CEOS SAR Calibration and Validation Workshop, ESA ESTEC 2015

Adding Precise Wave-Propagation Information and Geodetic Corrections to Standard SAR Products

M. Eineder[1,3], U. Balss[1], X. Cong[3], S. Suchandt[1], C. Gisinger[2], H. Runge[1]

[1]Remote Sensing Technology Institute (IMF), German Aerospace Center (DLR)

[2]Institute for Astronomical and Physical Geodesy (IAPG), Technische Universität München (TUM),

[3]Chair of Remote Sensing Technology (LMF), Technische Universität München (TUM)

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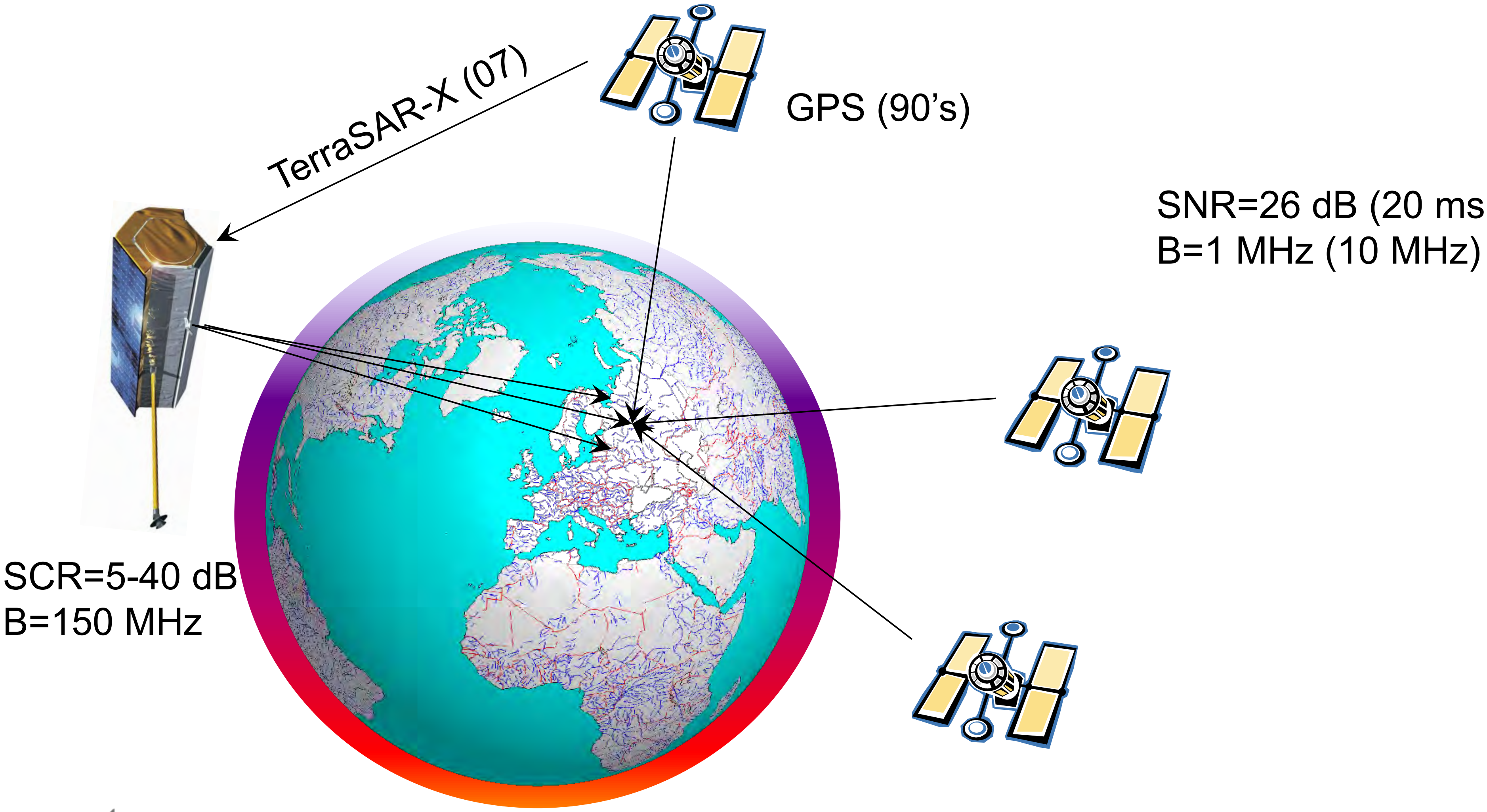
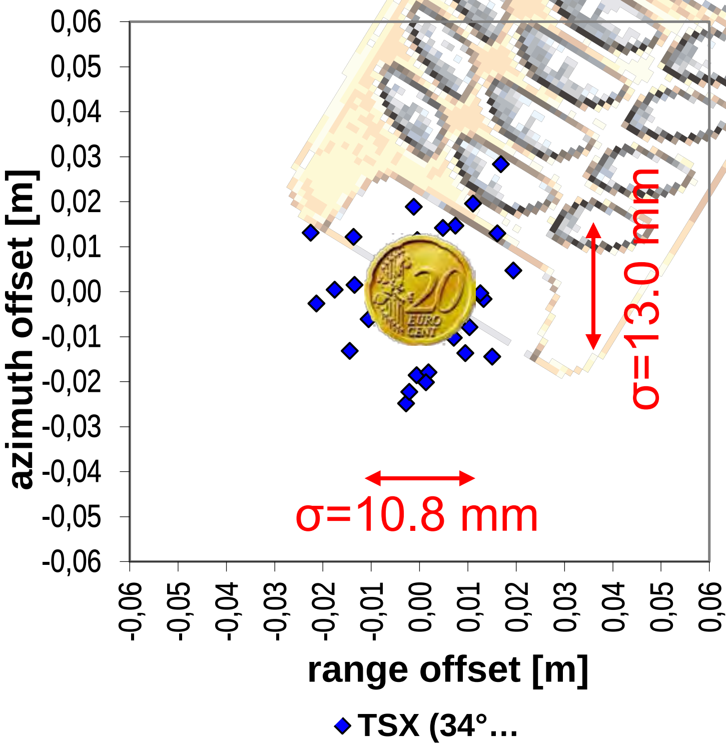
Point Positioning Accuracy: SAR versus GNSS



Yes, it is Possible to Localize Objects with cm Accuracy

Local TSX positioning accuracy of a CR, corrected for solid earth tides, atmospheric refraction (H_2O, TEC), pole tides, etc.



Literature:

1) Eineder, M., Minet, C., Steigenberger, P., Cong, X., Fritz, T., Imaging Geodesy—Toward Centimeter-Level Ranging Accuracy With TerraSAR-X. IEEE TGRS, 2011
2) Schubert, A., Jehle., M., Small, D., Meier, E., Mitigation of atmospheric perturbations and solid-Earth movements in a TerraSAR-X time-series, J. of Geodesy, 86(4), 2012.
3) Cong, X., Balss, U., Eineder, M., Fritz, T., Imaging Geodesy—Centimeter-Level Ranging Accuracy With TerraSAR-X: An Update. IEEE GRSL, 2012
4) Gisinger, C., Balss, U., Pail, R., Zhu, X.X., Montazeri, S., Gernhardt, S., Eineder, M., Precise Three-Dimensional Stereo Localization of Corner Reflectors and Persistent Scatterers With TerraSAR-X. IEEE TGRS, 2015
5) Schubert, A., Small, D., Miranda, N., Geudtner, D., Meier, E., Sentinel-1A Product Geolocation Accuracy: Commissioning Phase Results, Remote Sens, 2015

… but not yet for everybody and everywhere!

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Geodetic SAR Product: Goals & Challenges

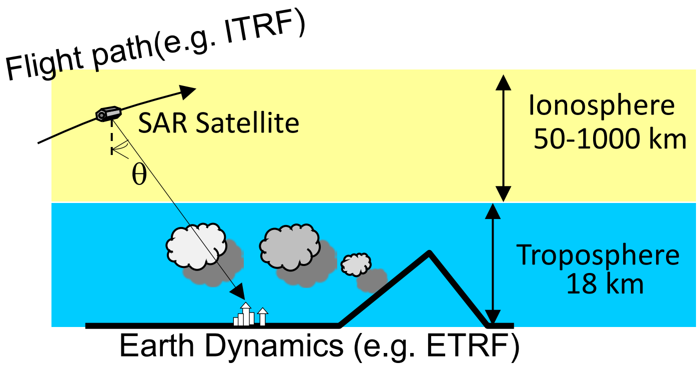
Design goals:

- Improve positioning of SAR image data
- As accurate as possible / foreseeable: mm-level
- Not to impact data integrity
- Usable for InSAR phase corrections
- Easy to use for scientists & SW developers

Challenges:

- Projection: 3D→2D
- Height dependency

$$\cancel{R = \frac{\tau c}{2}} \rightarrow R = \frac{1}{2}\int_0^{\tau} c(t)dt$$



Decision:

→ Not: interpolation of SAR image data

→ But: <u>correction layer in time coordinate system</u>

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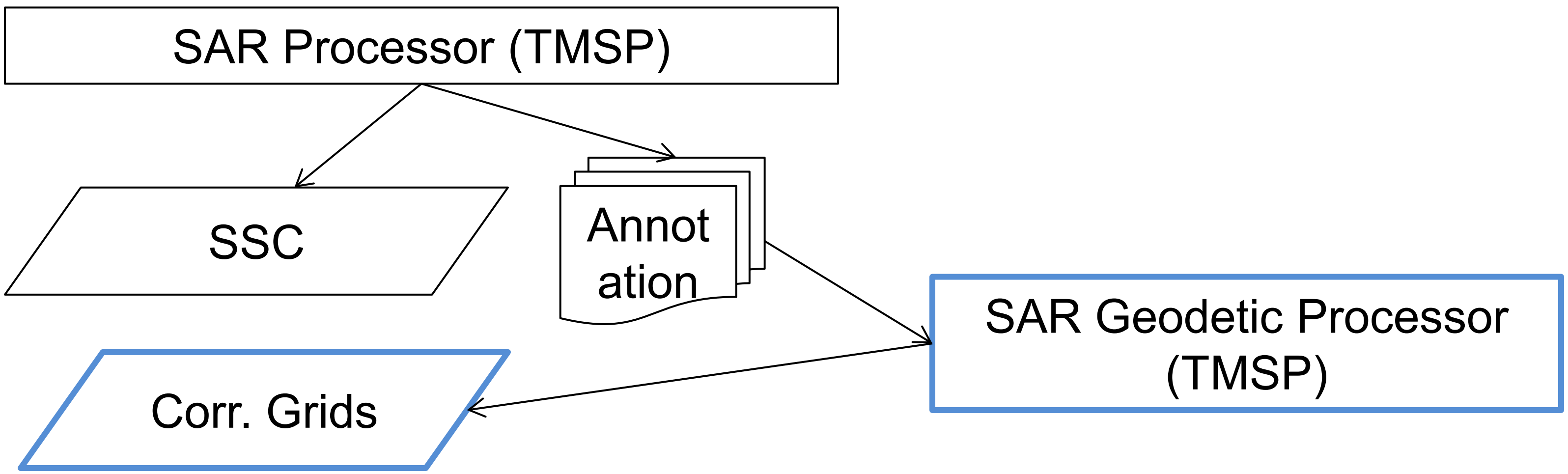
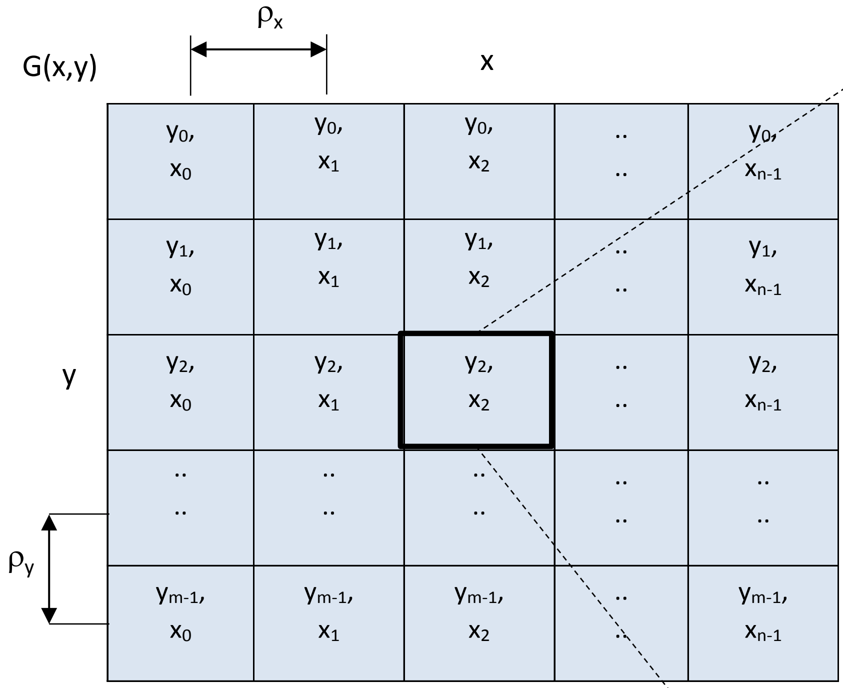
SAR Geodetic Processor Architecture & Flow Chart



Geodetic SAR Product Design: Correction Layer



Annotations per Grid Cell:

Base Parameters

t	Slow time (UTC)
τ	Fast time
λ,φ,h	**Geographic coord. (WGS84)**
x,y,z	x,y,z coordinates in ITRF
a, r	image pixel coordinates
los	Line-of-sight vector in ITRF
ϑ	local incidence angle
h_{sat}	Platform elevation
Δt_{sum}	**Sum of slow time corrections**
$\Delta\tau_{sum}$	**Sum of fast time corrections**

Atmospheric Corrections

Δt_{tropo}	Slow time correction (0.0)
$\Delta\tau_{tropo}$	Fast time correction
$\Delta'\tau_{tropo}$	$d\Delta\tau_{tropo}/d\Delta h$ for assumed height h

Ionospheric Corrections

Δt_{ion}	Slow time correction (0.0)
$\Delta\tau_{ion}$	Fast time correction

Spares for Future Corrections

Δt_{OL}	Slow time correction, ocean load
$\Delta\tau_{OL}$	Fast time correction, ocean load
Δx_{OL}	delta-x in ITRF, ocean load
Δy_{OL}	delta-y in ITRF, ocean load
Δz_{OL}	delta-z in ITRF, ocean load
	:

Solid Earth Tide Corrections

Δt_{SET}	Slow time correction
$\Delta\tau_{SET}$	Fast time correction
Δx_{SET}	delta-x
Δy_{SET}	delta-y
Δz_{SET}	delta-z
$\Delta\lambda$	latitude correction
$\Delta\varphi$	latitude correction

- (x,y): Point coordinates in radar & map projection
- G (x,y): Regular grid w.r.t. (x,y)
- ρ_x, ρ_y: Grid resolution 200 – 1000 m

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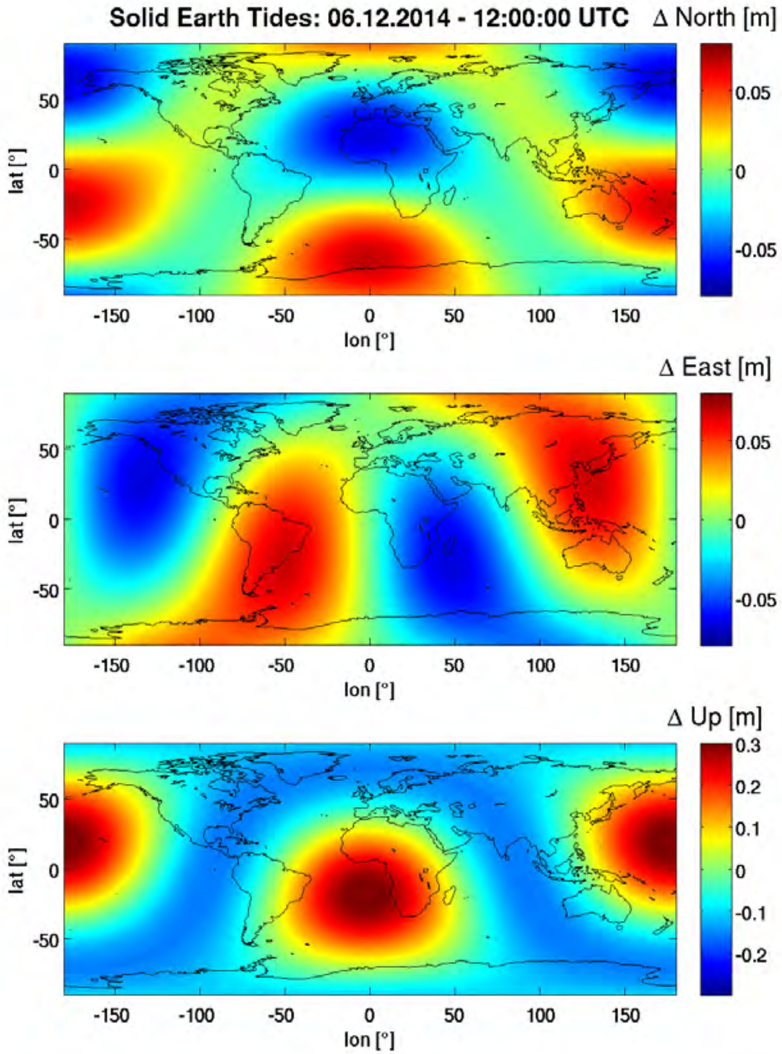
Data Sources for Correction Layer

- Geodynamic effects:
  - IERS Conventions for solid earth tides (GNSS compatible)
  - Coordinate transforms (e.g. ITRF-ETRF)

- Tropospheric delays:
  - 4D ECMWF ERA-Interim data; 80 km res, 60 vertical levels, 1/(6 hours)

- Ionosphere:
  - CODE (Center for Orbit Determination Europe) Uni Bern
  - DLR Space Weather Applications Center (SWACI)

Example: Solid Earth Tides - IERS Conventions

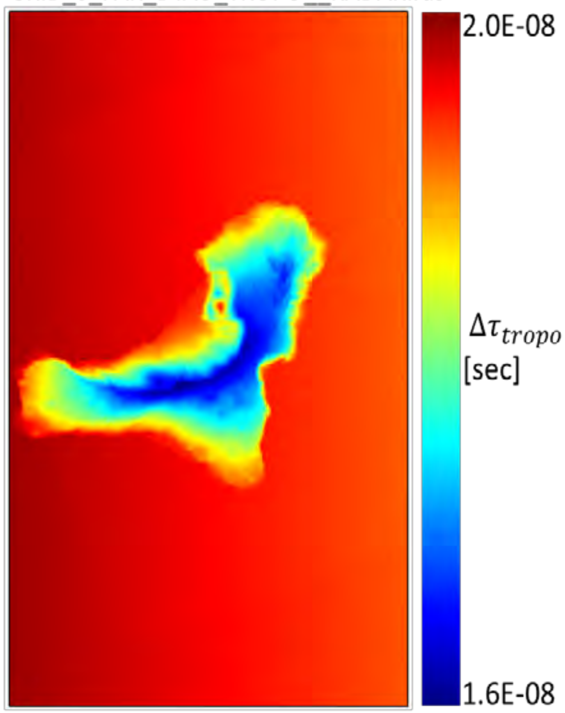


Global map of geometric surface shifts caused by solid Earth tides on December 6th, 2014, 12:00:00 UTC (full moon).

SAR Geodetic Product Product Example

Tropospheric Delay

GRID_0_PAR_DTAU_TROPO__RADAR.ras

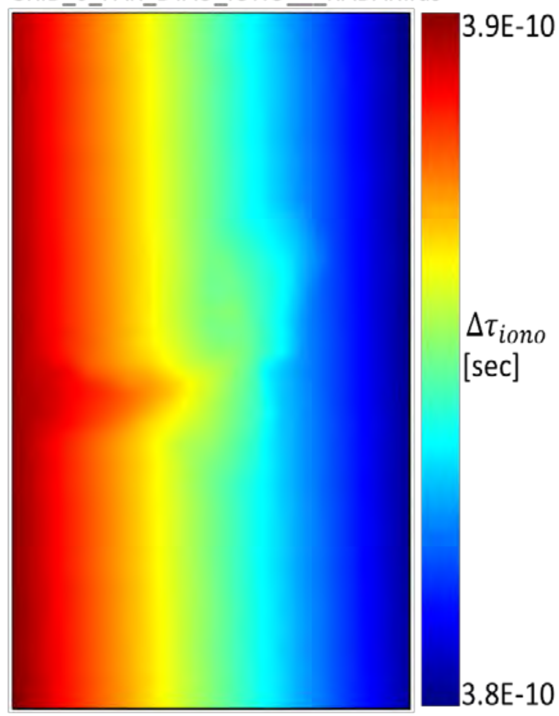


Tropspheric range correction (ECMWF)

+

Ionospheric Delay

GRID_0_PAR_DTAU_IONO___RADAR.ras

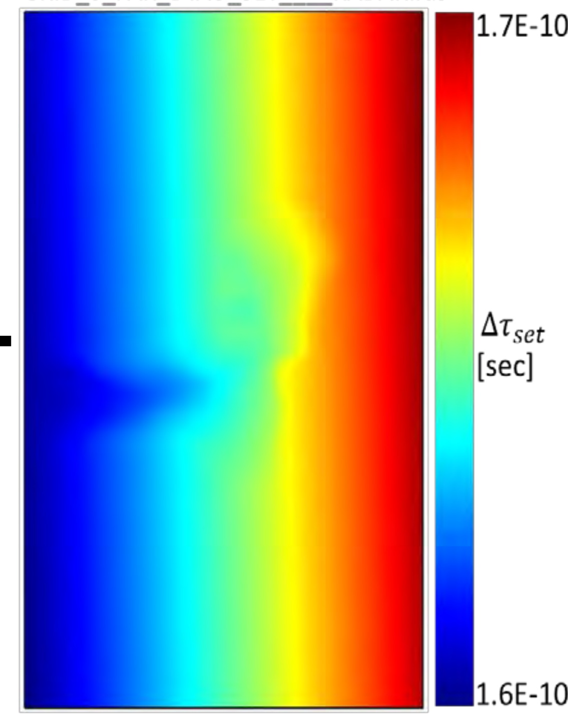


Ionosphericm range correction (CODE)

+

Solid Earth Tides in Range

GRID_0_PAR_DTAU_SET____RADAR.ras



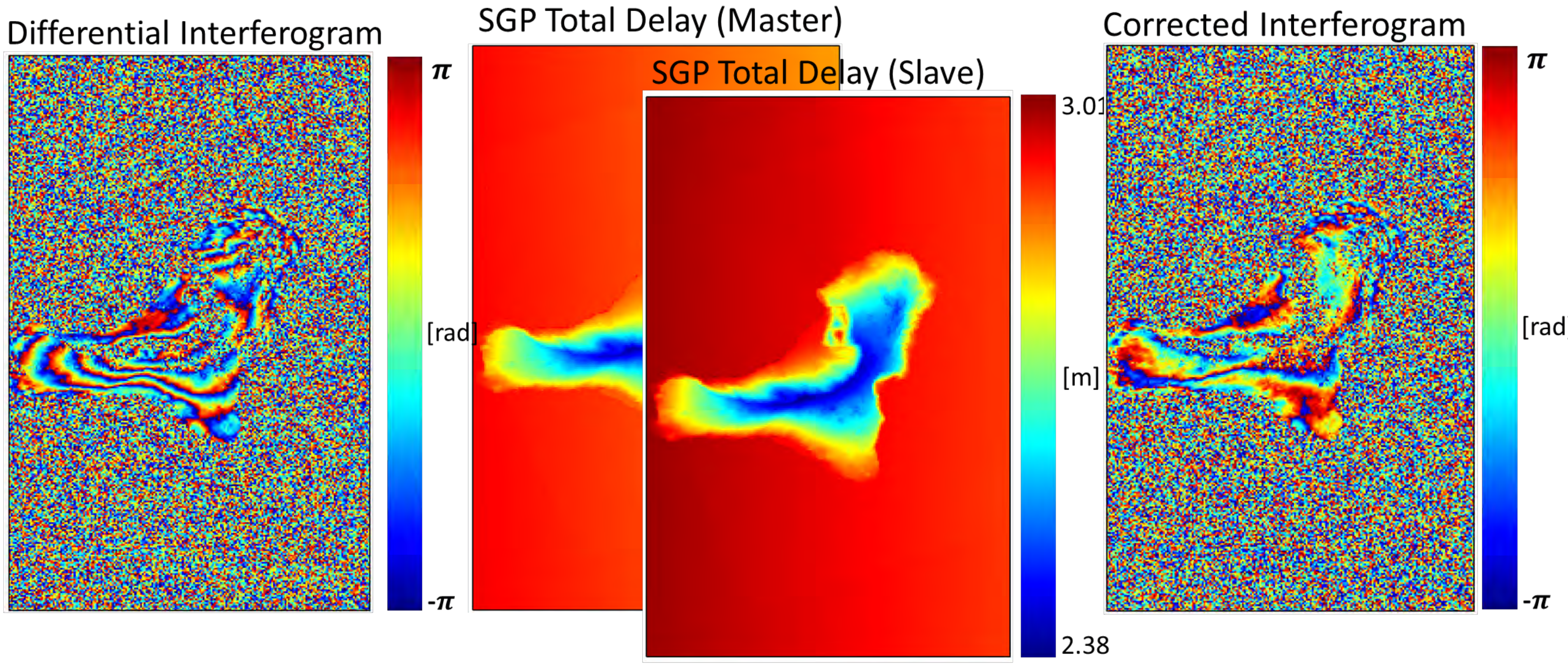
Geodynamic range correction (IERS)

Recipe

- Example 1: precise geocoding
  - For every sample (t, τ)
    - Read correction values $\Delta t(t, \tau)$, $\Delta\tau(t, \tau)$ from grid; interpolate
    - Zero-Doppler geocoding of pixel with timing $(t+\Delta t, \tau+\Delta\tau)$

- Example 2: InSAR phase correction
  - For every sample (t, τ)
    - Read correction values $\Delta\tau_{master}(t, \tau)$ and $\Delta\tau_{slave}(t, \tau)$ from grid; interpolate
    - Correct InSAR phase by $2\pi(\Delta\tau_{master}(t, \tau)-\Delta\tau_{slave}(t, \tau))/\lambda$
    - Optional: apply differential phase correction from high resolution DEM

Example: Removal of Stratified Troposphere



Test Site:	Hierro
Master acquisition	2013-04-23T07:15:32
Slave acquisition	2011-11-10T07:15:31
Incidence angle	33°

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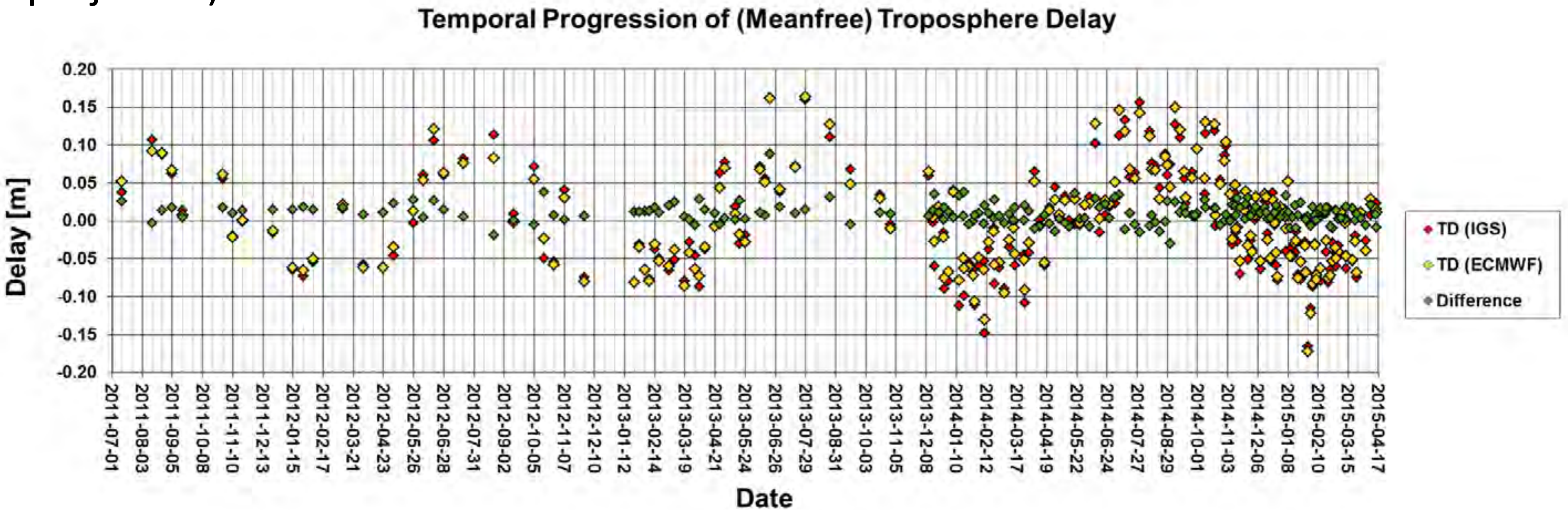
Validation with local GNSS

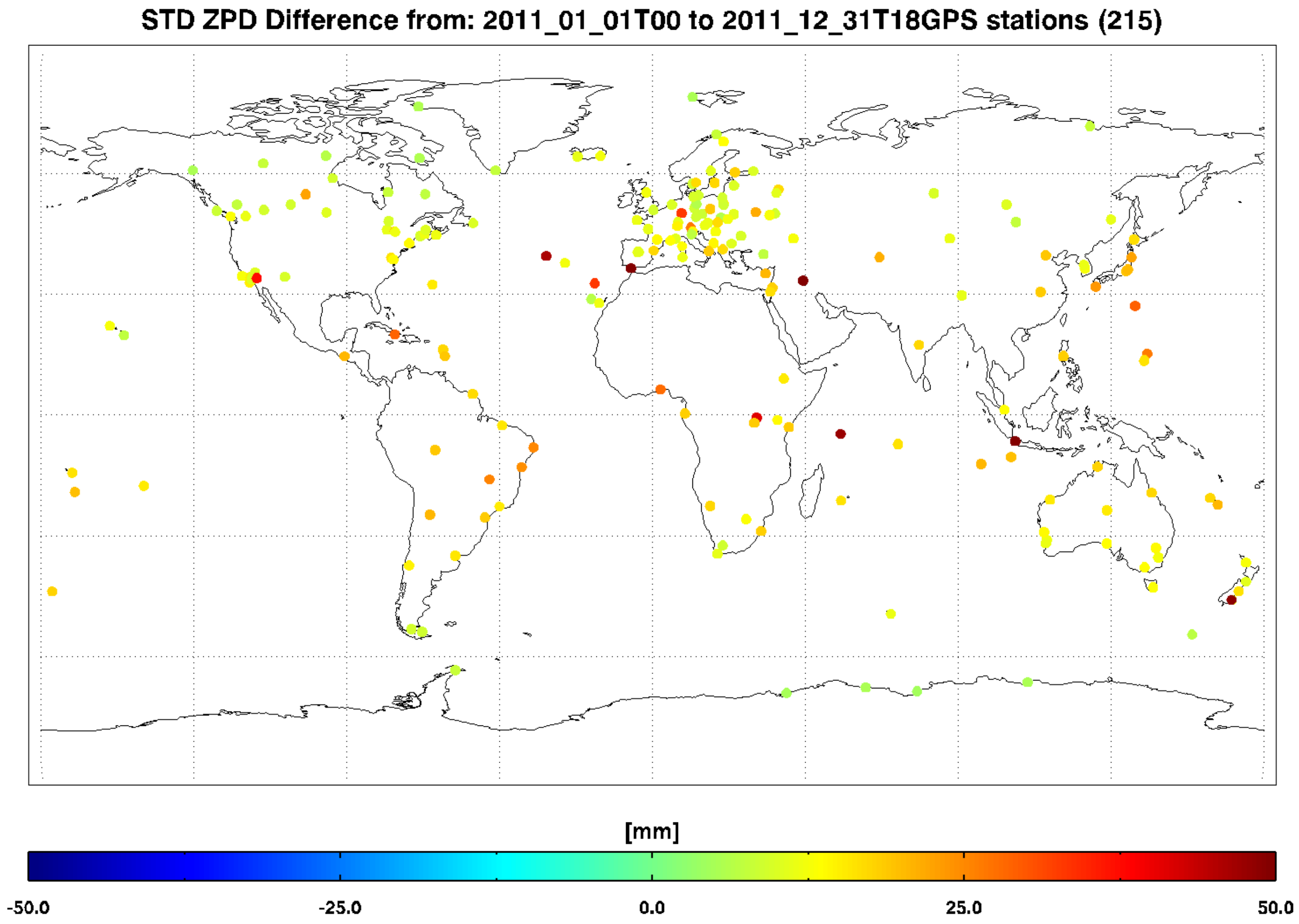
Test & validation of tropospheric and ionospheric delays with GNSS measured delays for the Wettzell testsite during TerraSAR-X data takes (radar slant range projected).



Parameter	Component	Difference
Troposphere (ECMWF – local GNSS)	Range	9.9 ± 13.0 mm
Ionosphere (CODE – local GNSS)	Range	2.5 ± 2.8 mm

→ **Globally available corrections are only 13 mm worse than local GNSS measurements**

Validation of ECMF Zenith Path Delay IGS Network



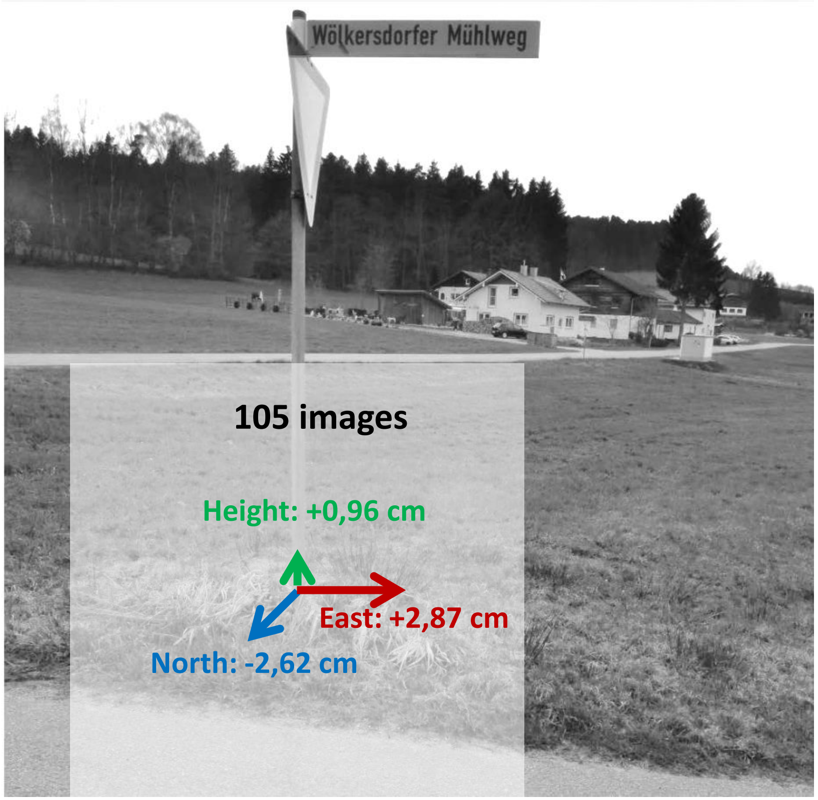
Application: 3D Coordinates from TerraSAR-X Stereo

→ DLR/HGF-Project DriveMark®

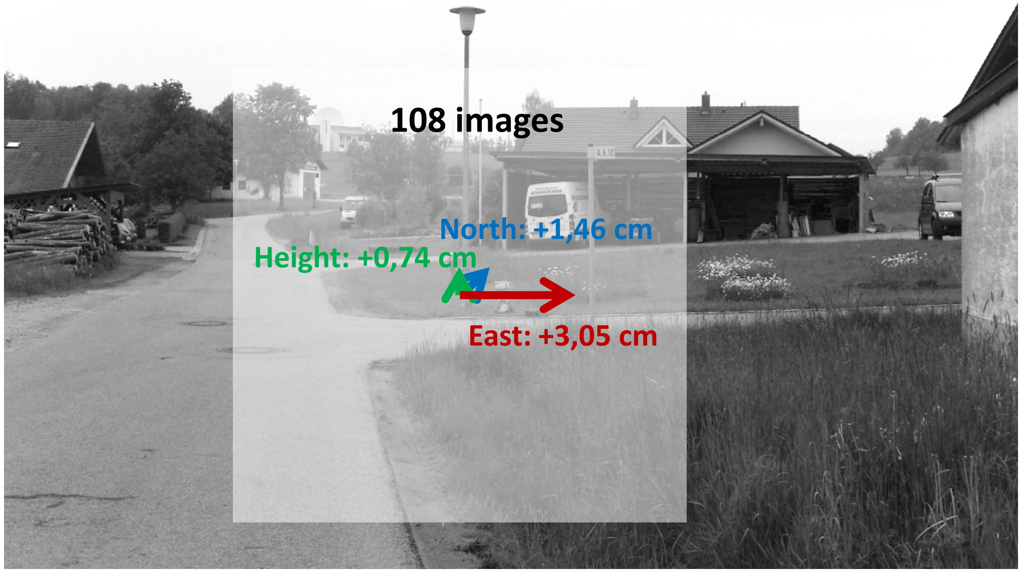
Lantern

Application: 3D Coordinates from TerraSAR-X Stereo

→ **DLR/HGF-Project DriveMark®**

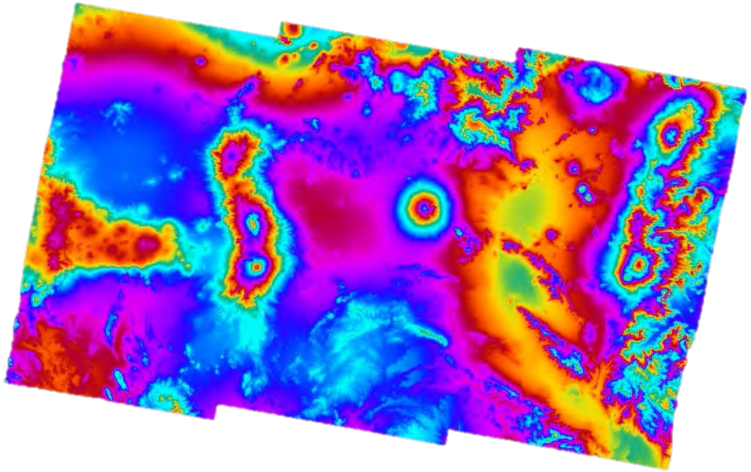


Lantern



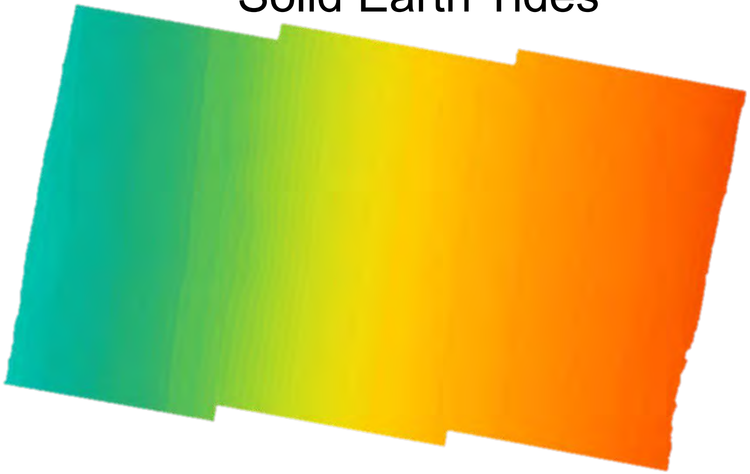
Application to Sentinel-1 Data: Mexico City

Troposphere



Ionosphere

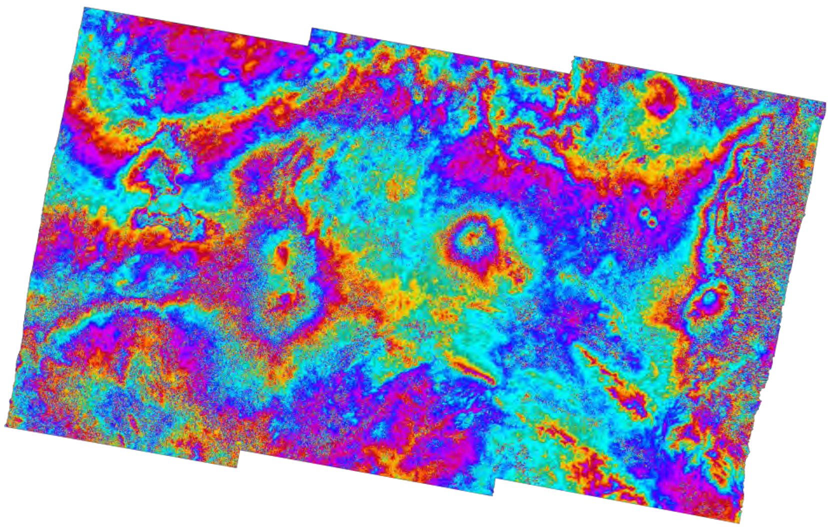
Solid Earth Tides



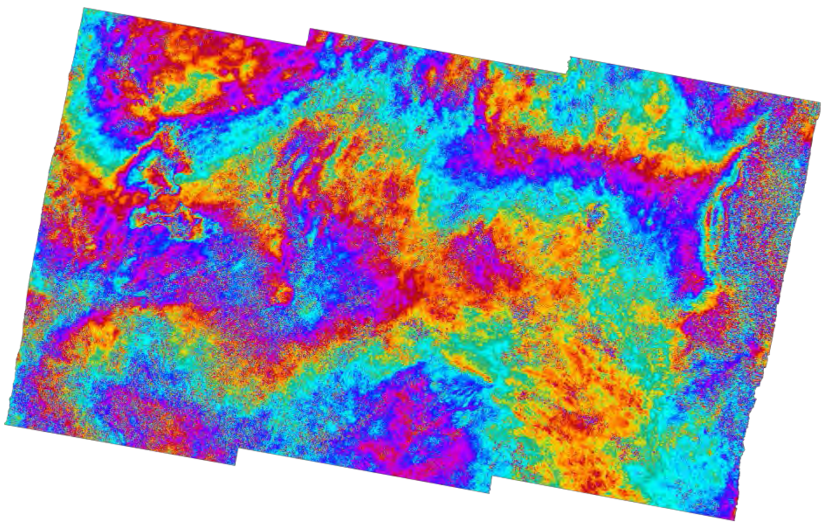
F. Rodriguez, DLR-IMF

Application to Sentinel-1 Data: Mexico City

Original DInSAR



SGP corrections applied



Conclusions

- New, easy to use realization of a geodetic SAR product demonstrated
- Manifold applications
- Product layer must tightly fit to a(n accurate) SAR processor
- Further study with Sentinel-1 recommended
- Discussion expected

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