSAR technique
→ deformation measurements
of volcanoes, earthquakes,
tectonic, cities, CCS

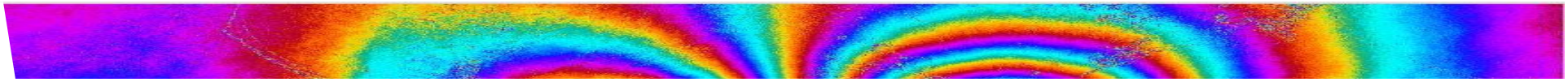
Across track PolInSAR technique
→ selective penetration
→ forest height, biomass
→ L-band DEM



Applications Driving Geosphere Requirements







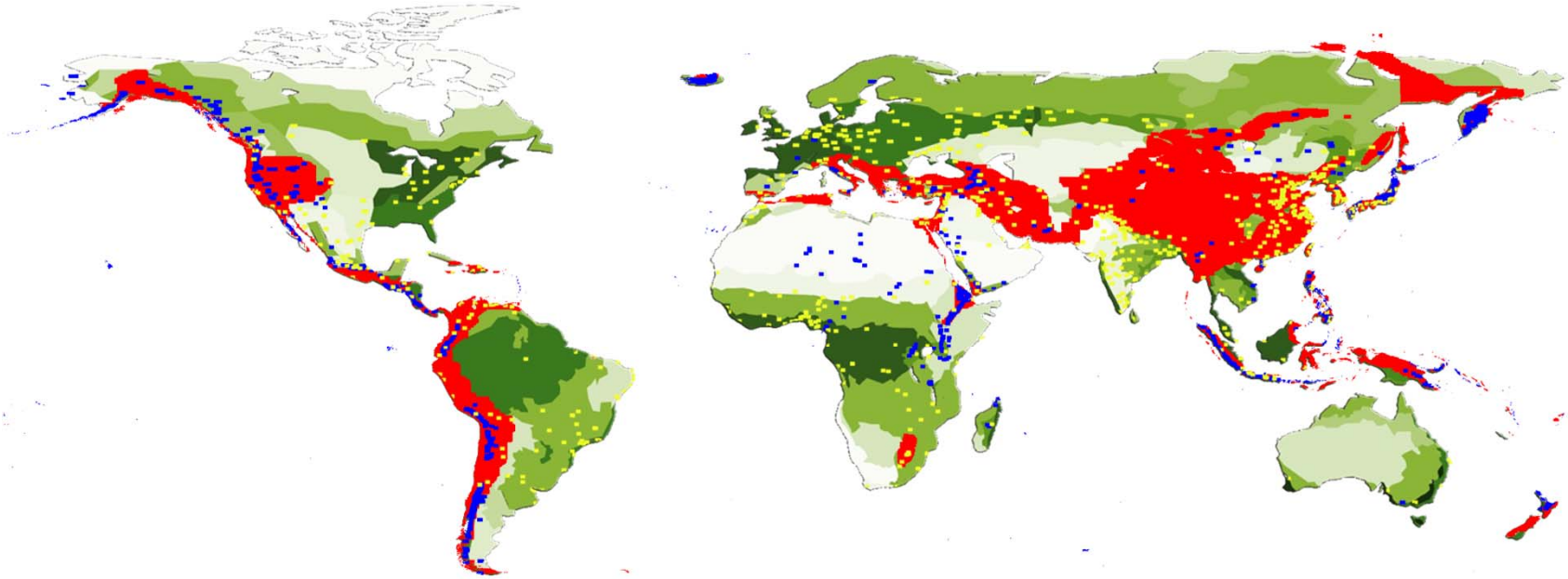
Motivation

- Many InSAR examples have been shown - exciting technique - but results opportunistic (selected) and incomplete
- Why?
  - Temporal decorrelation, e.g. TerraSAR-X, ERS, ASAR
  - Insufficient coverage, e.g. TerraSAR-X
  - Infrequent revisit: ALOS-PALSAR
  - Improper viewing geometry: 1D, layover, …
  - Non-systematic data evaluation

- Challenge: operational & systematic & accurate Earth surface motion monitoring with an InSAR system tailored to needs (cf . SRTM, TanDEM-X):
  - Tandem-L German study / proposal (Moreira et al.)

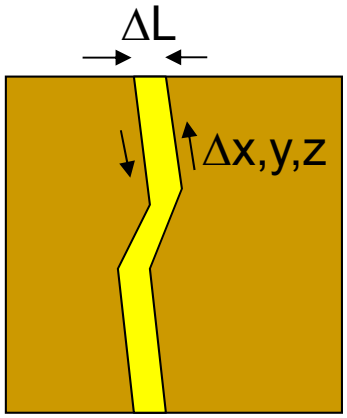
  → German Helmholtz Study
  → JAXA Study

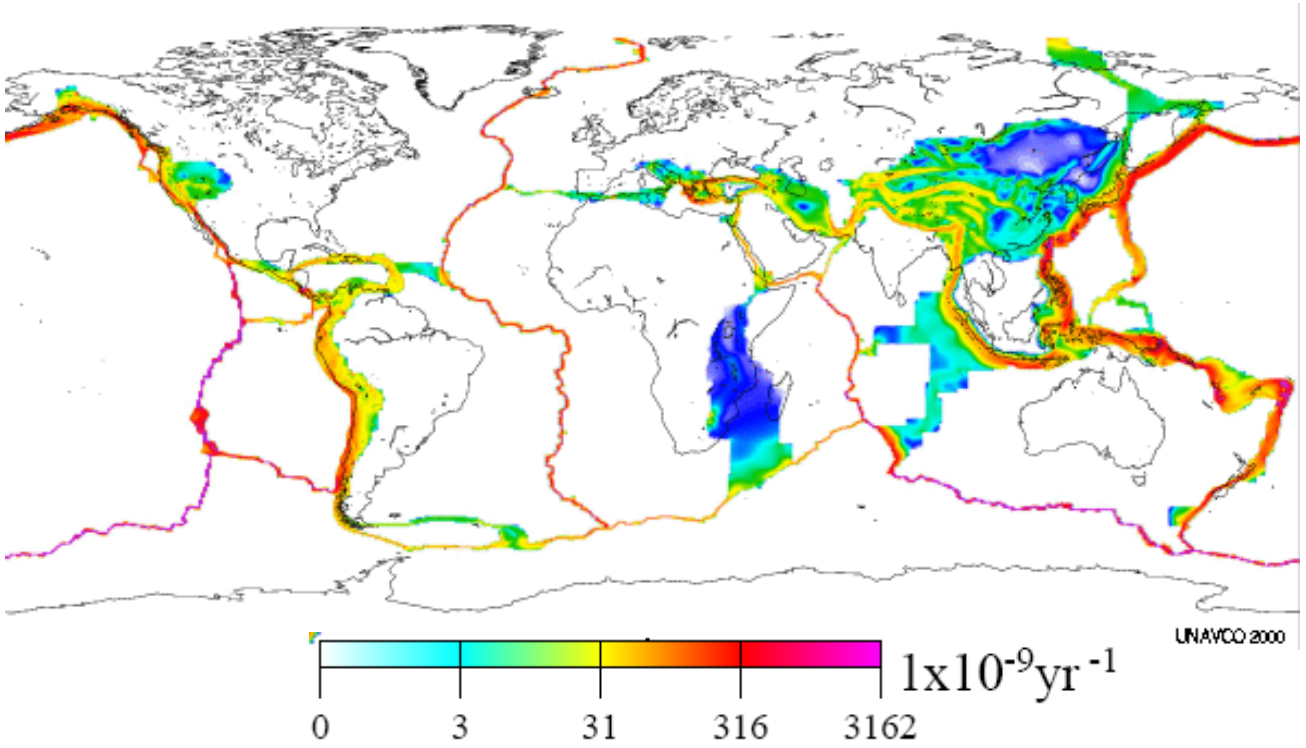
Tandem-L Requirements: Coverage



Green: biomass/forest areas (different heights)
Red: weekly high strain areas (UNAVO+seismic)
+ four global deformation images / year,
Blue: weekly volcanos
Yellow: weekly cities
+ TBD weekly landslides, CCS sites, etc.

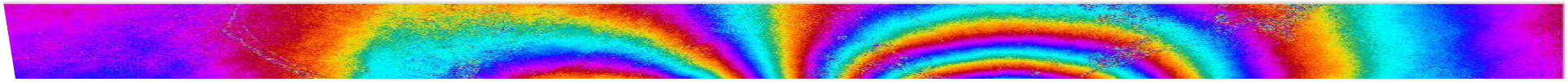
Accuracy Challenge: Small Interseismic Strain Rates





Requirement formulation: Δx=1 mm, ΔL=30 km, Δt=1 year, 1-5 y measurement

$$strain\_rate = \frac{\Delta x}{\Delta L \Delta t} = 33 \cdot 10^{-9}\, y^{-1}$$



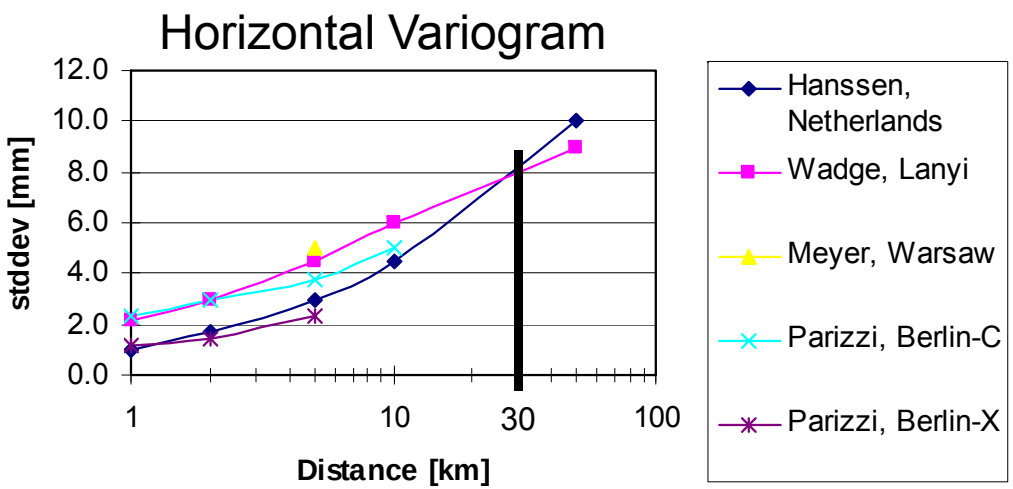
Requirements (Generalized & Compressed)

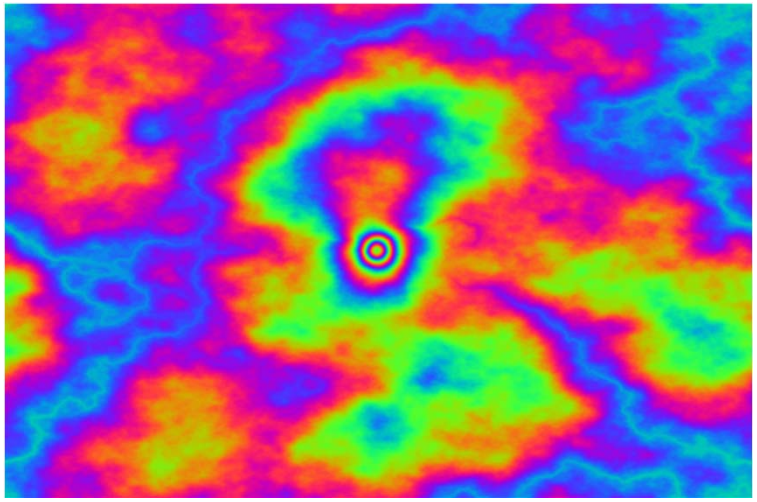
	Displacement Accuracy	Imaged area	Resolution	Frequency
Global	1cm/50km (5a)	approx. 150 Mio. km²	50 m	4/year
Earthquakes	1mm/30km (5a) or better 3D-Vector	approx. 25 Mio. km²	10-50 m	up to 4/week
Volcanoes	cm-range 3D-Vector	approx. 5 Mio. km²	50 m (→1-2 m?)	weekly
Anthropogenenic deformation	mm/cm-range	Metropolitan aereas	20 m (→1-2 m?)	monthly
Landslides	cm-range 3D-Vector	Selected mountainous regions	20 m	1-4/month

+ DEM times series (from TanDEM-X experience)

(→1-2 m?): Demand for higher resolution (from TerraSAR-X exp.)

Biggest Challenge: Atmospheric Water Vapor





Comparsion of reported atmospheric zenith delay InSAR phase errors

1. R. Hanssen, Radar Interferometry, Kluwer, Dordrecht, 2001
2. F. Meyer, R. Bamler, R. Leinweber, J. Fischer, A Comparative Analysis of Tropospheric Water Vapor Measurements from MERIS and SAR, Proc. of IEEE IGARSS 2008
3. EVINSAR, Proposal for an ESA Earth Exporer Mission, G. Wadge
4. Parizzi, GITEWS Project (DLR internal TN)

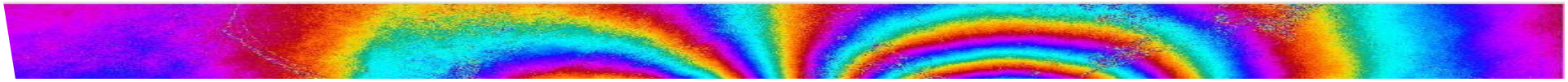
→ + high vertical stratification!

Countermeassures:

→ >1 year data averaging: PSI (€€€!)

→ Low res tropospheric model for correction of vertical stratification

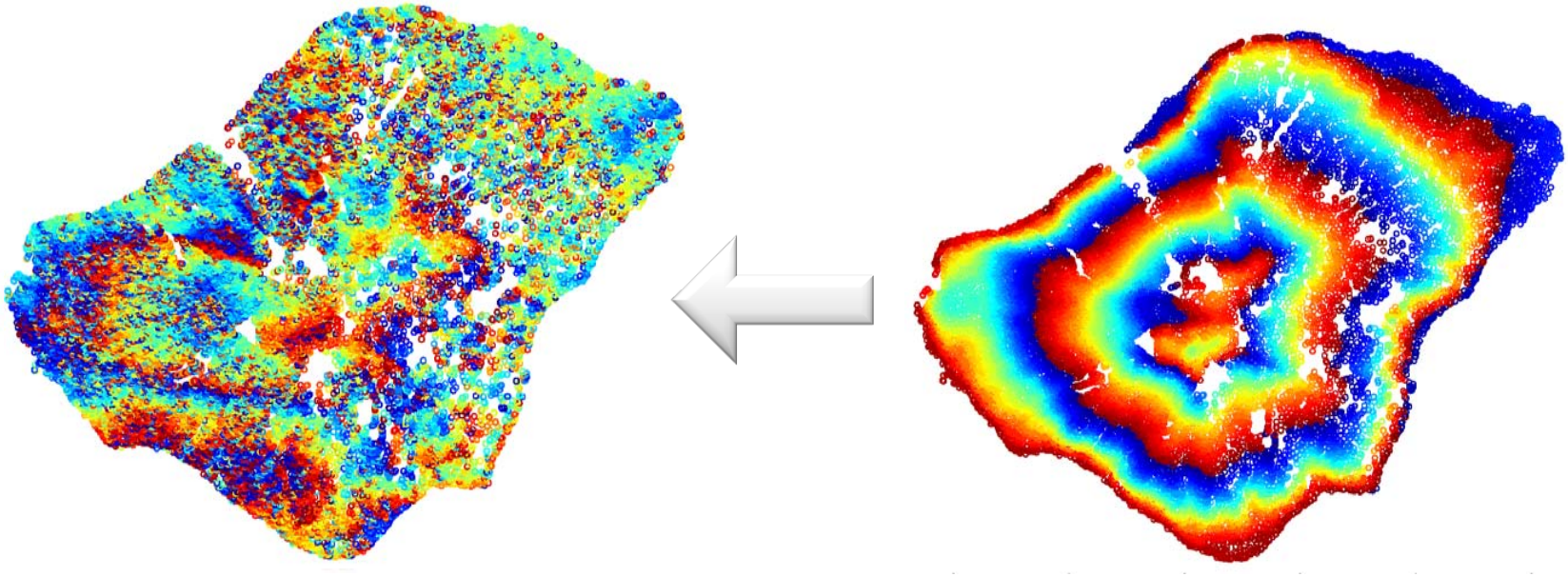
→ High res. tropospheric model for correction of horizontal variation TBD?



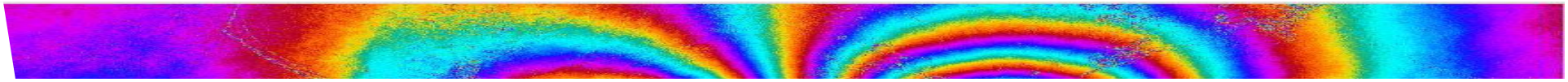
Compensation of Stratified Atmospheric Delay

Corrected PS Differential Phase

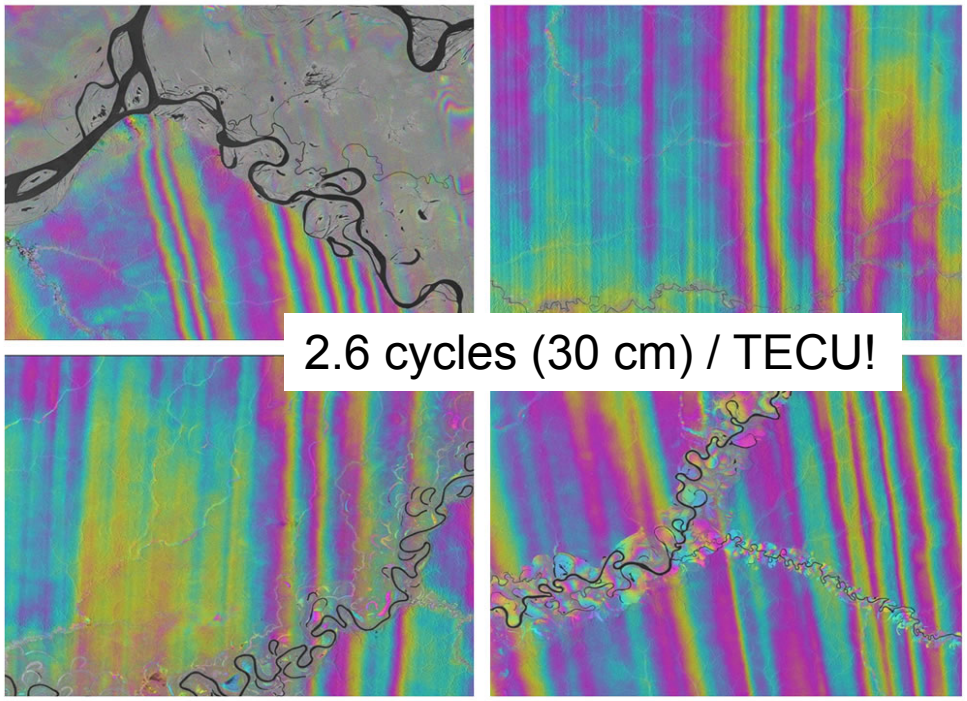
Atmospheric Phase (from ECMWF)



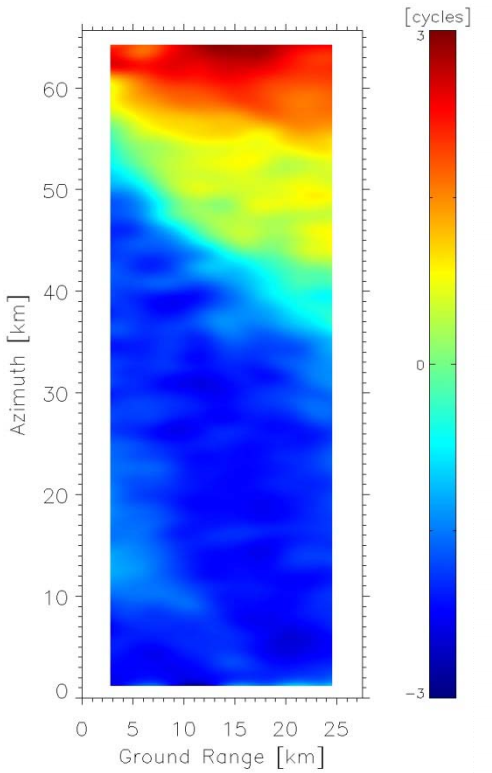
- ***Stromboli Volcano, Italy (926m)***
- **TerraSAR-X 2008-01-28/2008-08-02**
- **Baseline: 3.5 m**



Ionospheric Effects in L-Band



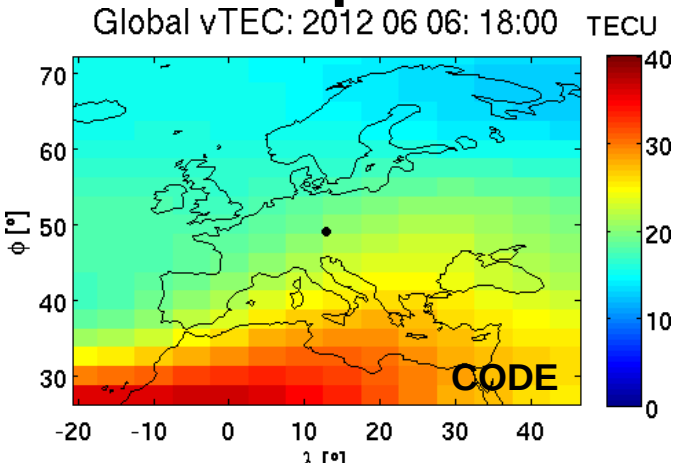
Ionospheric Signals in L-band InSAR Data near the Equator

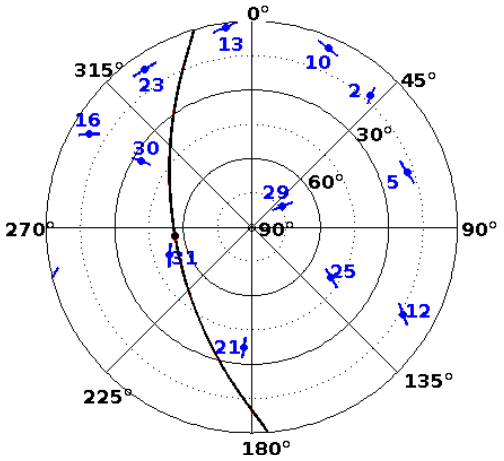


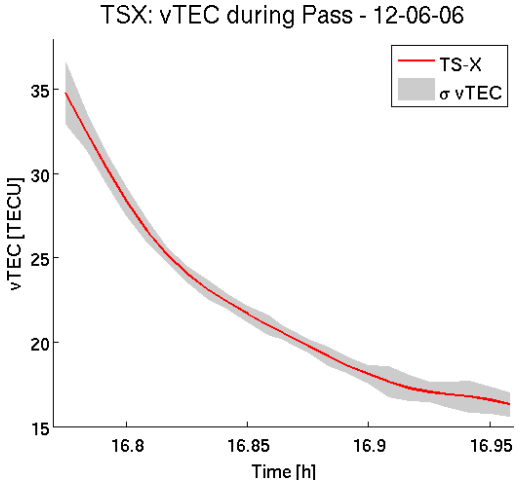
Countermeasures:

- Isolate dispersive Ionosphere using split-bandwidth techniques
- Use available global TEC maps
- Use satellite GNSS measurements

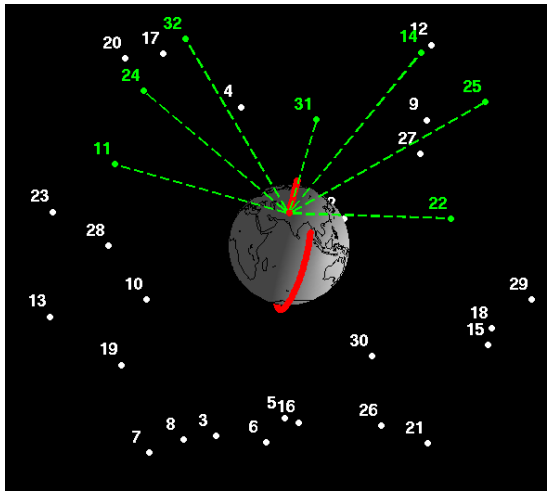
Ionospheric Correction: Global Models vs. Local GNS

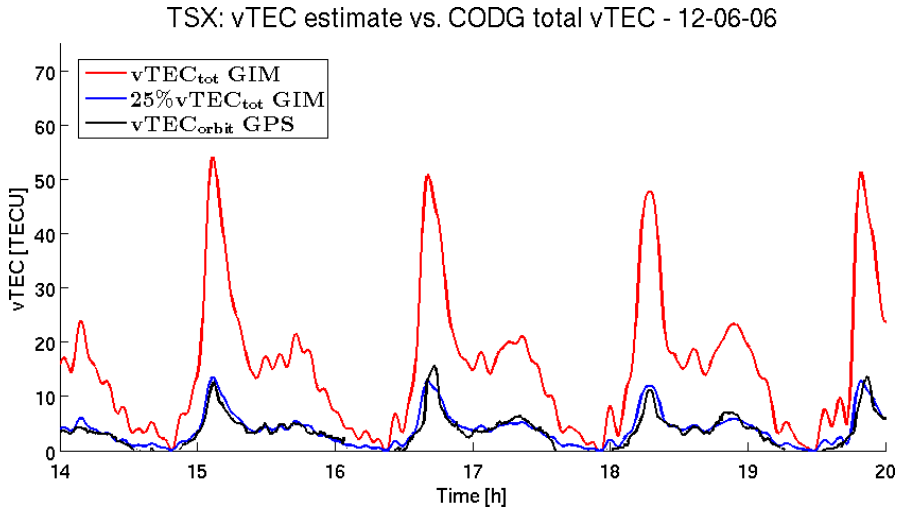




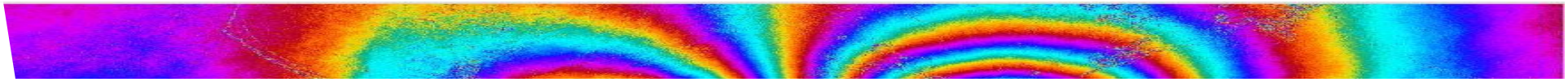


In orbit: Satellite to satellite tracking

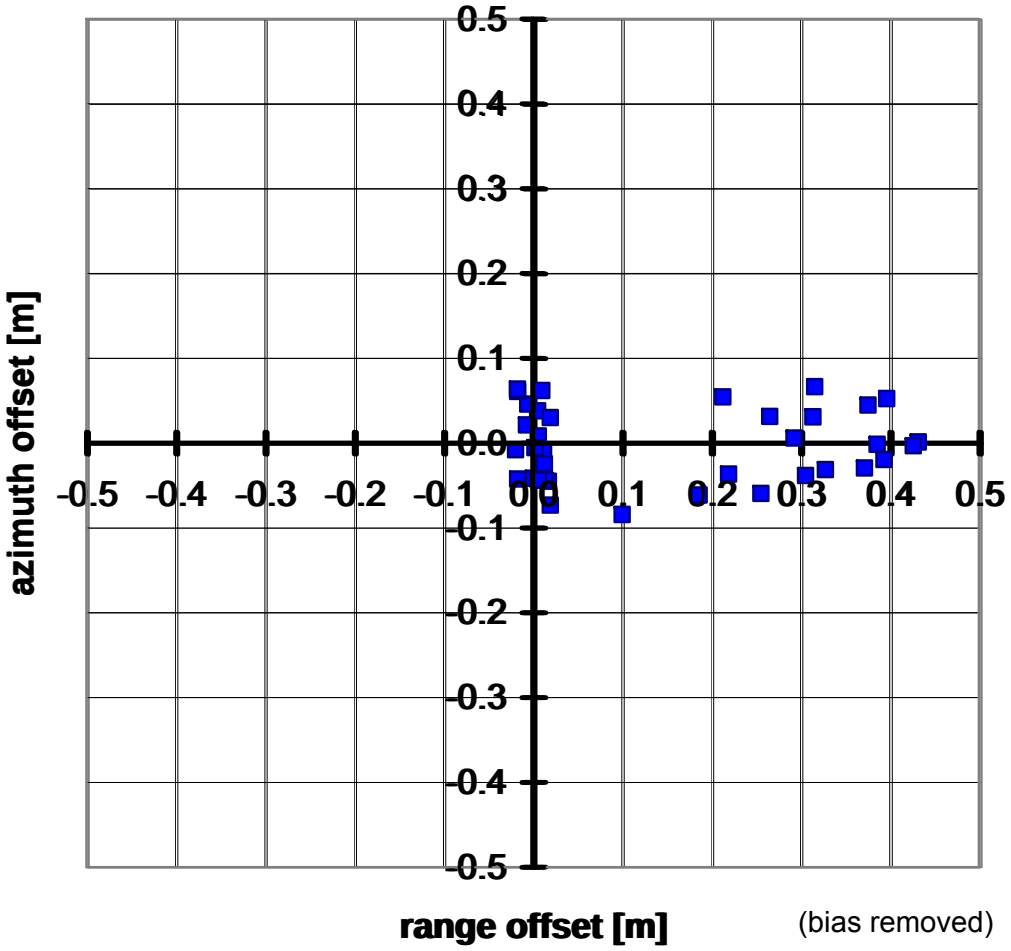




See: C. Gisinger, EGU 2013, Local ionospheric corrections derived from GNSS… ,



Atmospheric Correction - TSX Corner Reflector



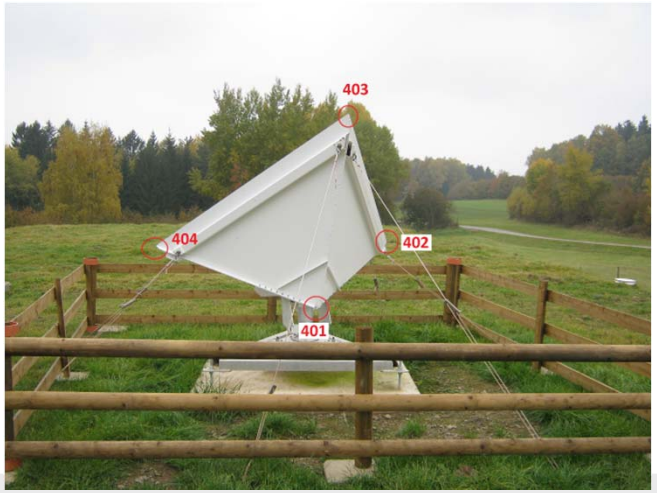
(bias removed)

Correction of

- IERS 2010 Conventions (earth tides, pole tides…,)
- Tropospheric delay
- Ionospheric delay
- Contintental drift

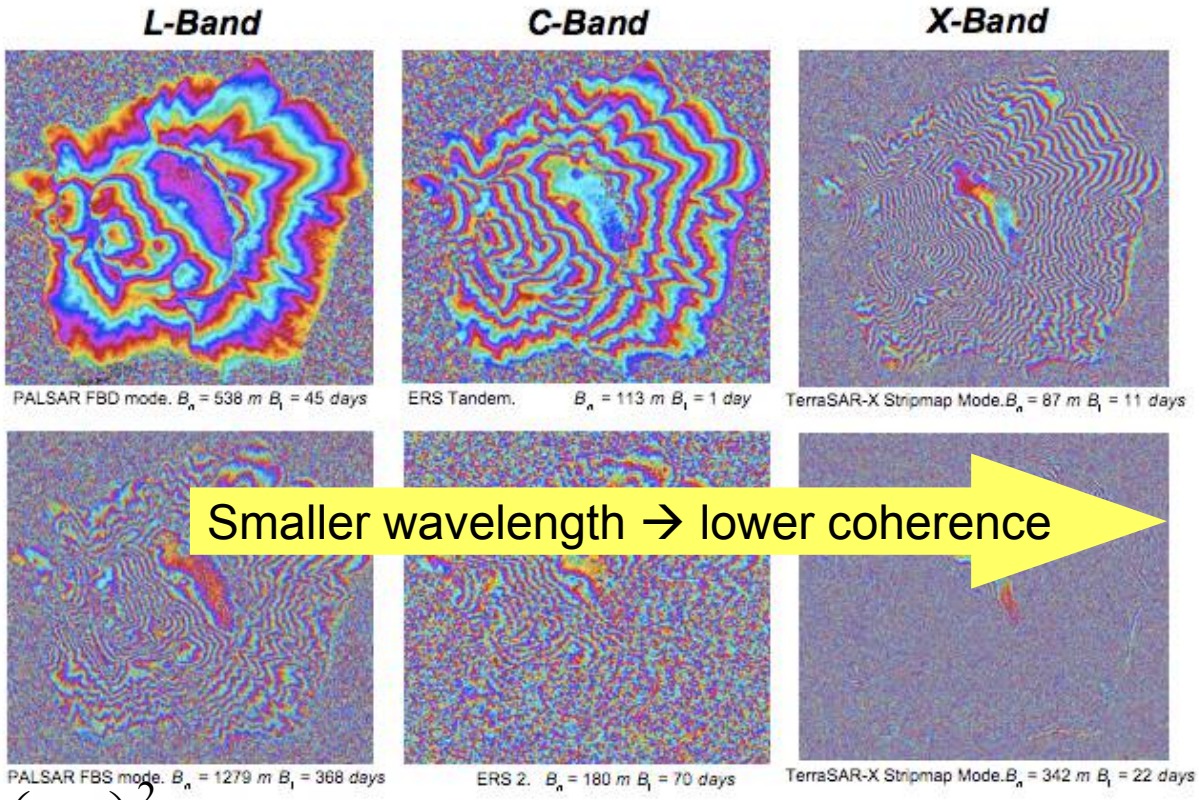
→Azimut error σ = 4.3 cm

→Range error σ= **1.2 cm**



Enemy of Stacking: Temporal Decorrelation

Nisiros / Greece

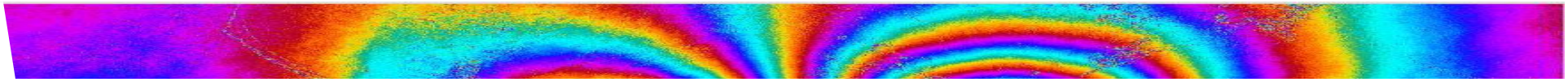


$$\gamma(t) = e^{-\frac{1}{2}\left(\frac{4\pi}{\lambda}\right)^2 \sigma_{drift}\, t}$$ (Zebker, 1992)

„time constant scales with square of λ“

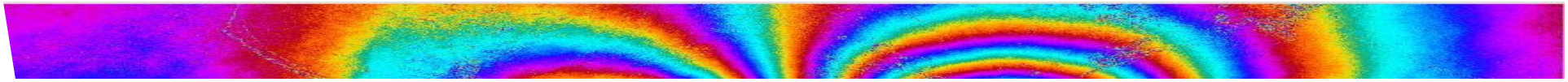
$$\gamma(t) = (\gamma_0 - \gamma_k) e^{-\frac{t}{\tau}} + \gamma_k$$

Our current model



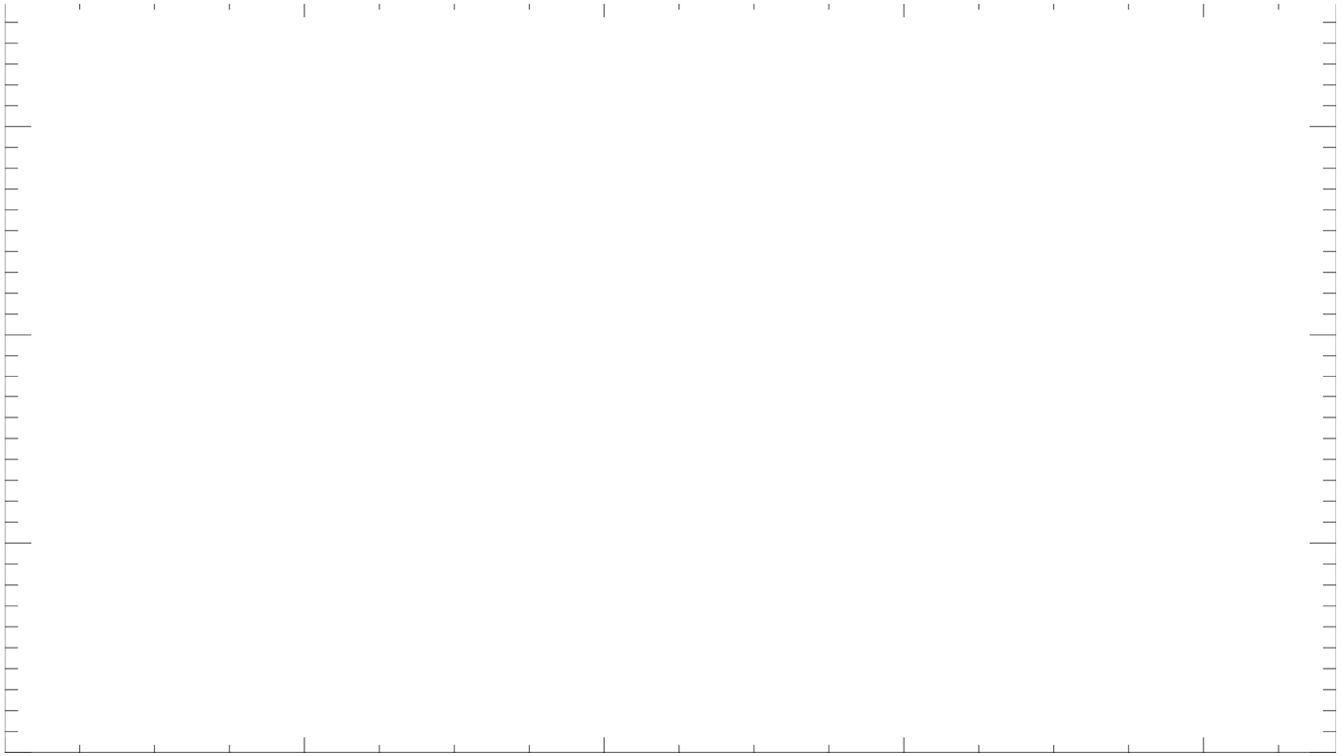
Coherence History in Indonesia (Java/Semarang)

0, 46, 92, 138, … 1472 Days (4 Years) Coherence Evolution (small baselines)

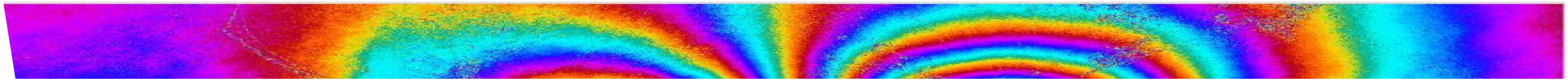


Coherence Evolution in Indonesia (Java/Semarang)

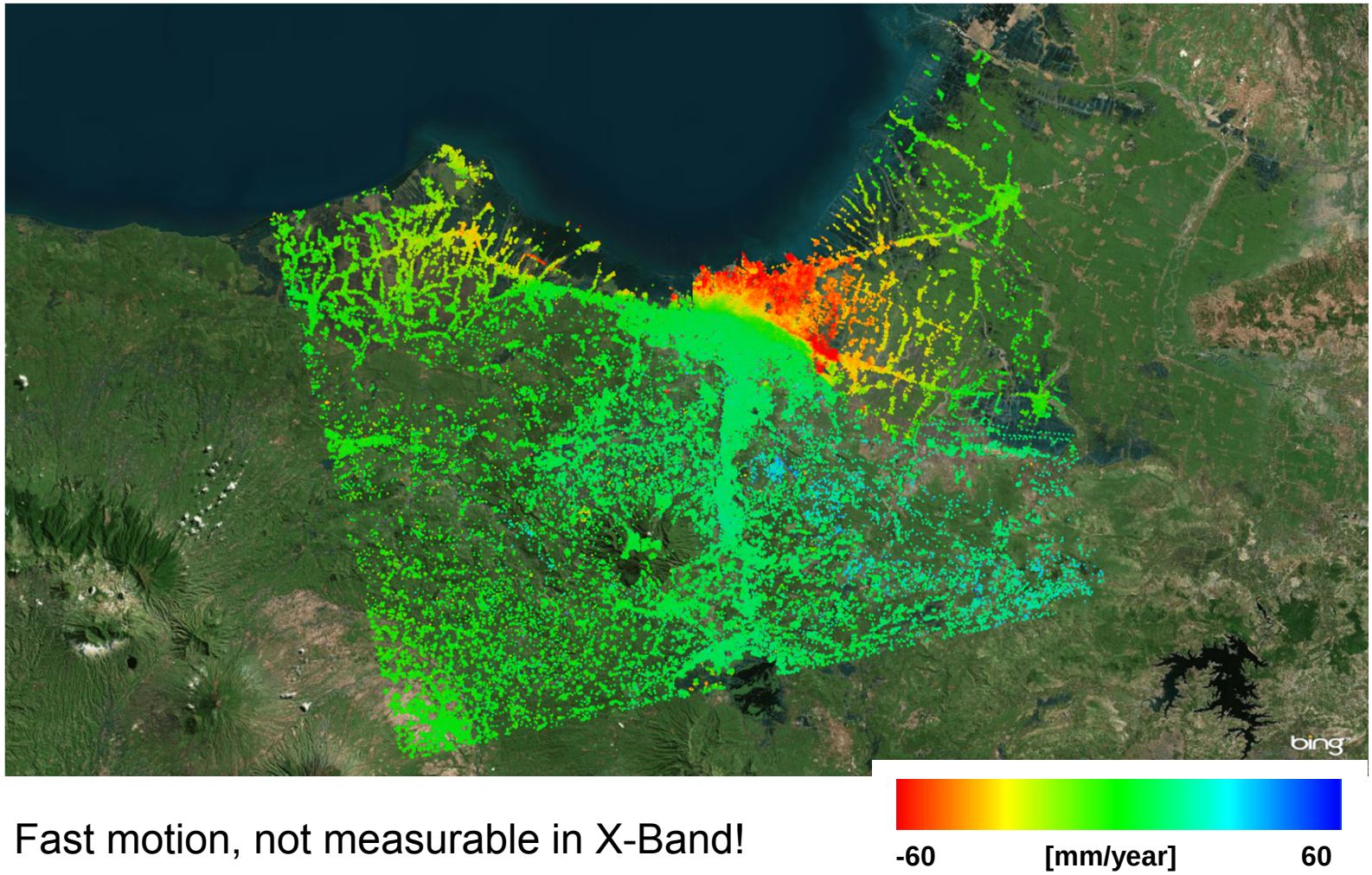
0, 46, 92, 138, … 1472 Days (4 Years) Coherence Evolution
25 PALSAR scenes, small baselines only



→Optimal observation and processing strategies will be developed

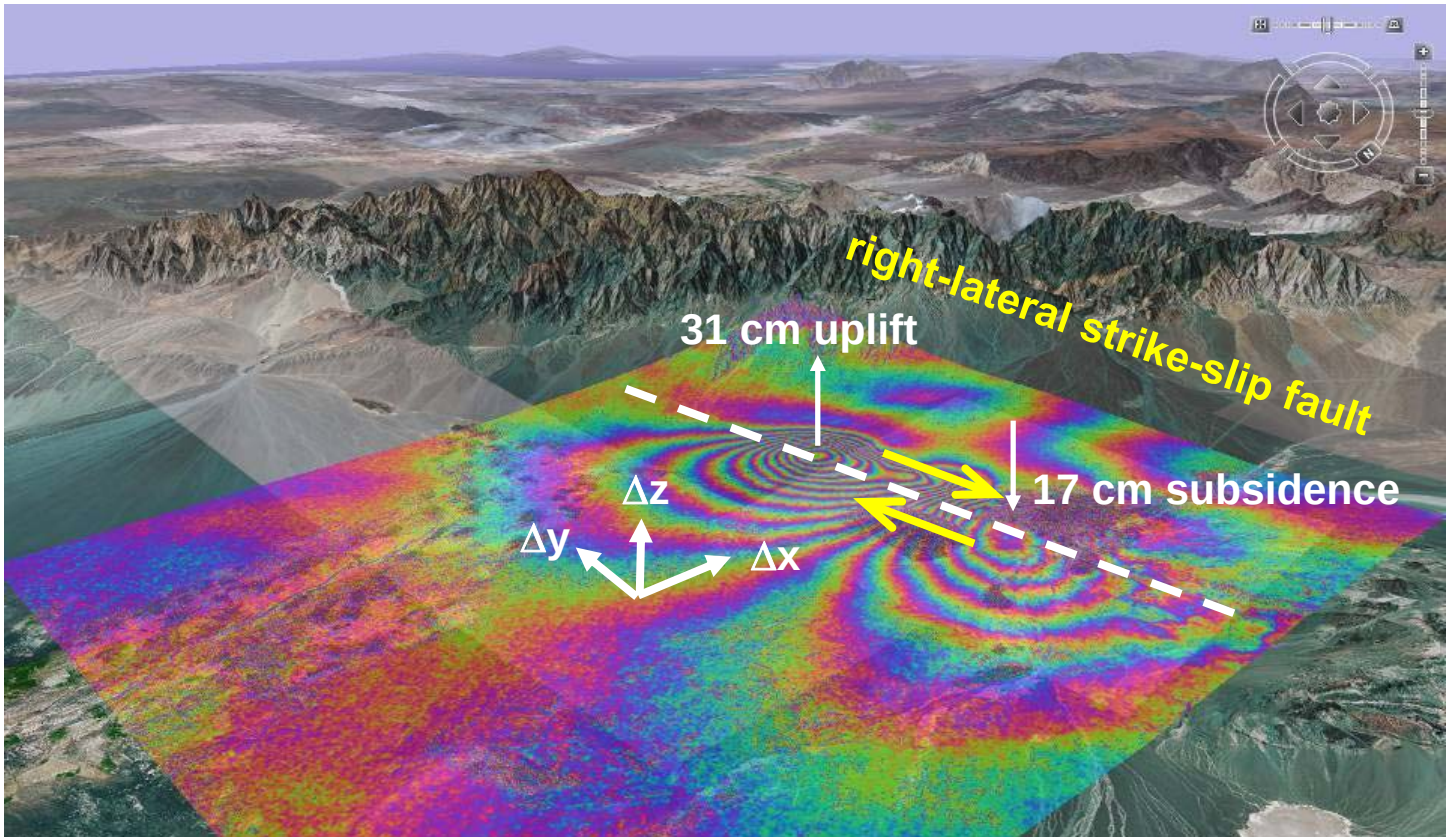


Semarang Persistent Scatterer Interferometry



Fast motion, not measurable in X-Band!

Challenge: 2/3-Dimensional Vector Wanted



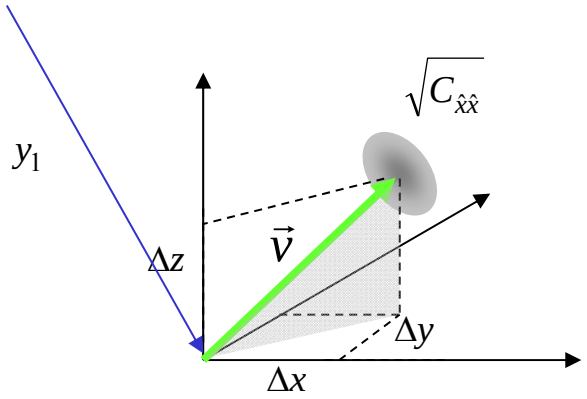
Co-seismic Bam / Iran interferogram 26.12.2003 (ASAR)

→ > 2/3 Observations from different angles required

MAP-Estimator for 3D-Vector from n Observations

Model

$$\vec{y} = K\vec{v} = \begin{bmatrix} \sin\theta_1\cos\alpha_1 & \sin\theta_1\sin\alpha_1 & \cos\theta_1 \\ \dots & \dots & \dots \\ \dots & \dots & \dots \end{bmatrix} \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta z \end{bmatrix}$$

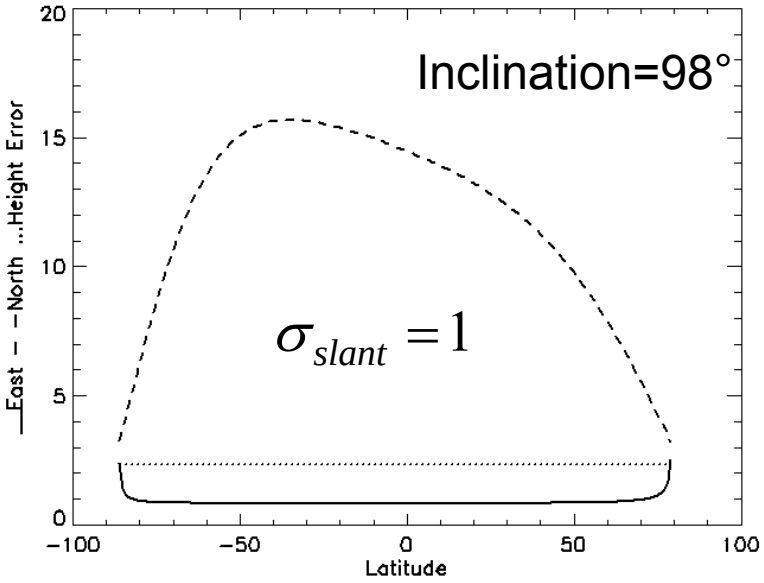


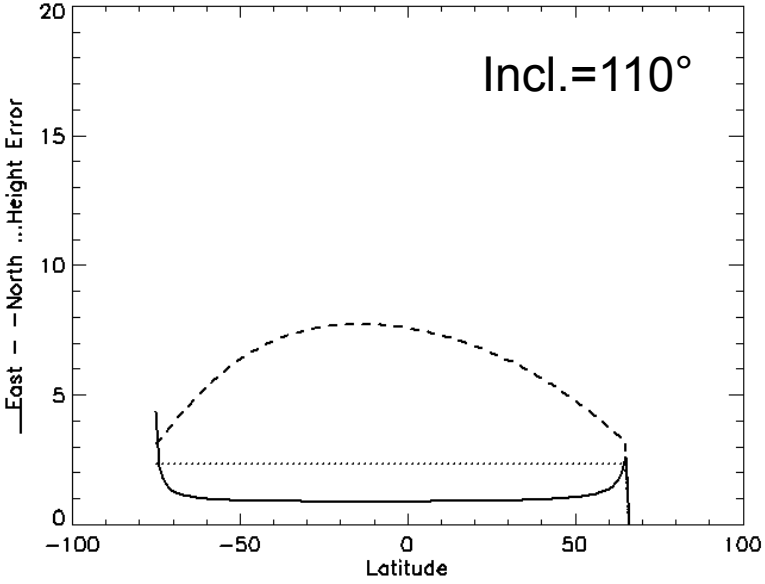
$$\hat{x}_{MAP} = \left(K^T C_{\varepsilon\varepsilon}^{-1} K + C_{xx}^{-1}\right)^{-1} K^T C_{\varepsilon\varepsilon}^{-1} y$$

$$C_{\hat{x}\hat{x}} = \left(K^T C_{\varepsilon\varepsilon}^{-1} K\right)^{-1}$$

Covariance matrix of required 3D Vector estimate,
diagonal elements give accuracies in x, y, z (e.g. East, North, Height)

Bad 3D-Vector Conditioning with Polar Orbits
σ_y=1, (Asc, Desc) × (30°, 45°)





Possible improvements:

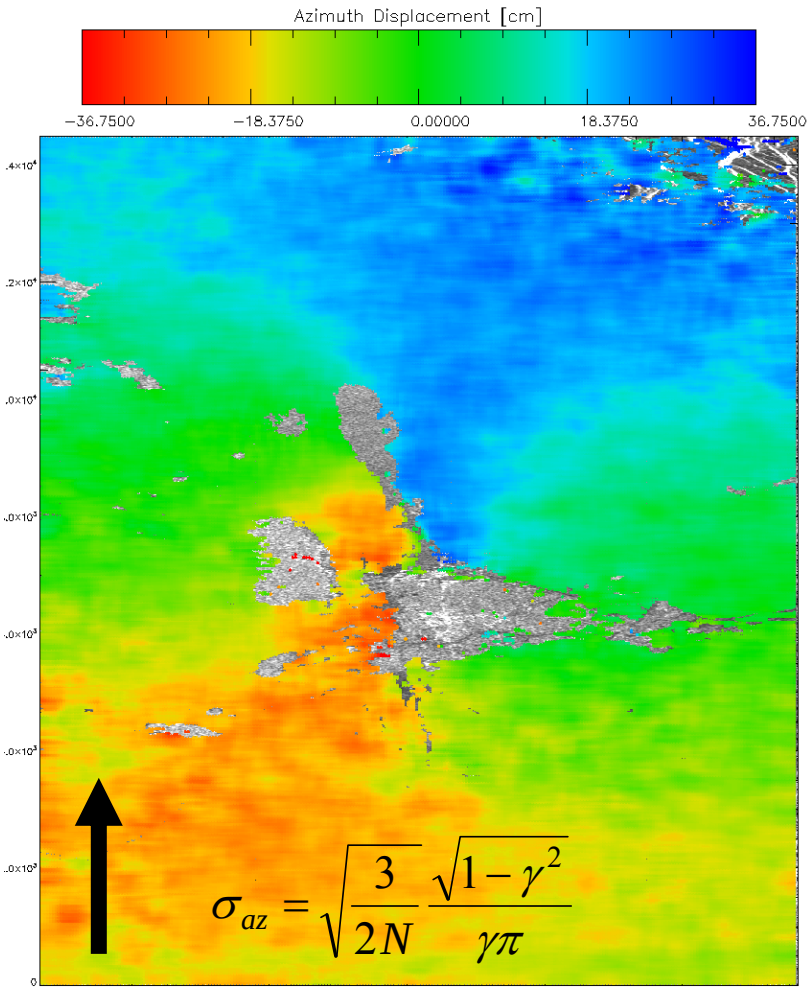
→ non-polar orbit (other problems: power, ground stations, cryosphere)

→ left and right look direction (requires maneuvers & special satellite design)

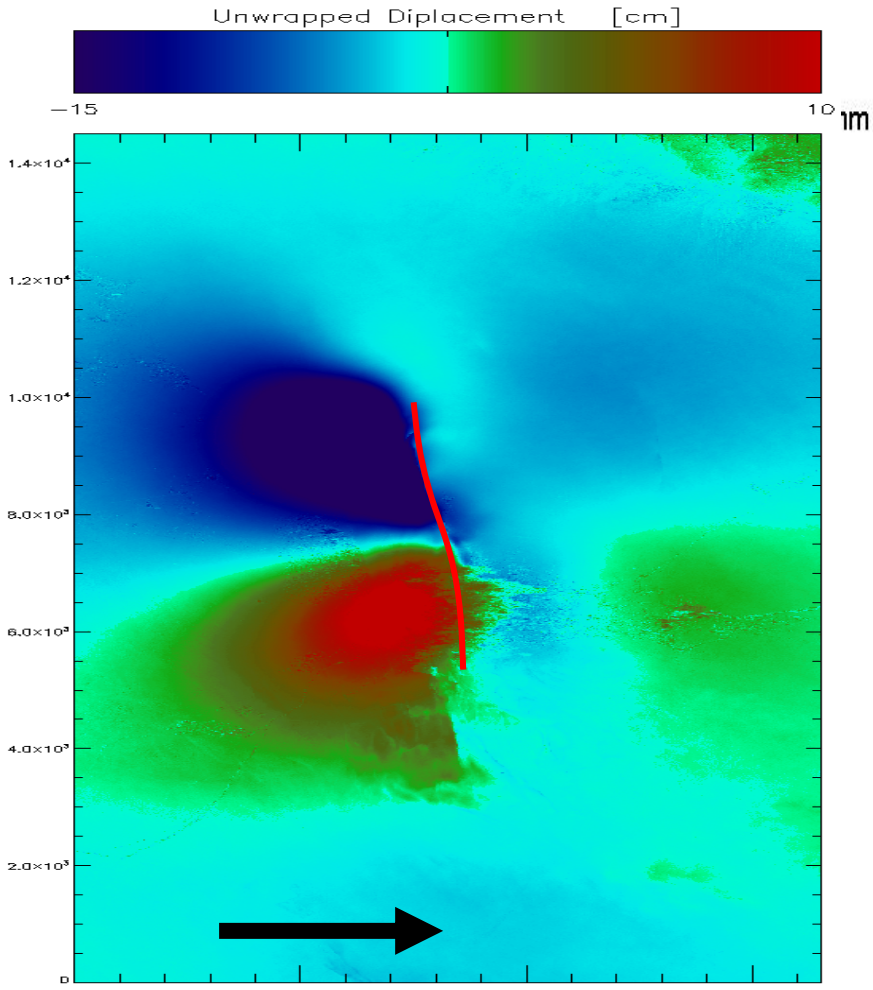
→ use second satellite

→ speckle tracking to support azimuth component …

Earthquake Shifts from InSAR & Speckle Tracking



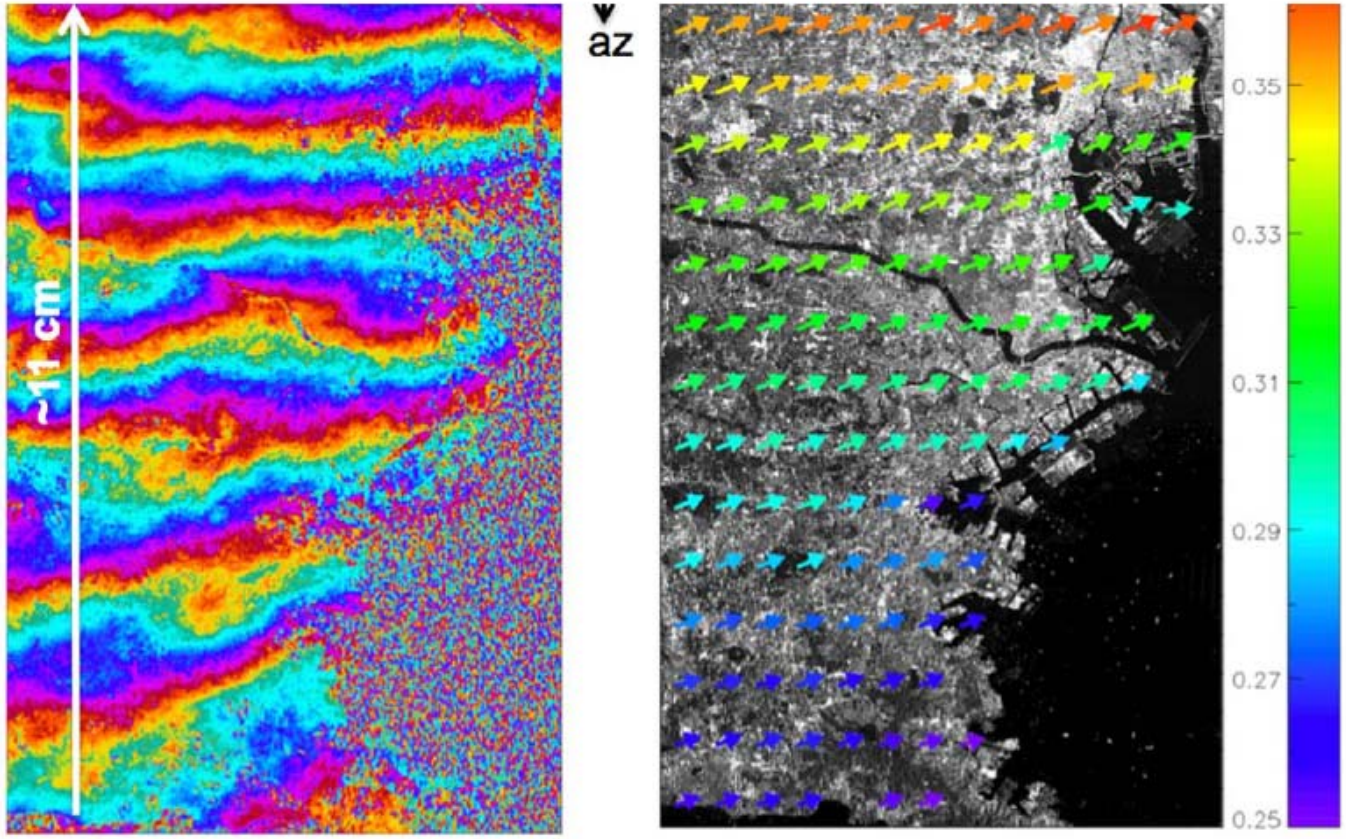
Azimuth (correlation)



Range (interferometry)

Bam / Iran 26.12.2003 (ASAR)

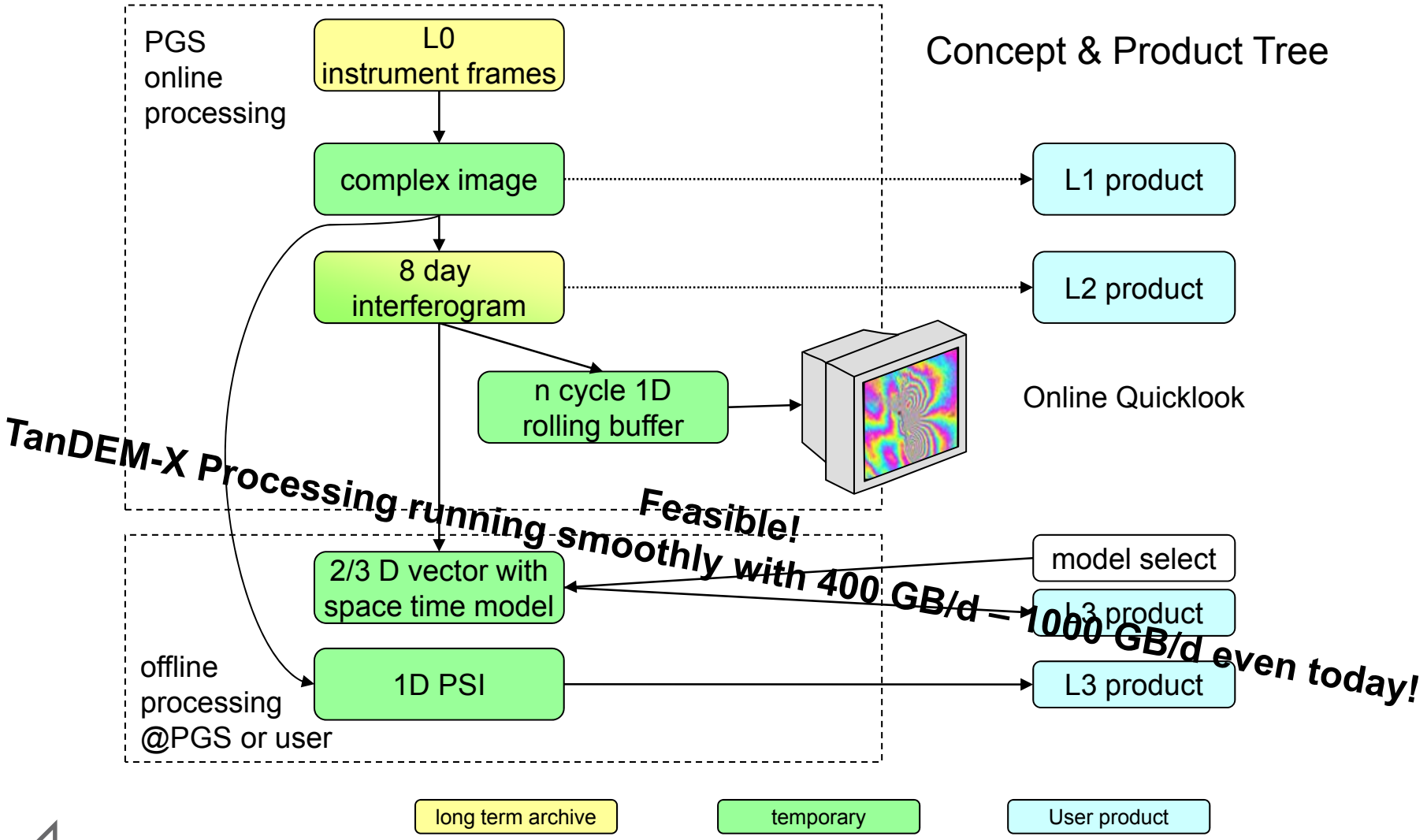
Ground Displacement from Speckle Tracking / Radargrammetry

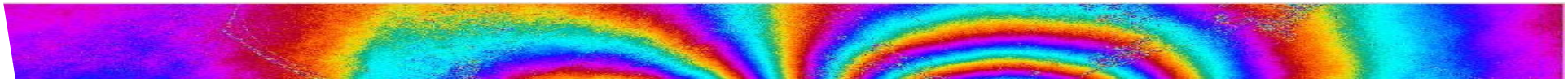


GRSL 2012: Ground Displacement Measurement by TerraSAR-X Image Correlation: The 2011 Tohoku-Oki Earthquake

Nestor Yague-Martinez, Michael Eineder, *Member, IEEE*, Xiao Ying Cong, and Christian Minet

Processing Challenge: 3-4 TB/day



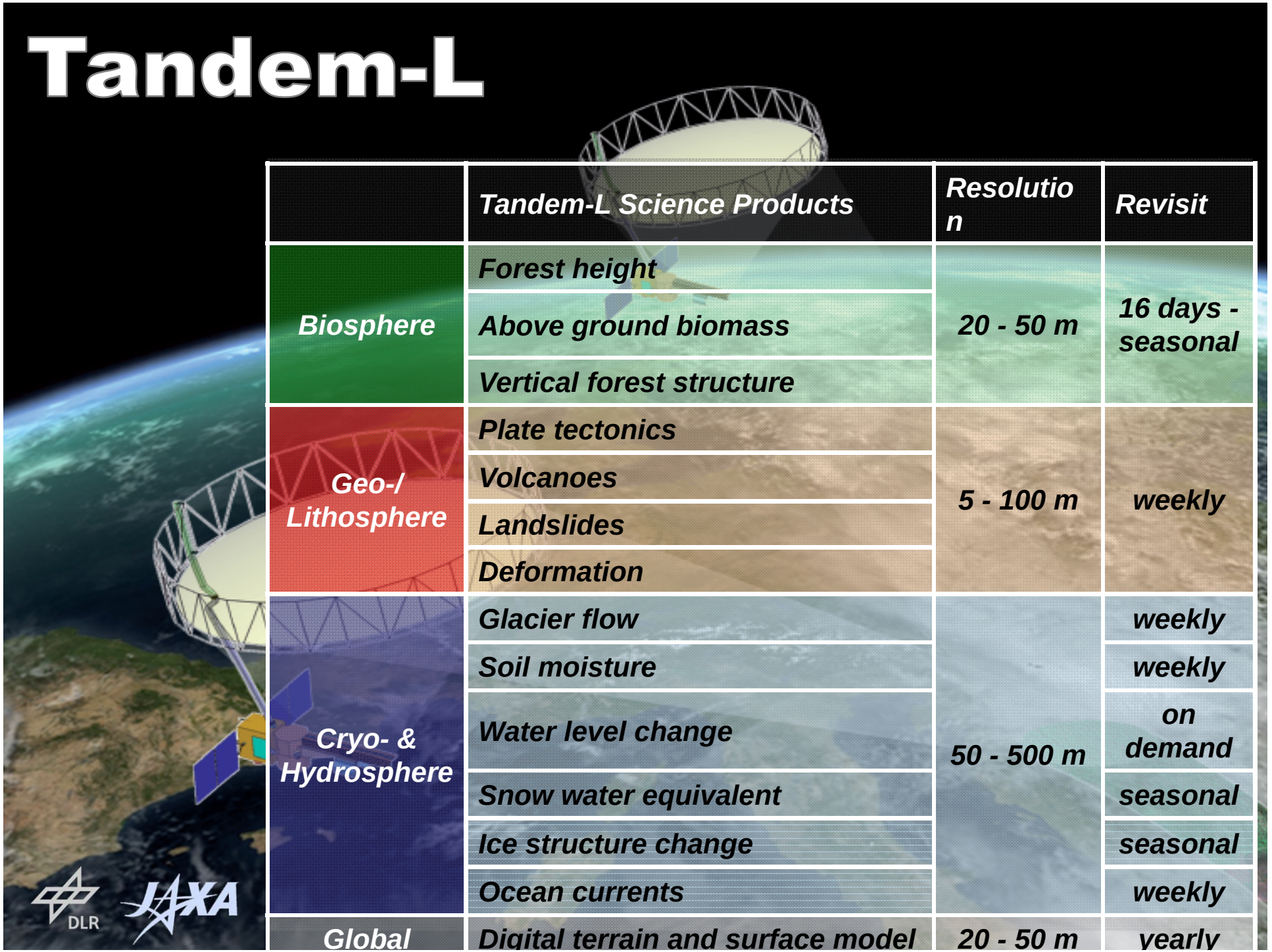


Conclusions

- Challenges are
  - accuracy over large areas
    - ionospheric and tropospheric correction required
  - 2/3D-vector
    - ascending + descending orbits
    - (inclusion of geophysical models)
  - Decorrelation
    - L-band promising

- **Exciting mission - challenges can be met**

Tandem-L



	Tandem-L Science Products	Resolution	Revisit
Biosphere	Forest height	20 - 50 m	16 days - seasonal
	Above ground biomass		
	Vertical forest structure		
Geo-/ Lithosphere	Plate tectonics	5 - 100 m	weekly
	Volcanoes		
	Landslides		
	Deformation		
Cryo- & Hydrosphere	Glacier flow	50 - 500 m	weekly
	Soil moisture		weekly
	Water level change		on demand
	Snow water equivalent		seasonal
	Ice structure change		seasonal
	Ocean currents		weekly
Global	Digital terrain and surface model	20 - 50 m	yearly