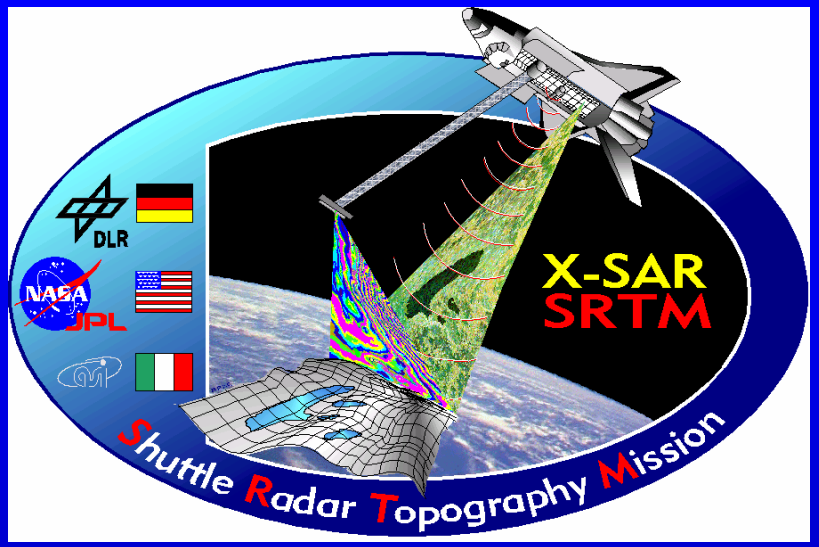

Workshop:
"The Shuttle Radar Topography Mission – Data Validation and Applications"
June 14-16, 2005 , Reston, Virginia, USA

Overview of the X-SAR/SRTM Data Processing and Scientific Investigations

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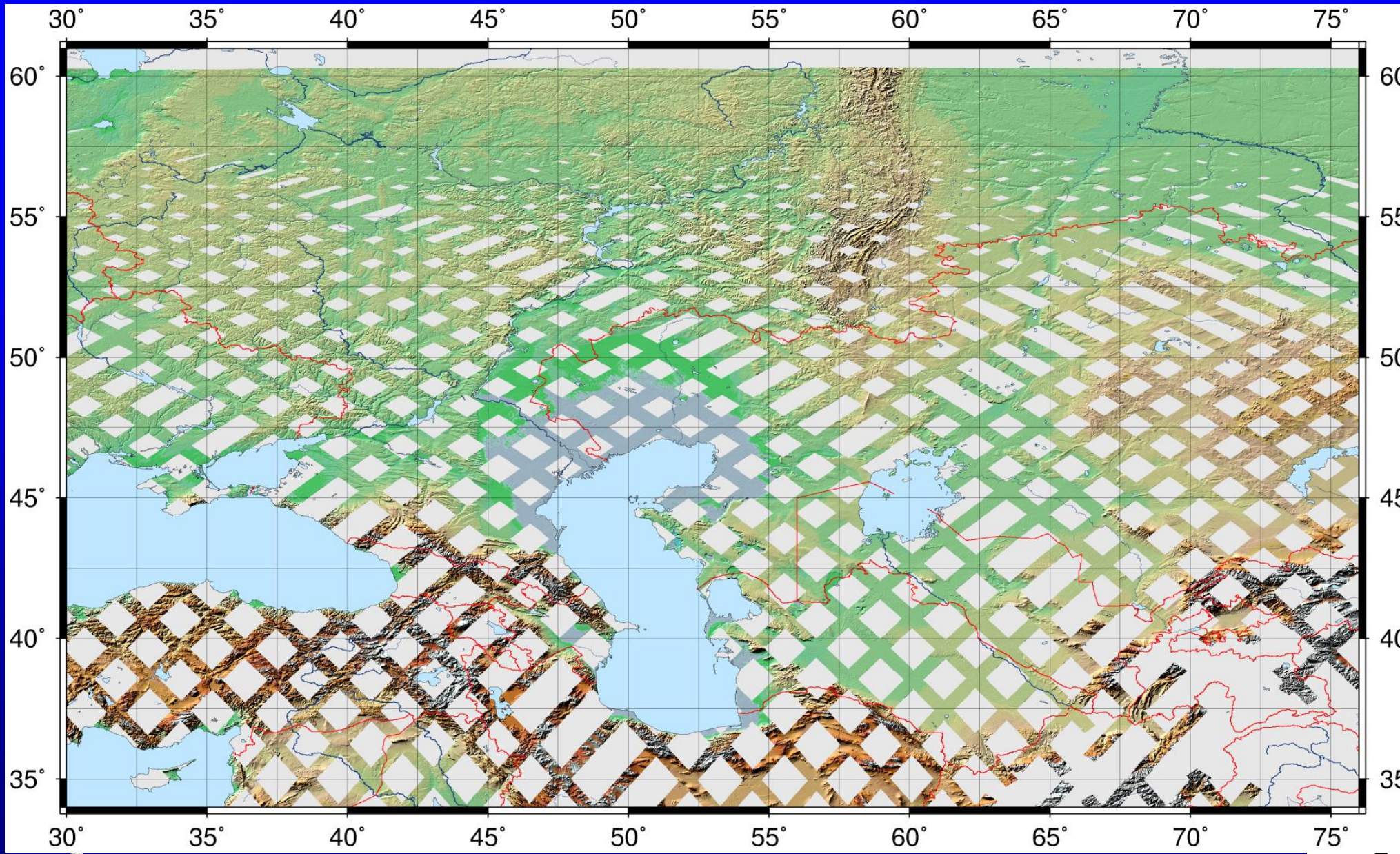


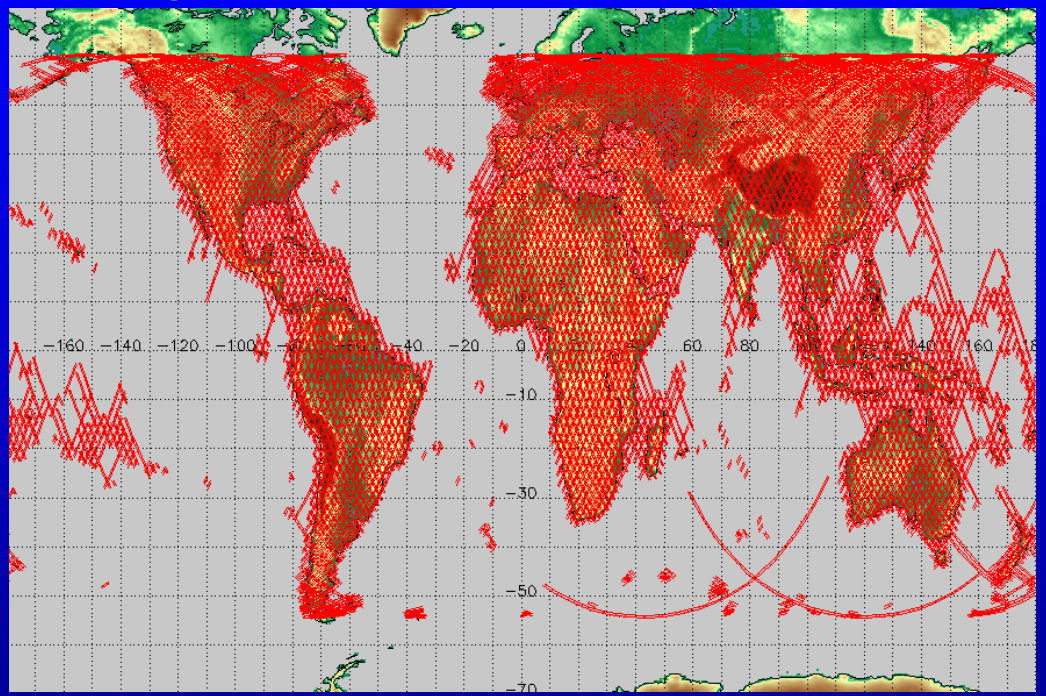
X-SAR/SRTM Shuttle Radar Topography Mission

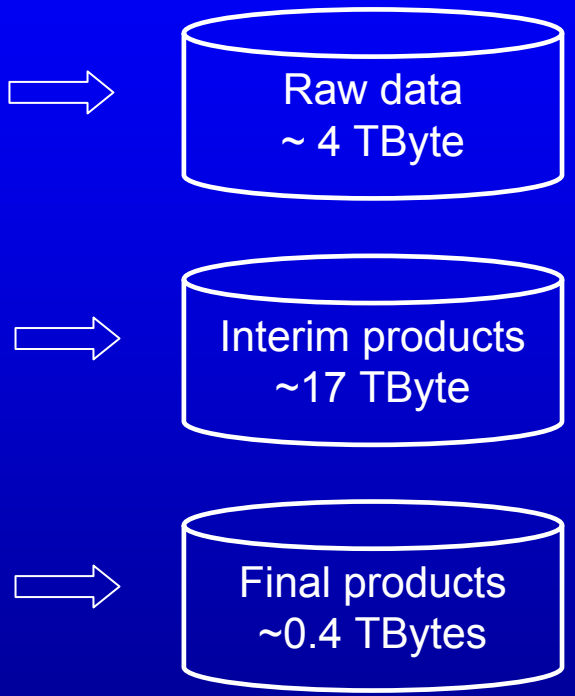
M.Werner 2003

DLR

SRTM XSAR-Data: Initial Processing Scenario

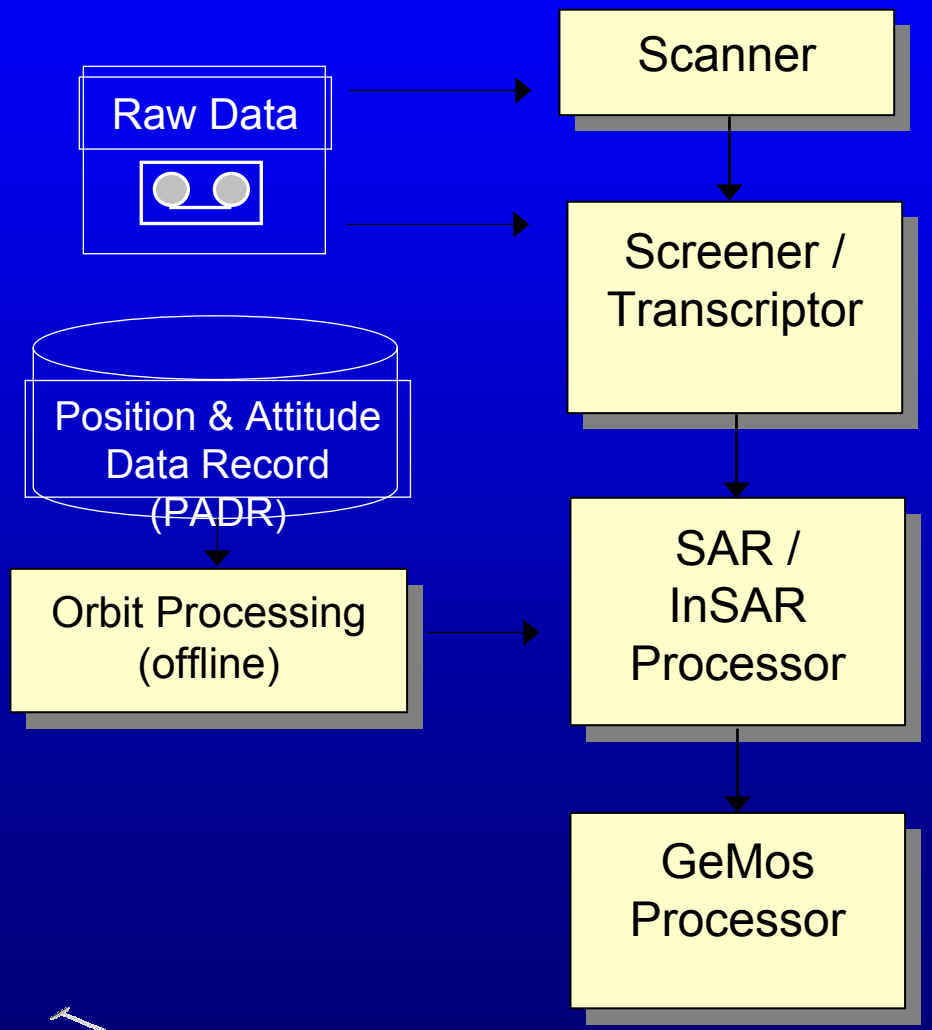
Coverage: 367 datatakes / 50 km swath width



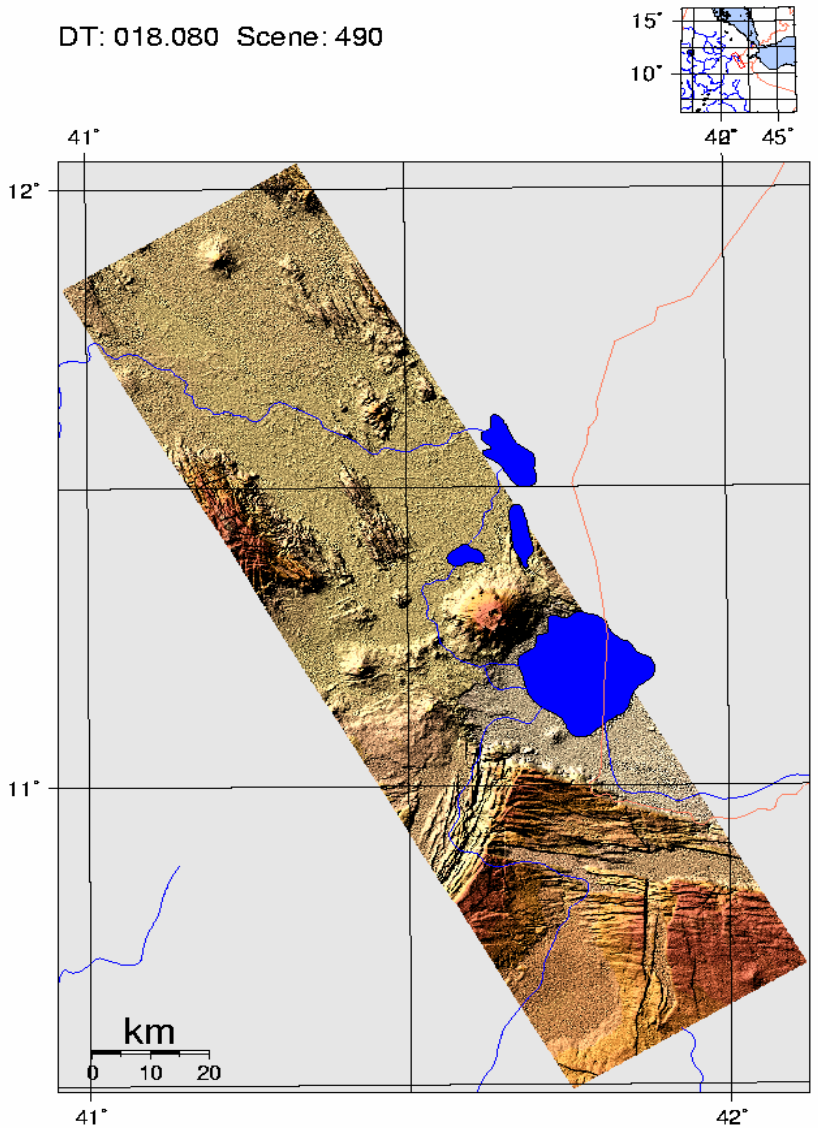


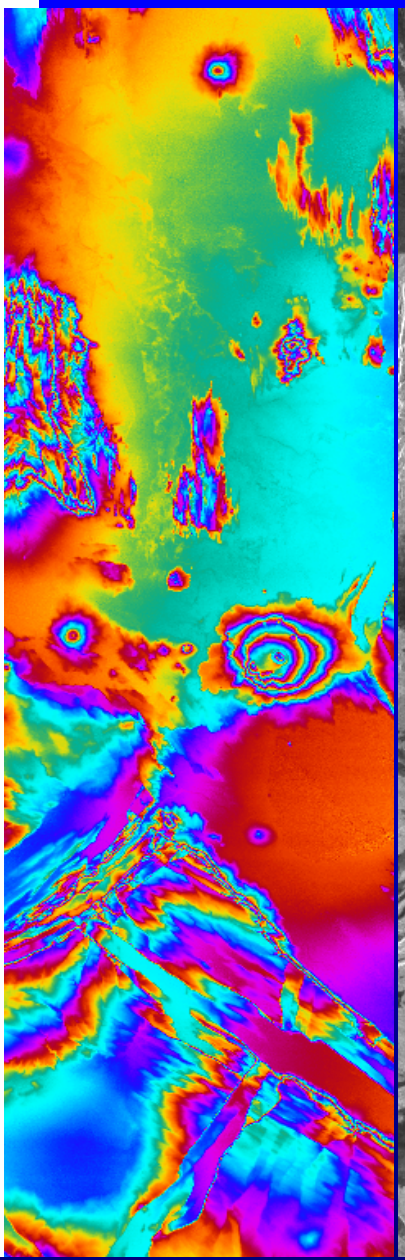
- Datatakes are split up into smaller scenes to limit computational requirements
- Processing Systems are embedded in a Data Information and Management System for high throughput and minimum operator interaction

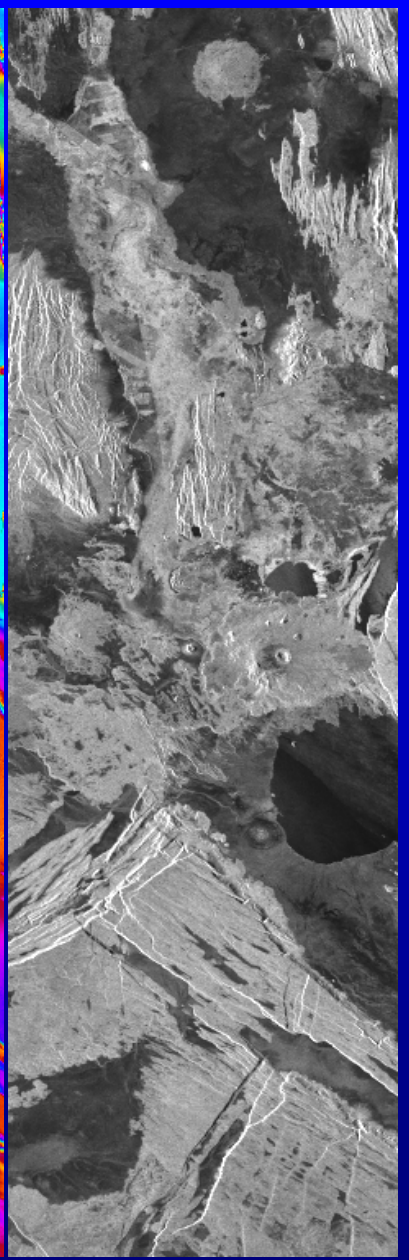
SRTM Data Processing Chain at DLR



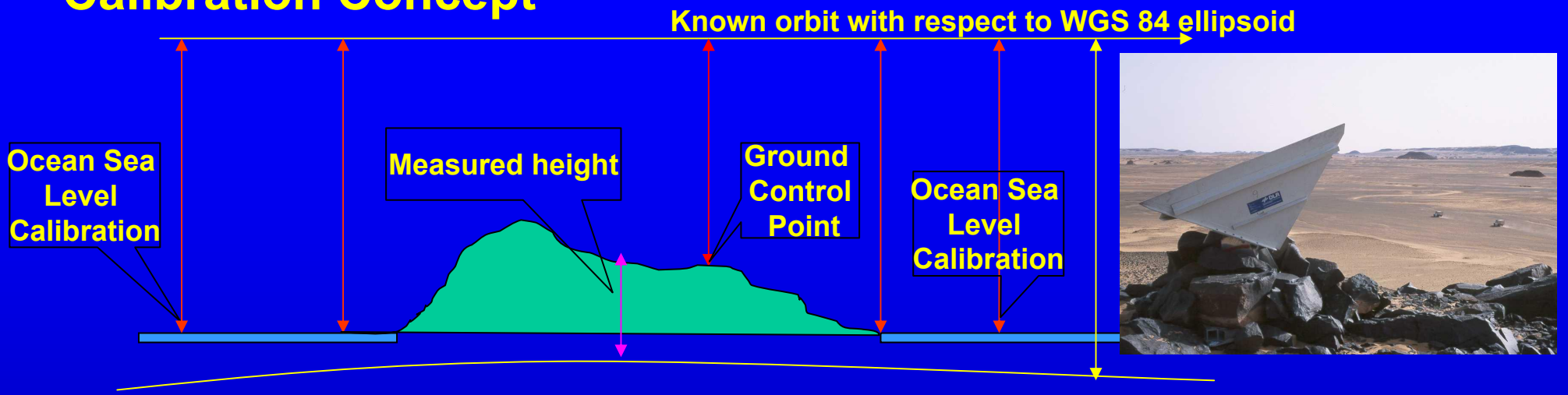
- Tape quality check & data take analysis
- Calculate parameter (e.g. Doppler history)
- Split raw data physically into tiles & divide tiles logically into scenes
- SAR focussing & Motion Compensation
- Creation of interferometric dataset (IFDS)
- Geocoding of IFDS
- Mosaicking of geocoded IFDS to large DEMs

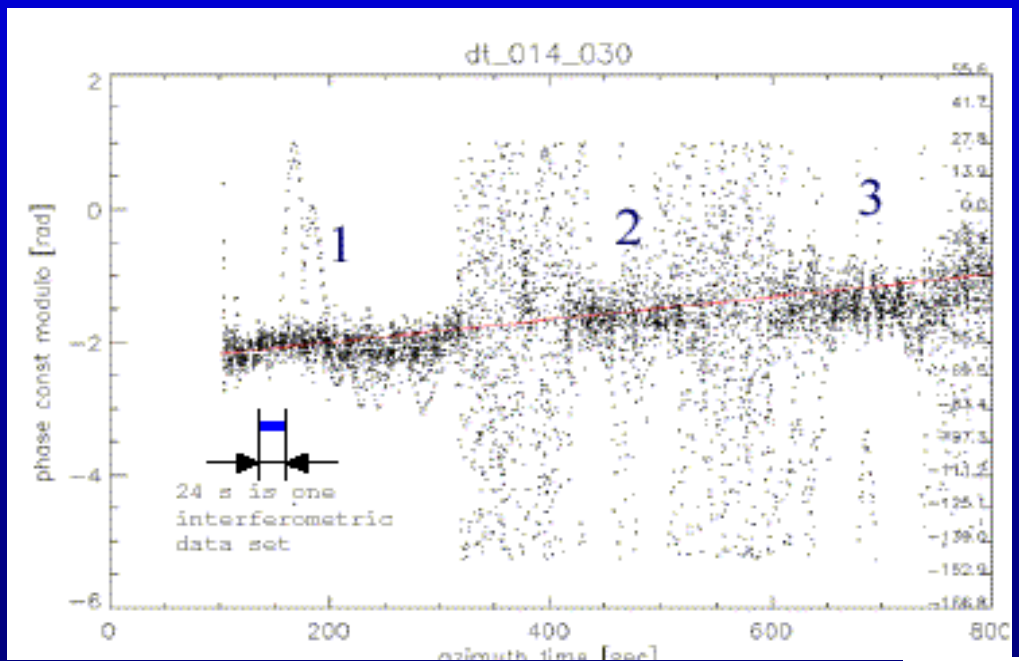

DT: 018.080 Scene: 490
15°
10°
41°
42°
45°
12°
11°
km
0 10 20
41°
42°



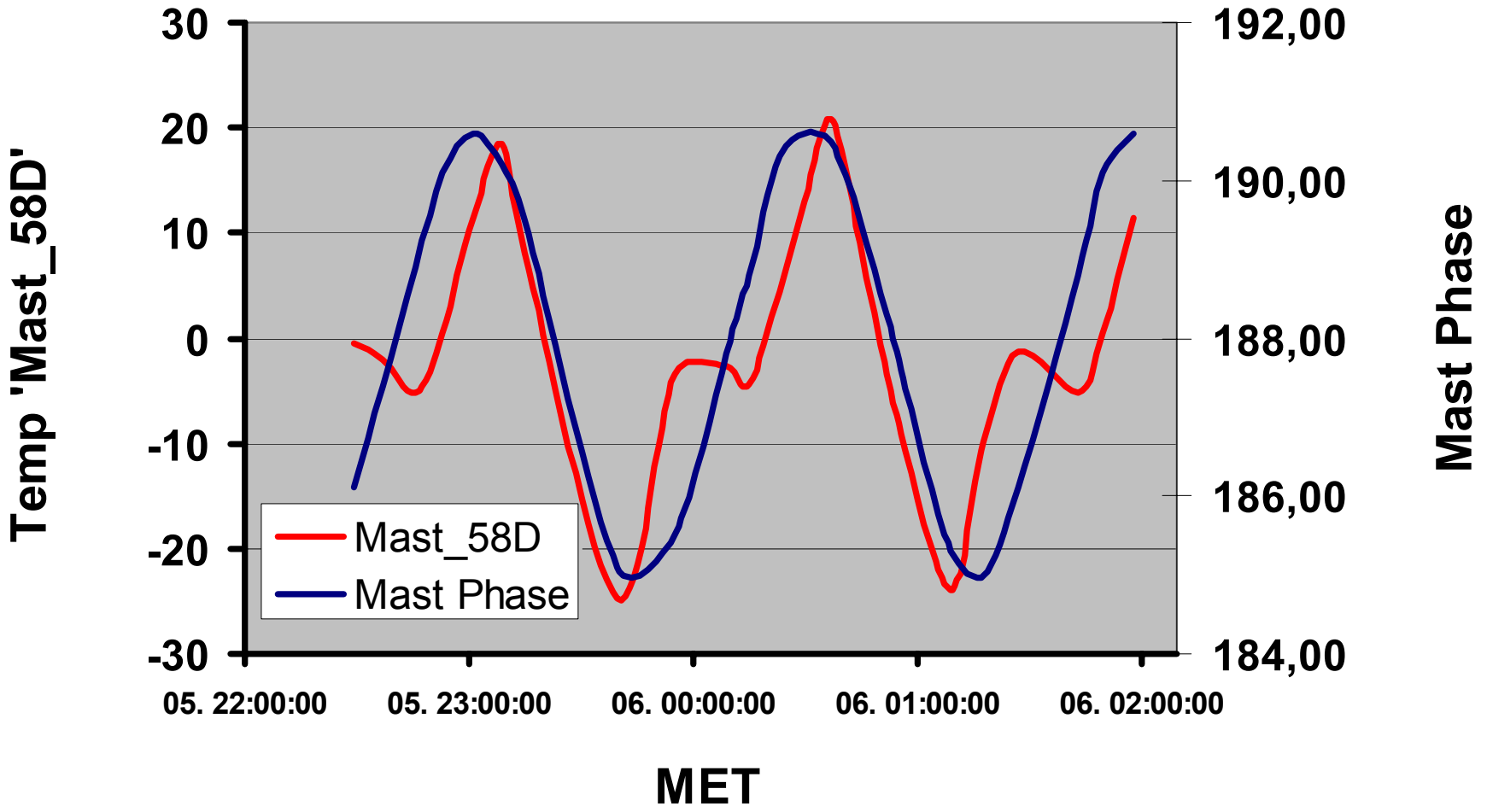


Calibration Concept

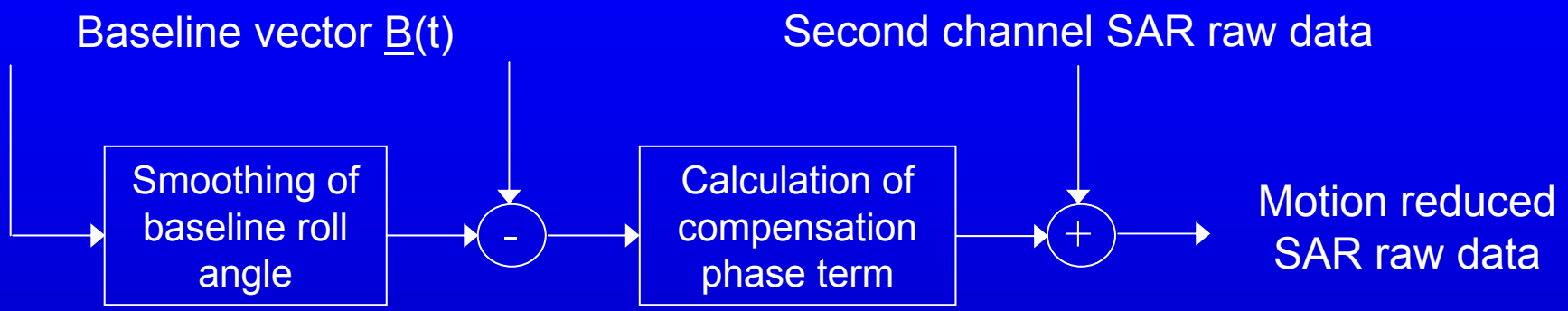


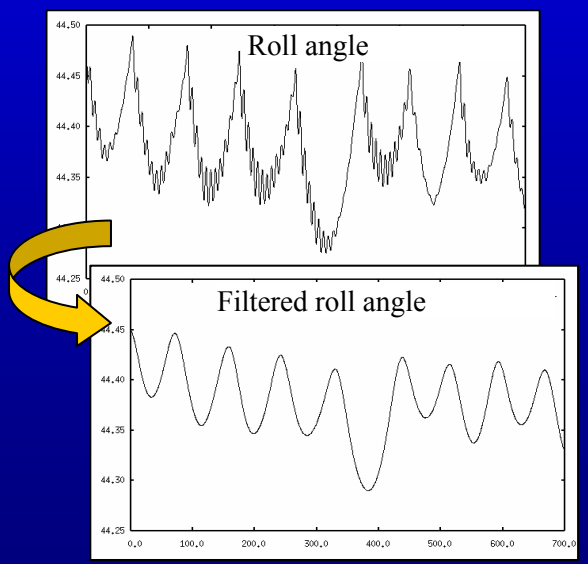


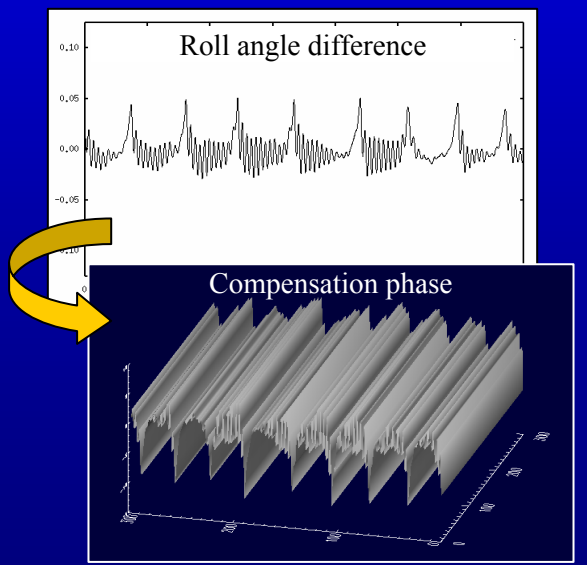
Phase Calibration due to Mast Temperature Influence



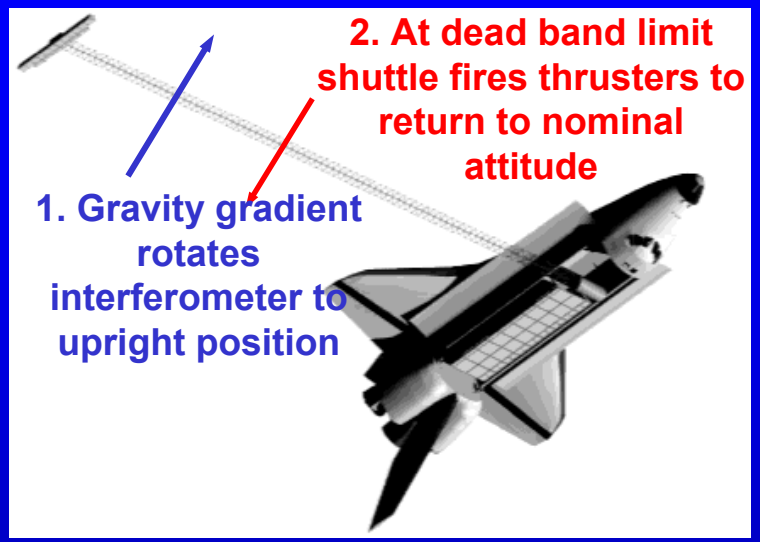
SRTM / X-SAR Baseline Motion Compensation



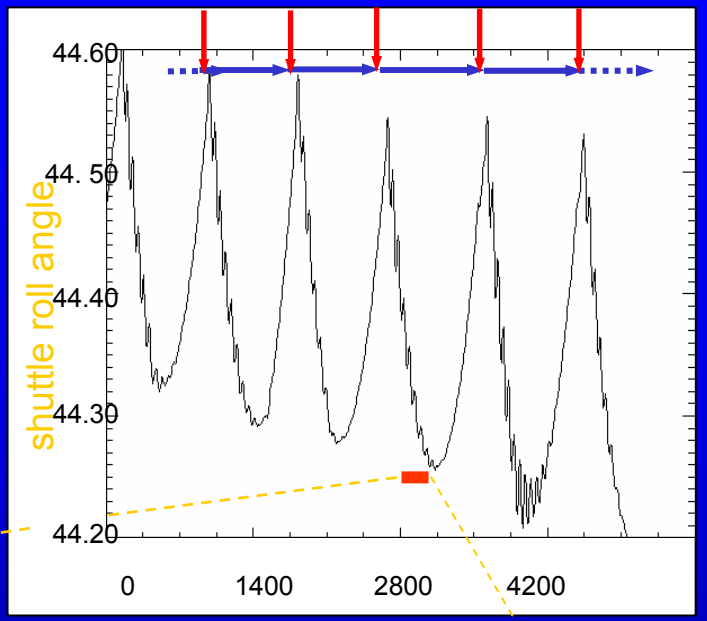


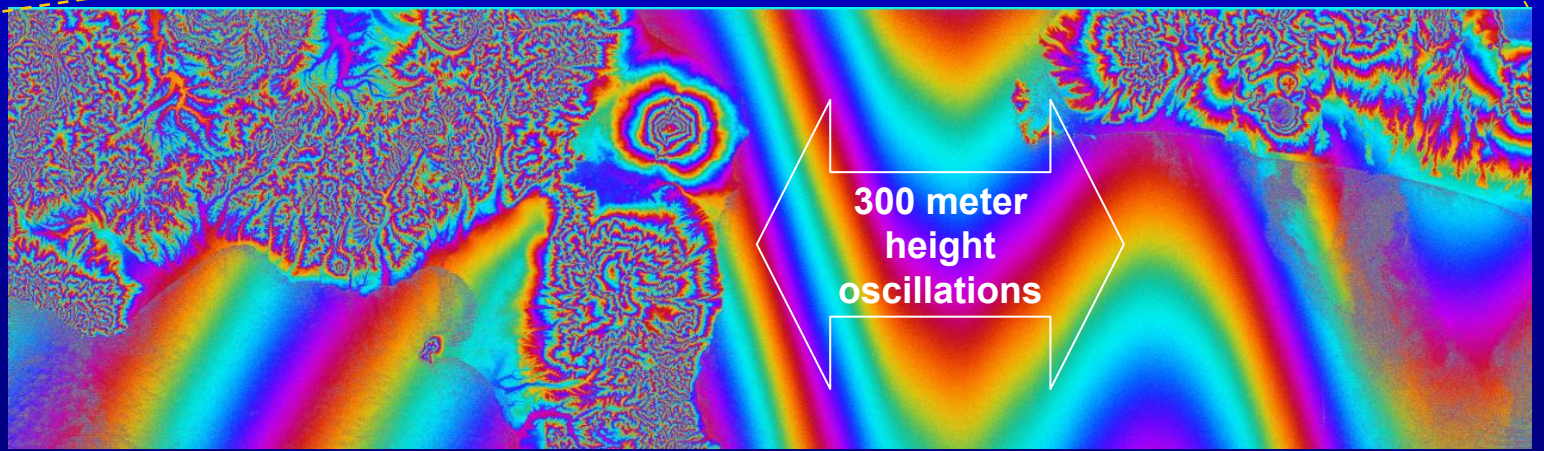


Effect of uncompensated mast oscillations



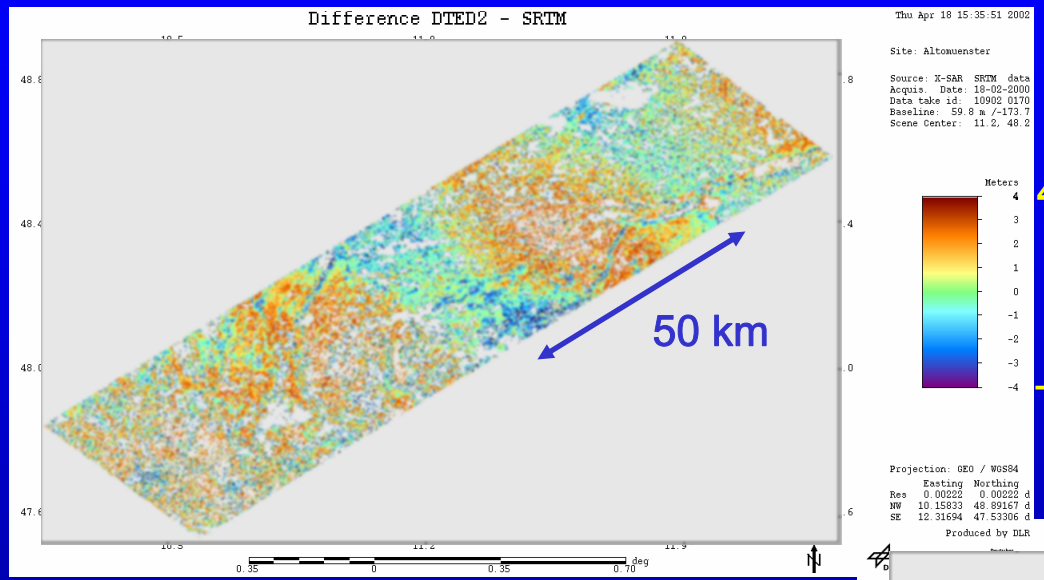
3. Shuttle acceleration causes mast oscillations ...





X-SAR/SRTM Shuttle Radar Topography Mission

Improvement of SRTM height accuracy with new PADR 600 (OP)

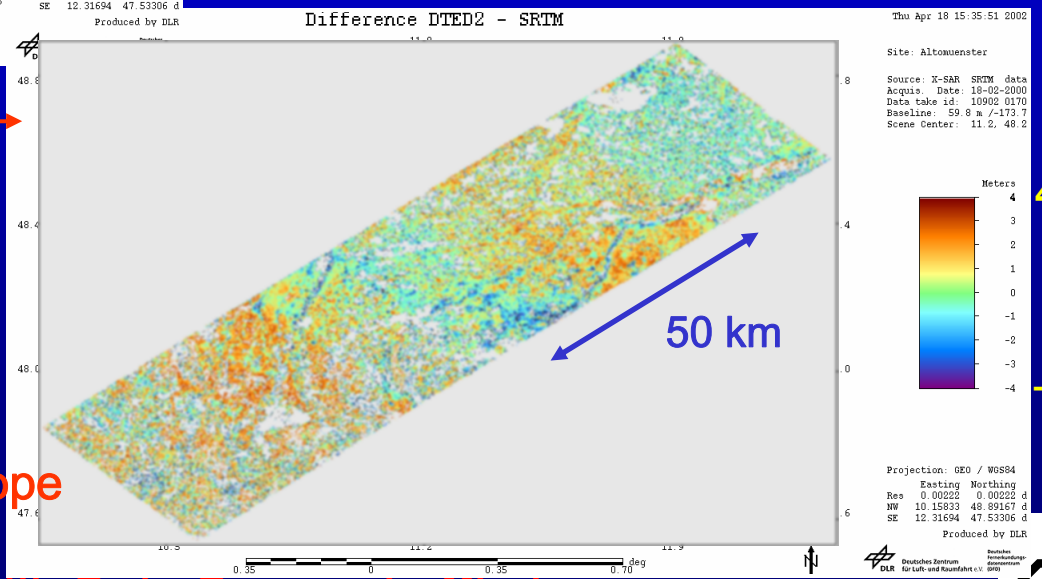


PADR 513, June 2001
has been used for:

- Europe
- Africa

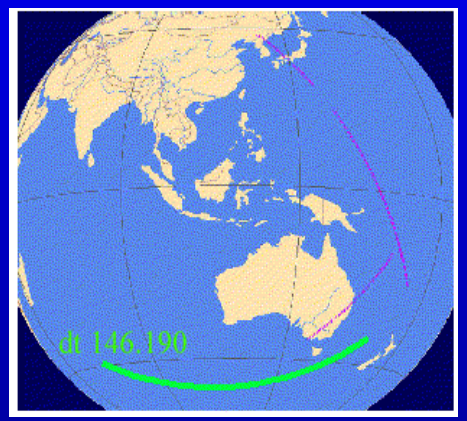
PADR 600, March 2002
was used for:

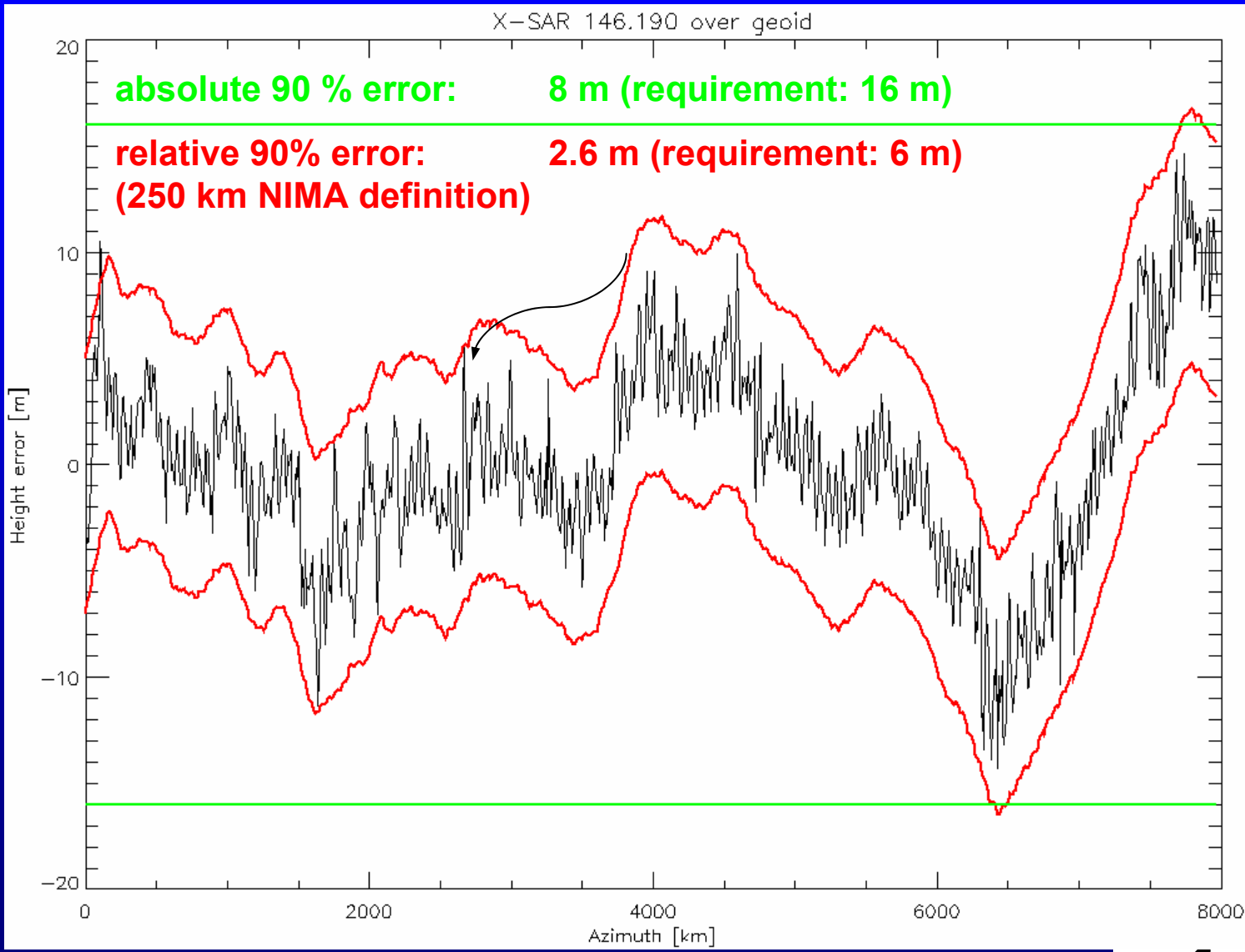
- North and South America
- Asia
- Australia
- optional reprocessing of Europe



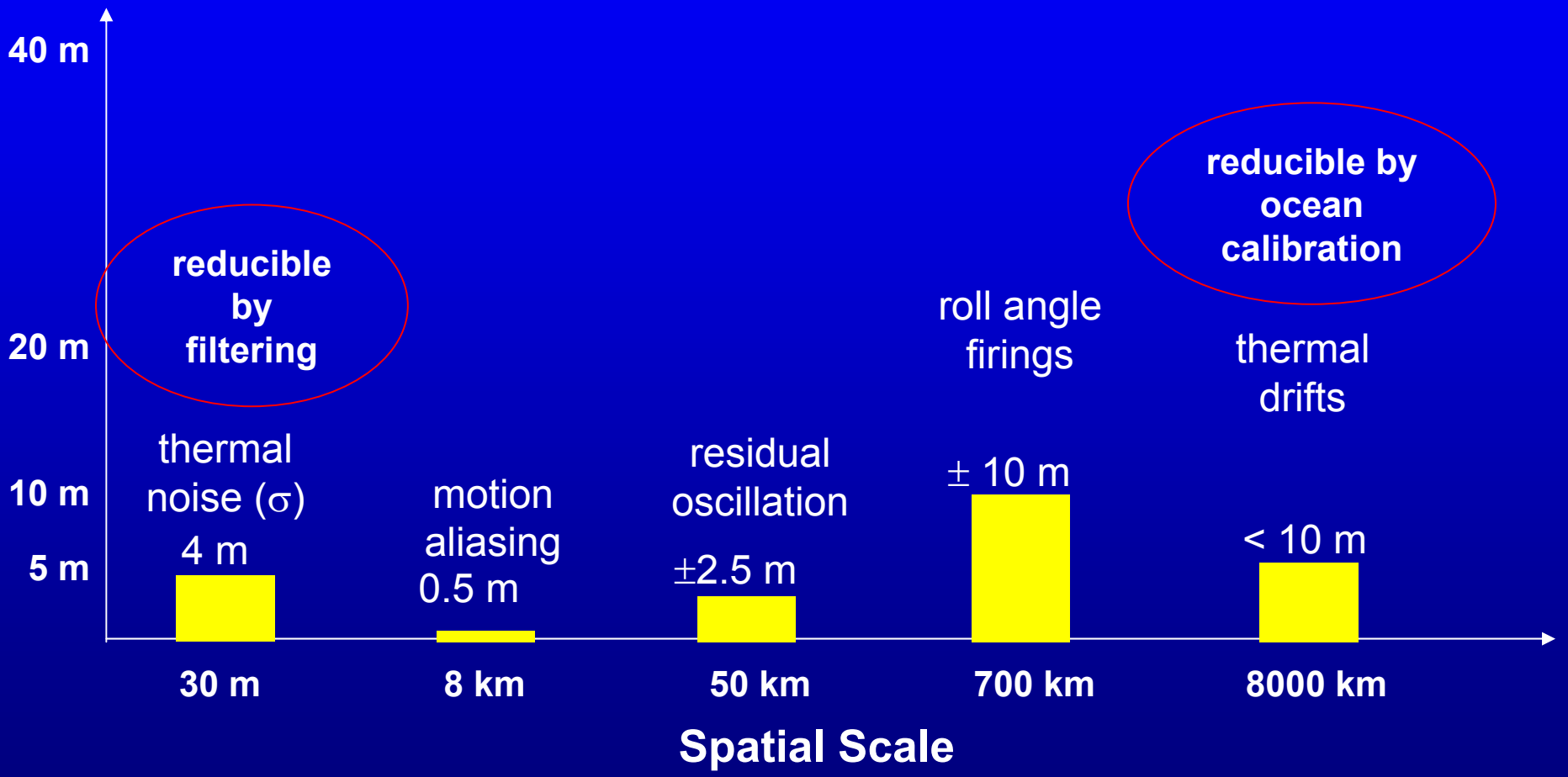
X-SAR/SRTM Shuttle Radar Topography Mission

SRTM/X-SAR Motion-Induced Height Errors (Measured Over Ocean)



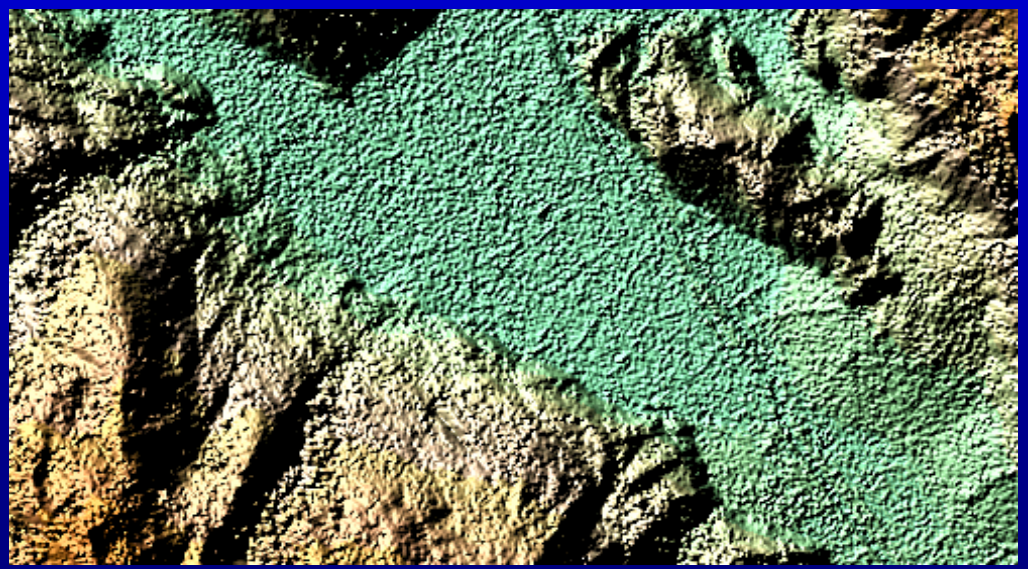


SRTM / X-SAR Height Error Spectrum

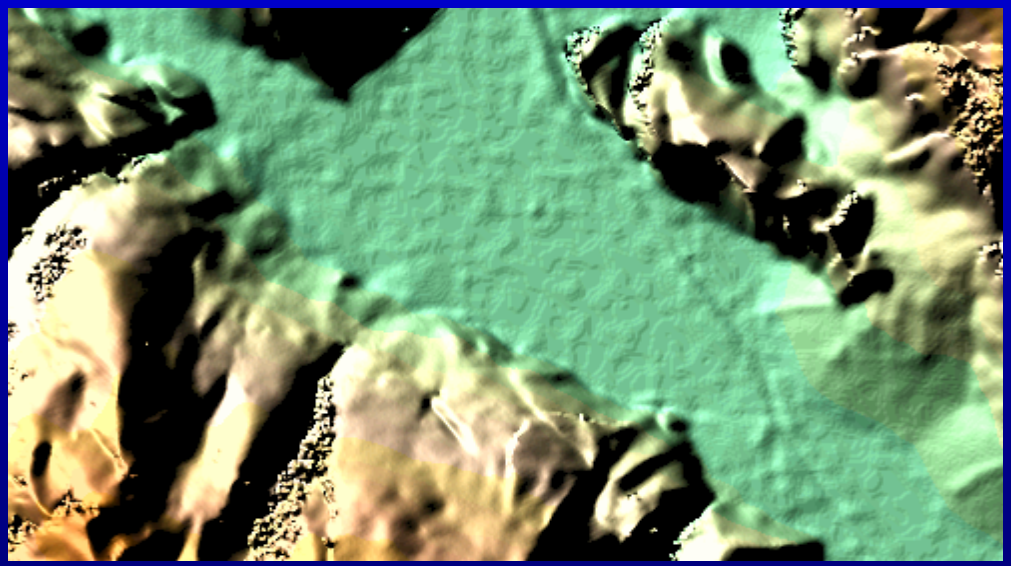


Data Filtering - Reasoning

- Due to varying backscatter and thus SNR, the required DEM error of 6 m (90%) was not achievable under all conditions
- Even the required 6 m thermal noise is not satisfactory because of the high frequency error pattern
- Quality improvements through filtering were investigated



Shaded DEM, unfiltered

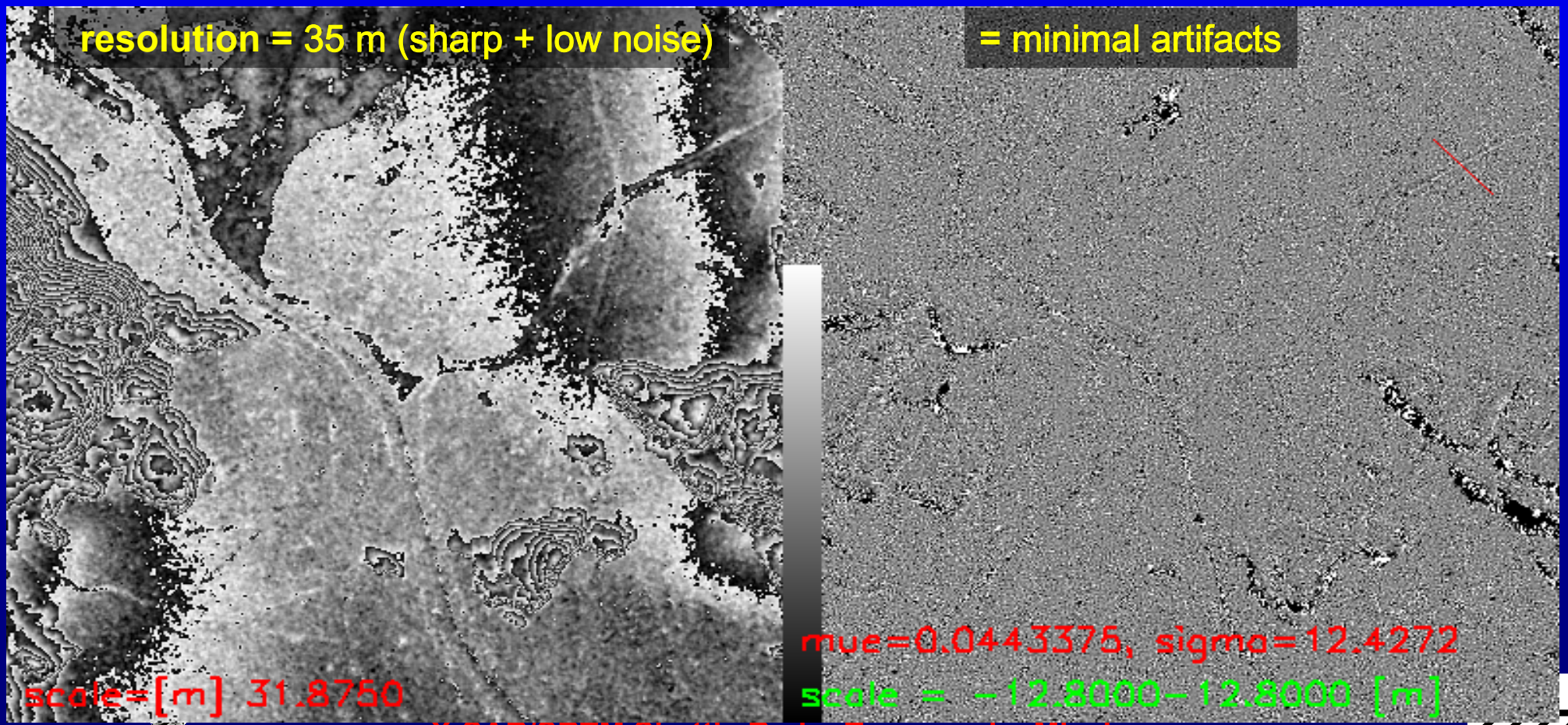


Strong, adaptive filter

Gaussian Filter (eff. width=2) selected as Filter for SRTM-Production

DEM,
scaled to 31.8 m per fringe

Difference
unfiltered-reference

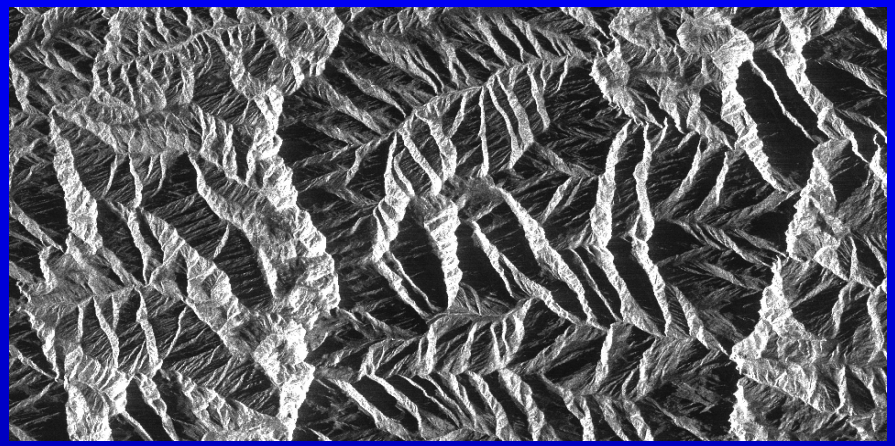


Filter Summary

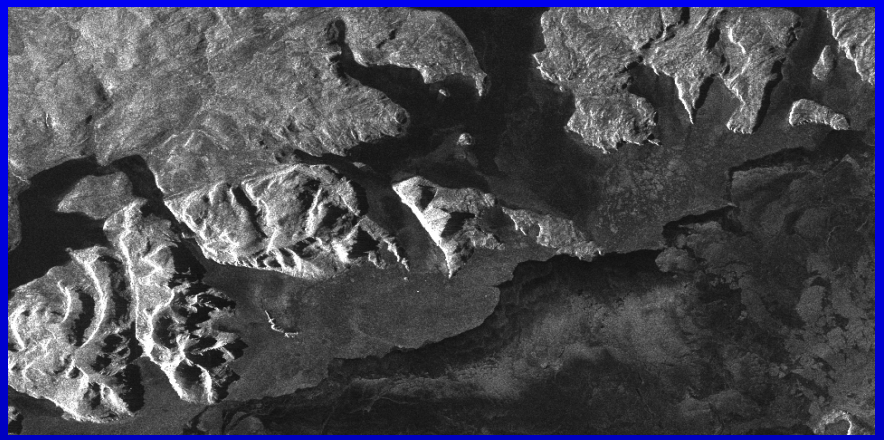
- A simple Gaussian filter was chosen for optimal trade-off between resolution and height error, resulting in ca. 10 effective looks (2 x 8) and a resolution of 35 m
- The predicted DEM error of less than 4 m s.d. has been confirmed by several investigators
- The differential DEM is an important indicator for conservation of details and visibility of artifacts
- MCF phase unwrapping time was generally reduced by filtering
- Phase unwrapping quality was not significantly influenced
- Interferogram amplitude clipping before filtering may reduce phase errors in urban areas

Difficult topographies with respect to phase unwrapping

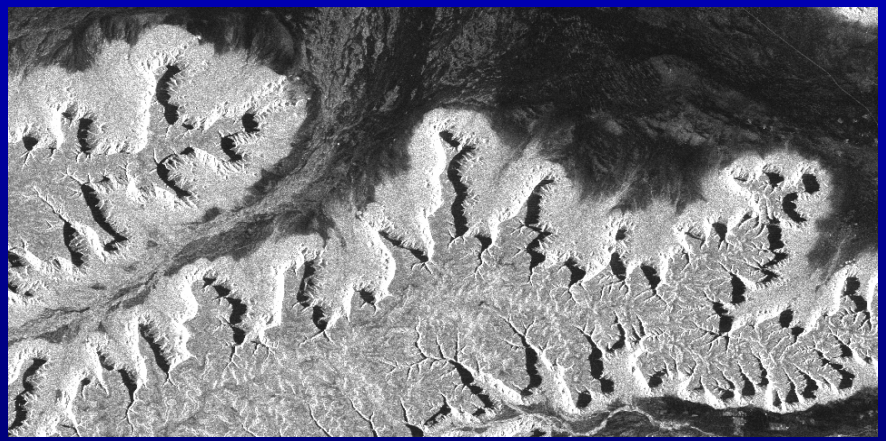
- Steep and rough alpine like terrain



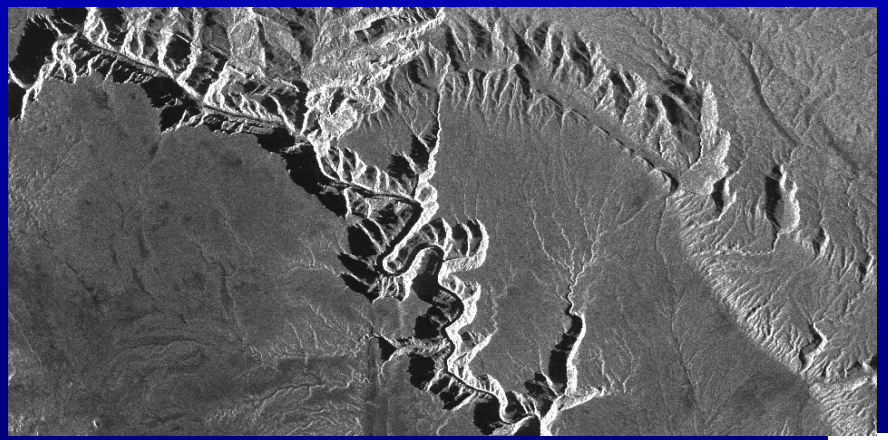
- Island / Main land with steep coasts



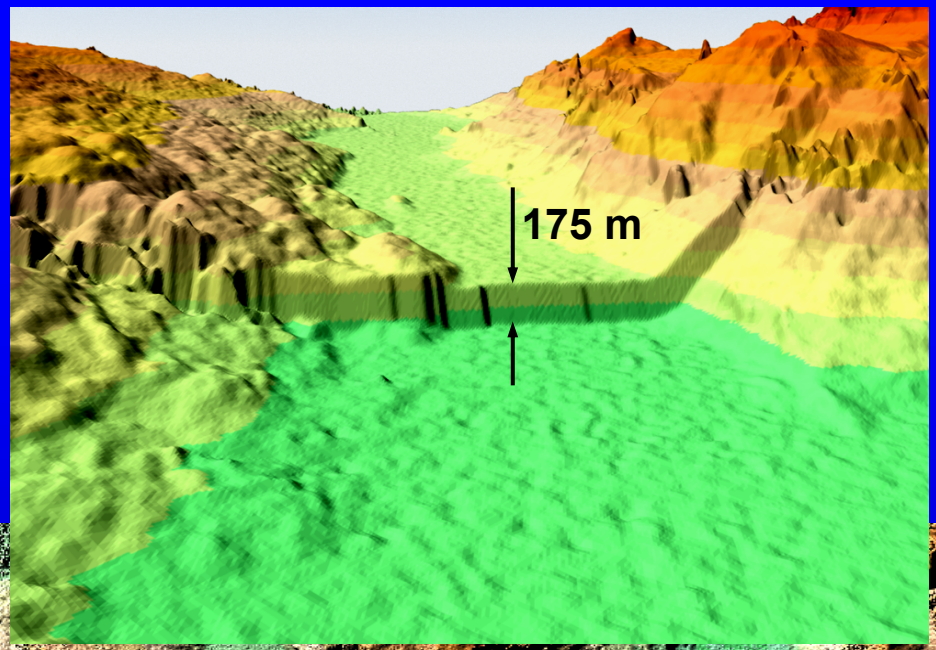
- Low backscatter with topography



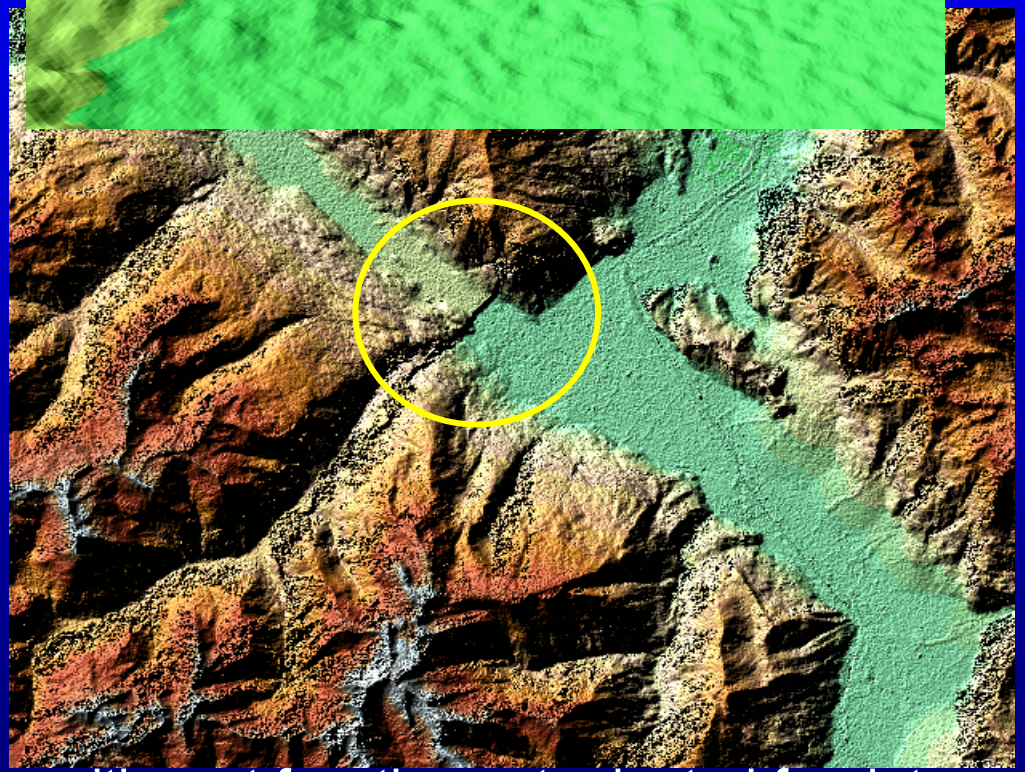
- Table mountains and canyons



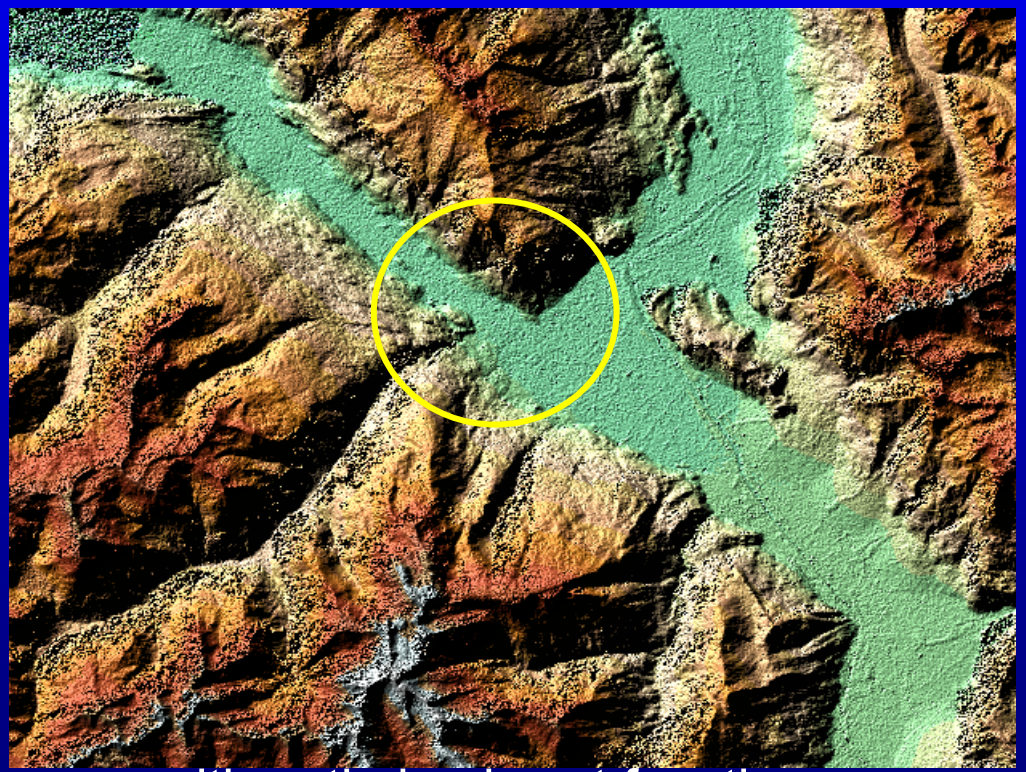
Phase Unwrapping Errors and Correction



Data: SRTM 2000



with cost function not adapted for data

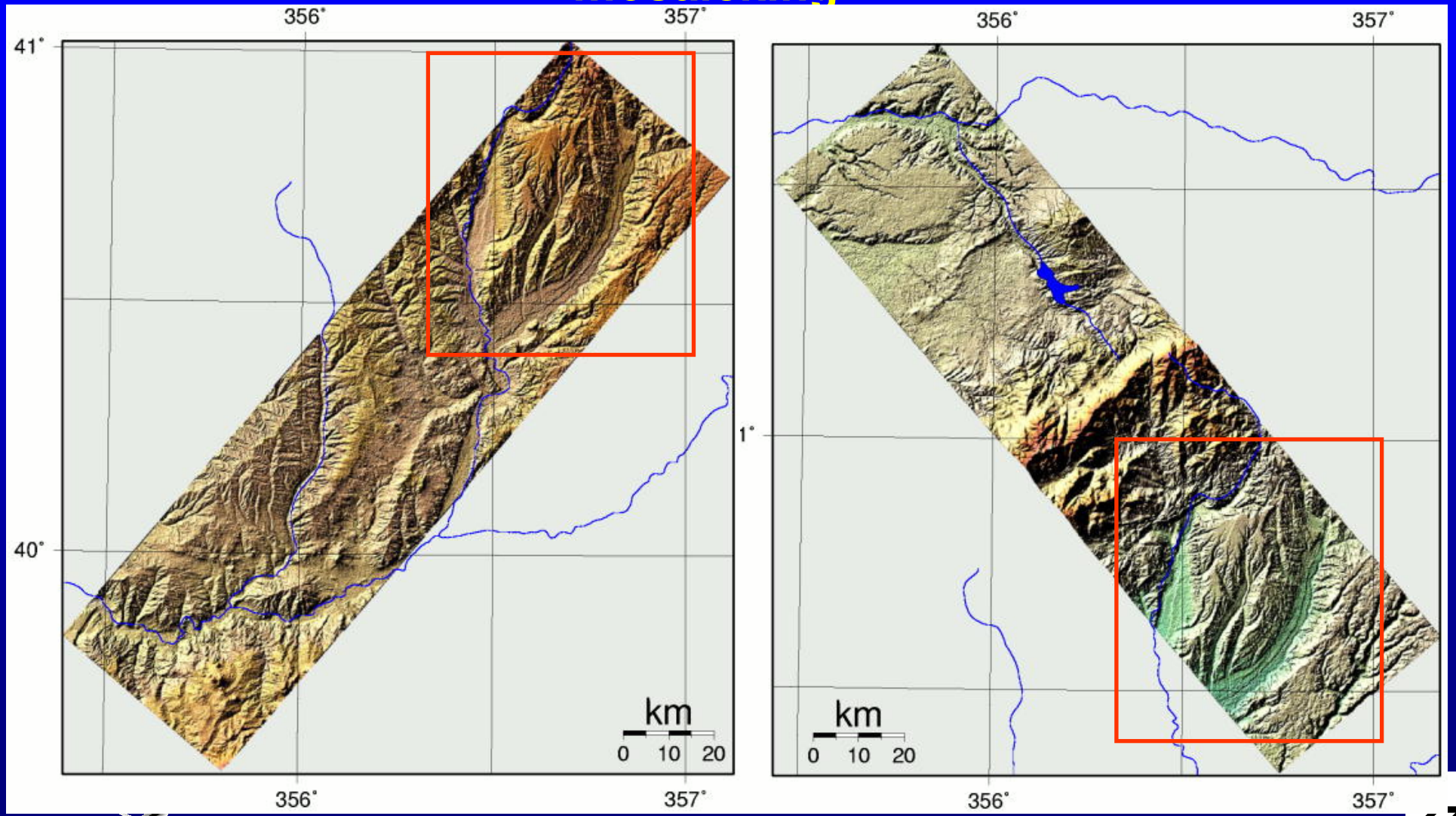


with optimized cost function

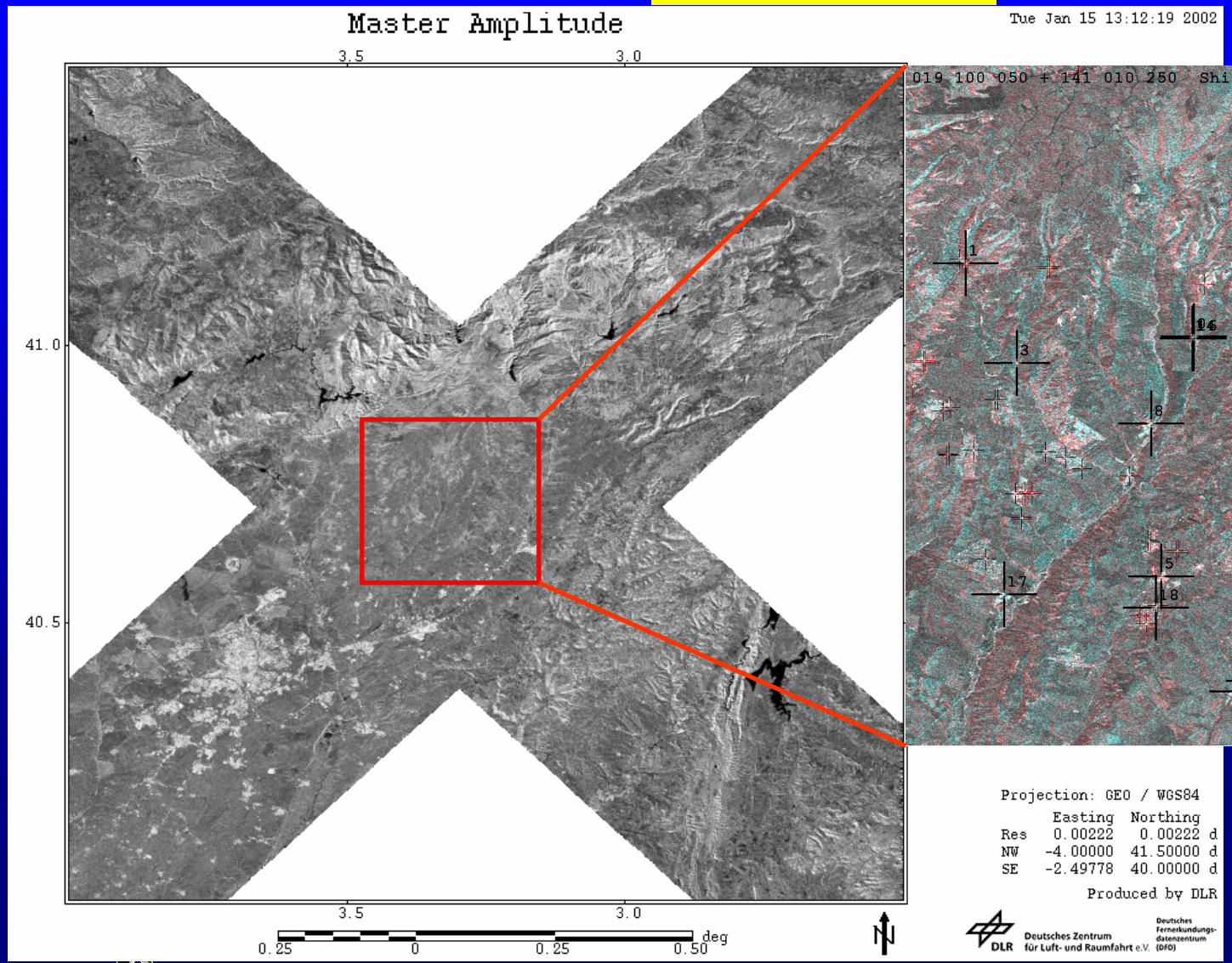
Phase Unwrapping Summary

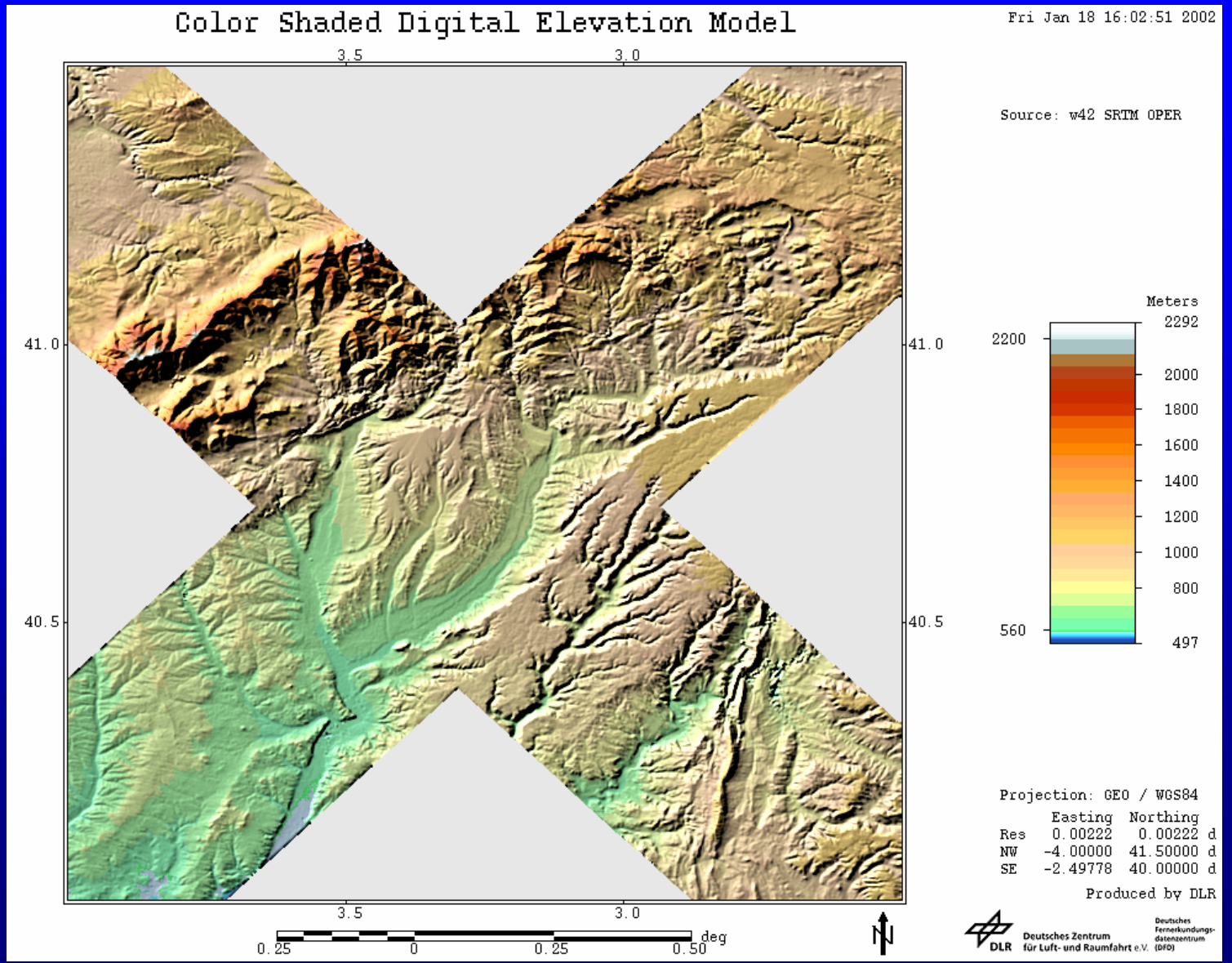
- Minimum Cost Flow (MCF) algorithm is used
- Differential InSAR control using external DEM has been operationally implemented
  - early detection of errors by InSAR operator
- Experienced operator as problem solver
- Phase unwrapping work bench established to further improve methods
  - reduction of errors

Phase offset corrected independently prior to mosaicking



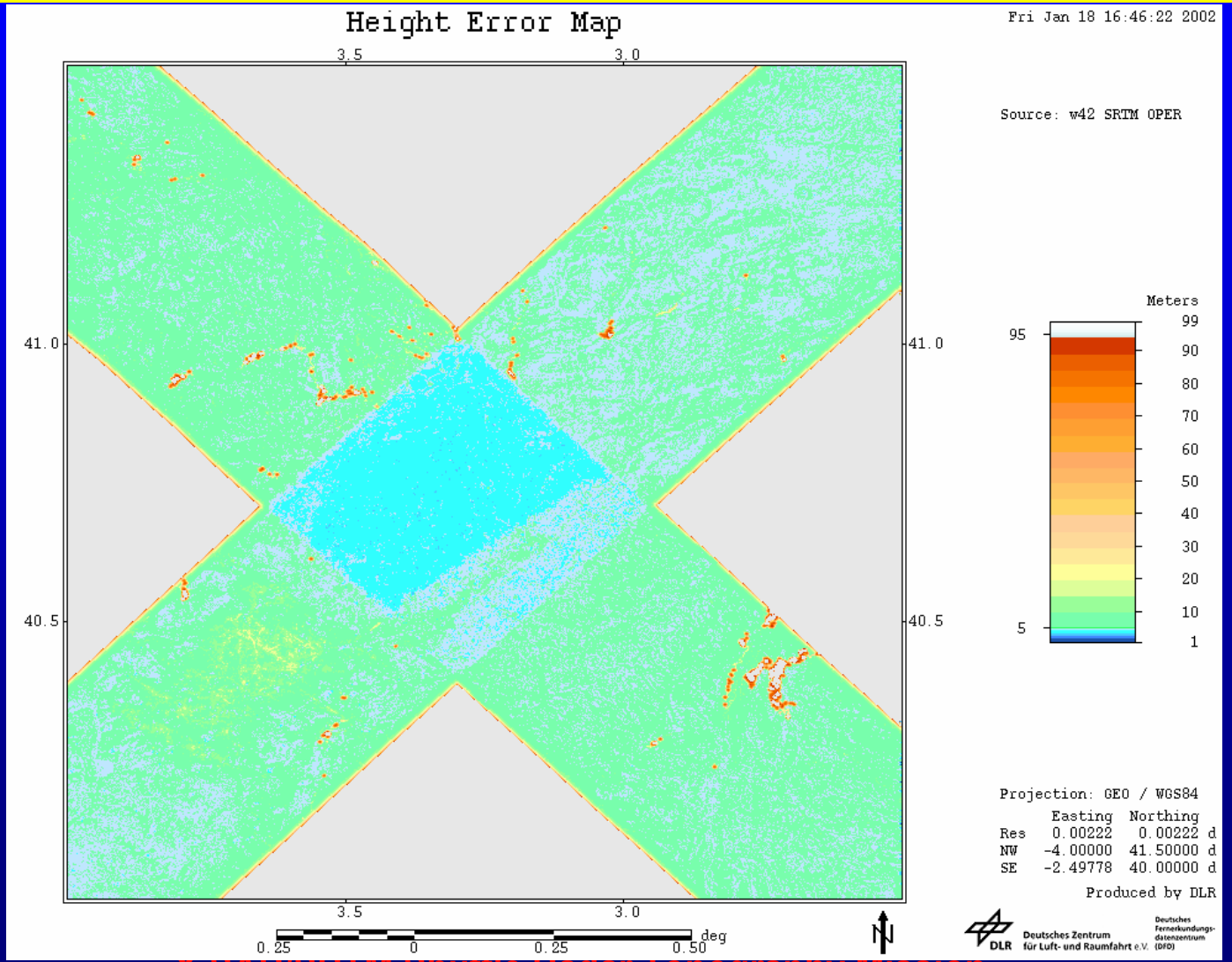
Operational measurement of lateral displacement for crossing DTs





X-SAR/SRTM Shuttle Radar Topography Mission

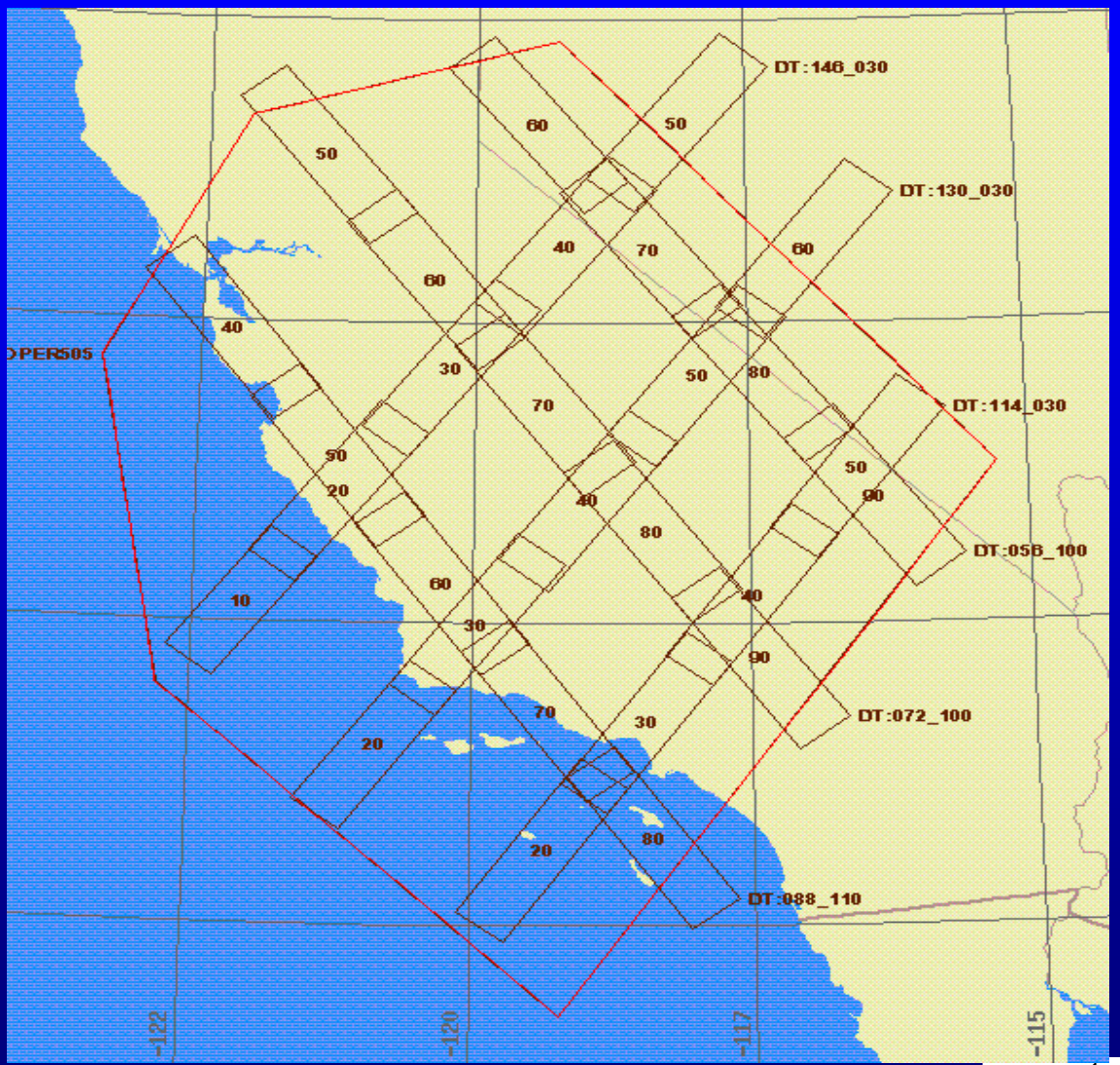
Improvement of height accuracy at data take crossings

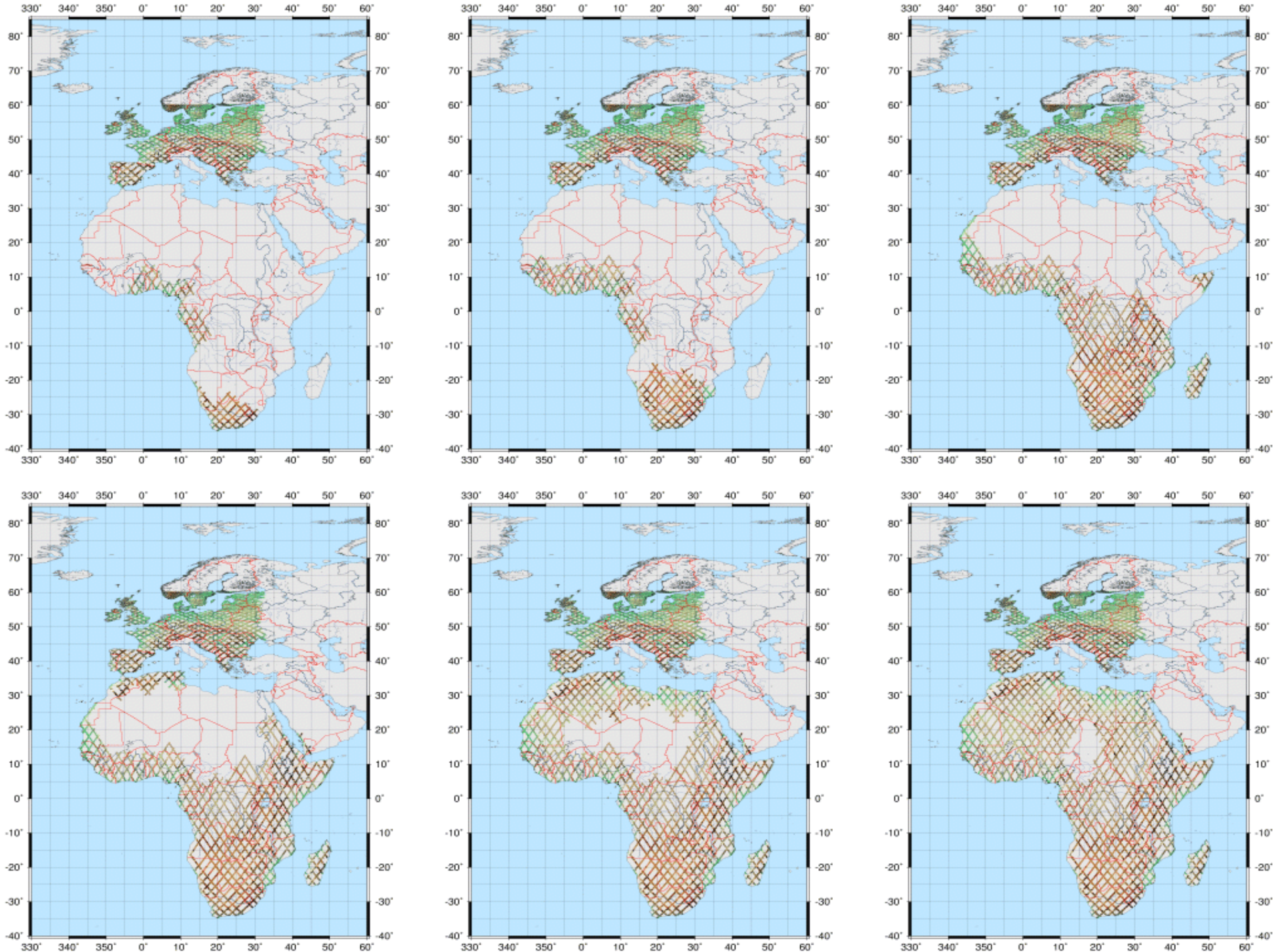


Block Adjustment Approach

- Find phase offset constants for all:
  - data take crossing areas
  - in orbit overlap areas (2π ambiguities)

  - coherent ocean areas
  - in orbit and/or crossing areas to already adjusted adjacent block scenes
- Result of LSQ:
  - Phase offset constants of scene center and gradient in azimuth direction for all scenes in block




330° 340° 350° 0° 10° 20° 30° 40° 50° 60°
80° 70° 60° 50° 40° 30° 20° 10° 0° -10° -20° -30° -40°

SRTM Processing Throughput

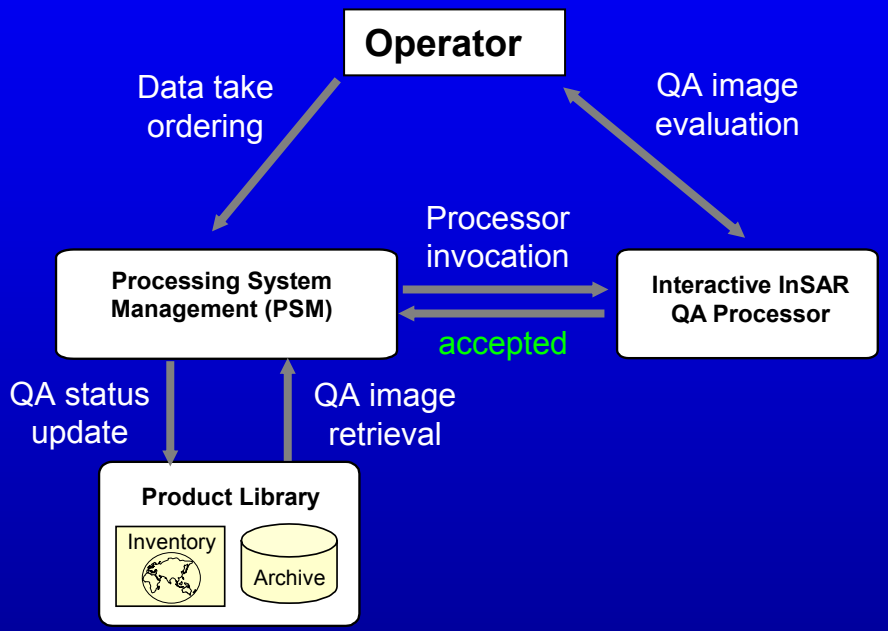
- Processing time of one scene is largely dominated by phase unwrapping time. This makes streamlining and parallelization difficult
- During operations, processing was tuned to optimize throughput:
  - 2 Computers (12 CPUs each)
  - 3 processing chains per computer
  - increase hard disk space
- Peak throughput after tuning: 100 scenes / day
- Average throughput over 1 year of production: 32 scenes / day
  - due to maintenance, etc.

Total products in archive: DEM-Tiles: 147 302

» GIFDS (GTC's): 14021

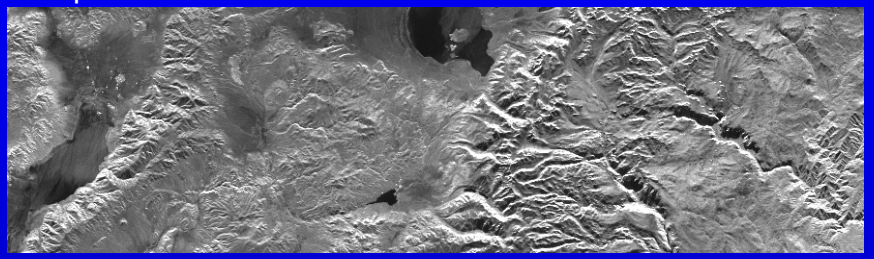
Interferometric Data Quality Assessment

QA Processing Scenario

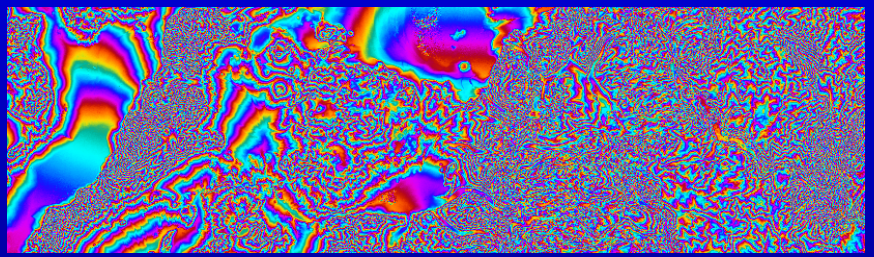


Interactive Assessment Of Each Scene (1)

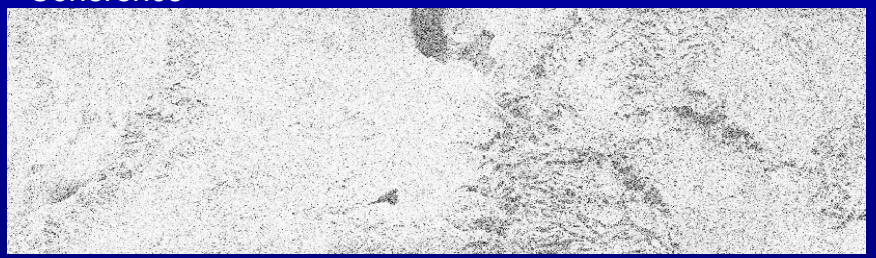
- Amplitude



- Interferometric Phase

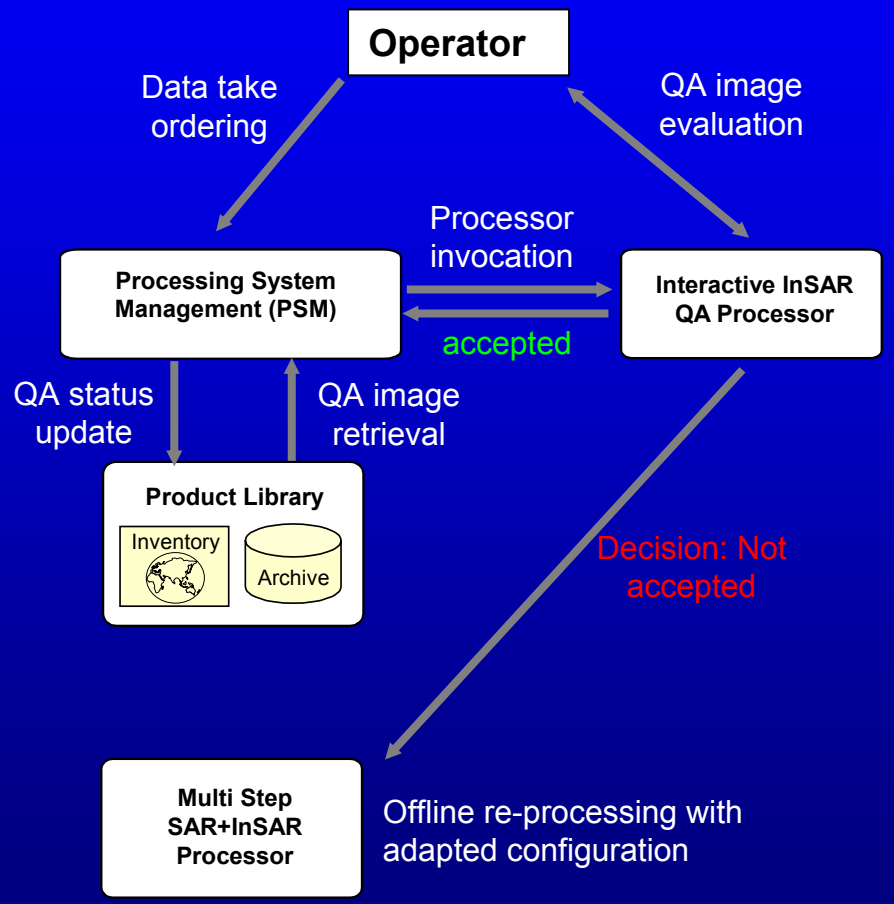


- Coherence



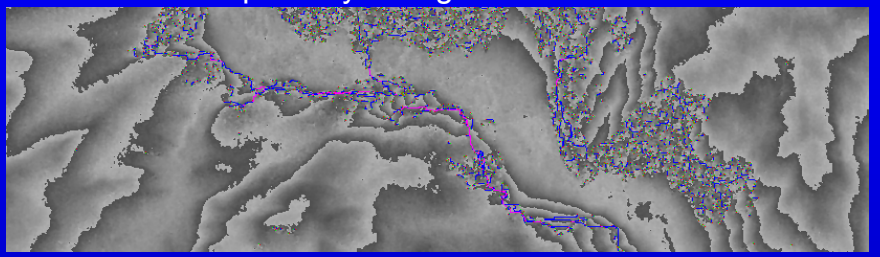
Interferometric Data Quality Assessment

QA Processing Scenario

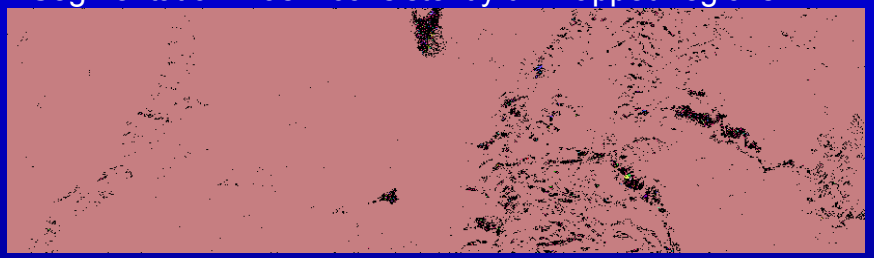


Interactive Assessment Of Each Scene (2)

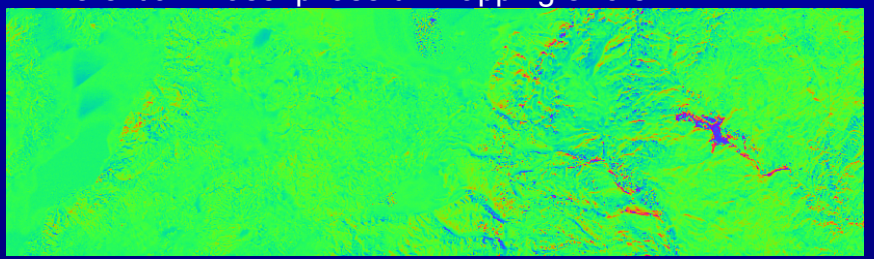
•Visualization of possibly wrong branch cuts



• Segmentation Mask: consistently unwrapped regions



• Differential Phase: phase unwrapping errors



SRTM / X-SAR Product Specification

DTED-2 DEM accuracy specification	
Horizontal (absolute)	± 20 m (90 % circular)
Horizontal (relative)	± 15 m (90 % circular)
Vertical (absolute)	± 16 m (90 % circular)
Vertical (relative)	± 6 m (90 % circular)

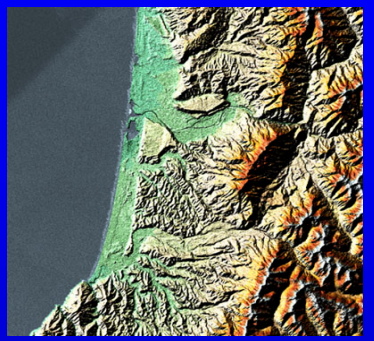
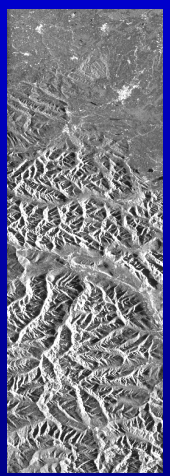
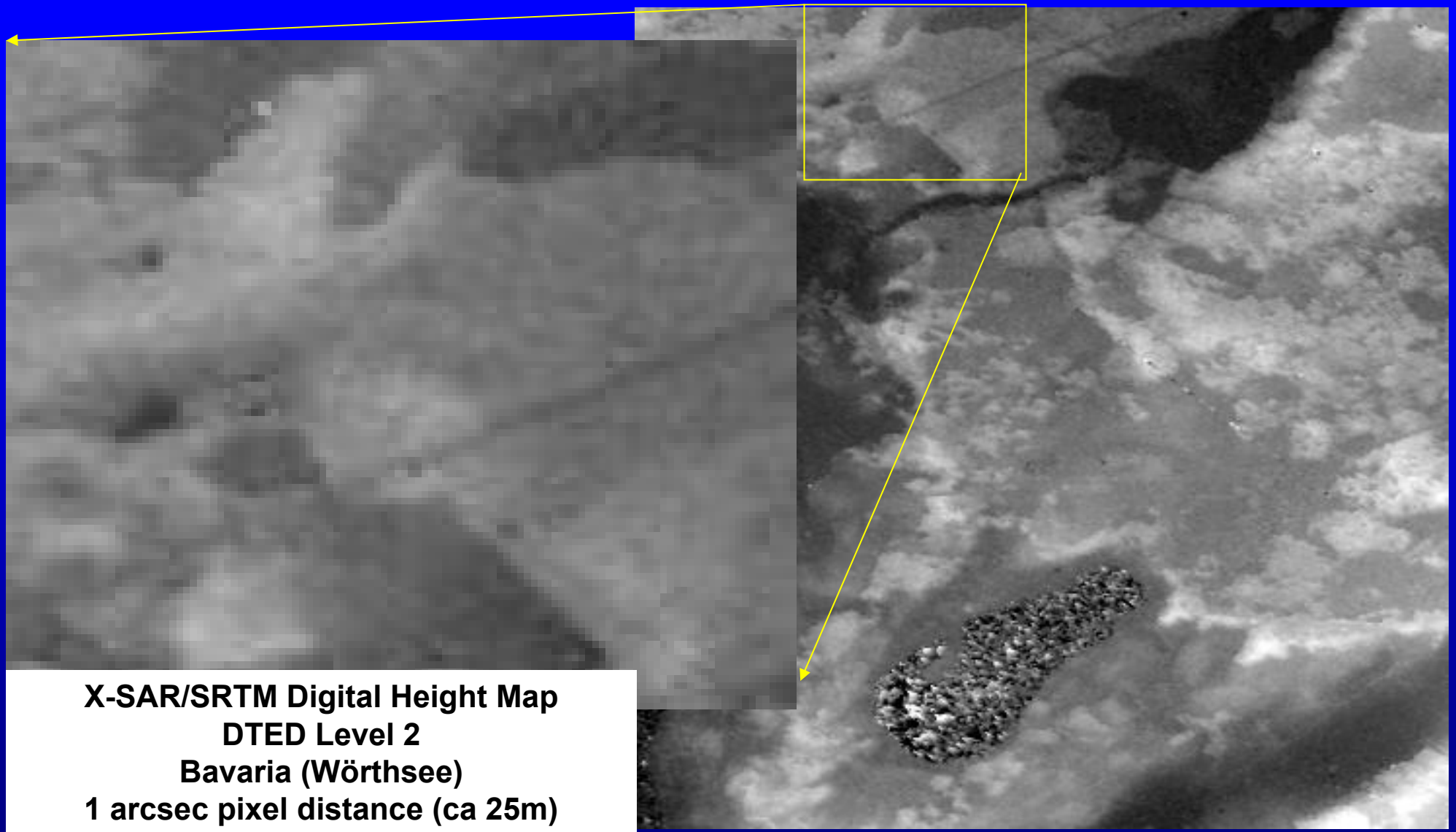


Image Products / Parameter		MGD	SSC	GTC
Spatial Resolution	Azimuth	25 m	8-12 m	25 m
	Range	25 m *	17 m	25 m
Absolute Location Error	Azimuth	< 4 m	< 4 m	< 30 m
(σ)	Range	< 3 km	< 4 m	< 30 m
Pixel Spacing	X-axis	12.5 m	4.33 m	25 m
	Y-axis	12.5 m	13.32 m	25 m



* At mid swath



X-SAR/SRTM Digital Height Map
DTED Level 2
Bavaria (Wörthsee)
1 arcsec pixel distance (ca 25m)

Validation: SRTM / X-SAR DEM over Germany

(Navigation Point Height) – (SRTM Height)

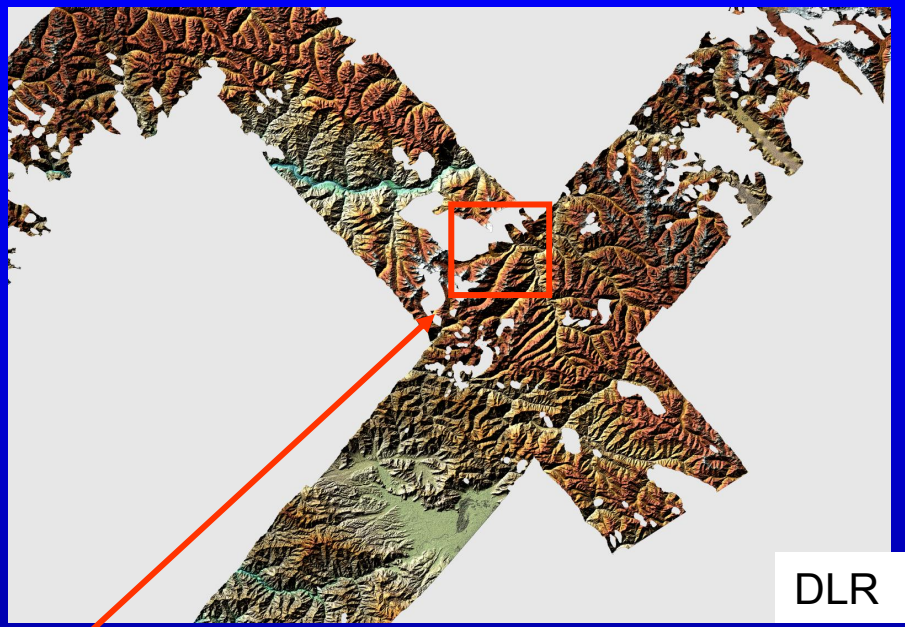
flat terrain				
	number	**μ**	**σ**	**RMS**
forested areas	2329	-6.20	6.74	9.16
urban areas	1683	-2.63	4.10	4.87
open landscape	**20786**	**-0.94**	4.31	**4.41**
Σ	24798	-1.55	4.84	5.08
moderate relief				
	number	**μ**	**σ**	**RMS**
forested areas	1970	-1.98	7.60	7.86
urban areas	725	-1.14	4.86	5.00
open landscape	**8000**	**+0.15**	4.54	**4.54**
Σ	10695	-0.33	5.33	5.34
highlands				
	number	**μ**	**σ**	**RMS**
forested areas	2272	-4.43	8.62	9.69
urban areas	766	-1.04	5.29	5.39
open landscape	**7693**	**-0.74**	5.36	**5.41**
Σ	10731	-1.54	6.37	6.55

Tab. 1: SRTM DEM validation against navigation points in the western part of Germany

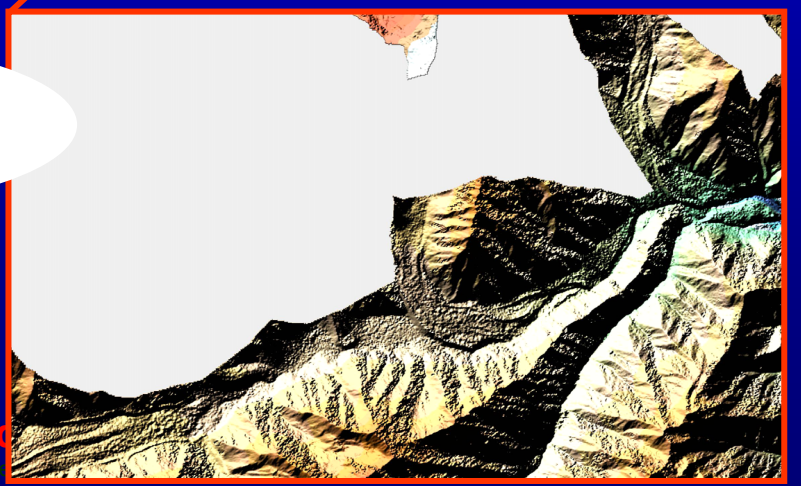
Reference Data:

- 46231 Navigation Points (NPs), provided by AMilGeo Euskirchen, Germany
- Test area: western part of Germany 1000 km x 300 km
- The mean of the SRTM heights is in good accordance to the NPs for open landscape
- Urban and forested areas show the expected bias (= mean difference between surface and terrain height)
- Standard deviations correspond to the height errors induced by the uncompensated boom oscillations
- PDF of tree heights => higher RMS values for forested areas

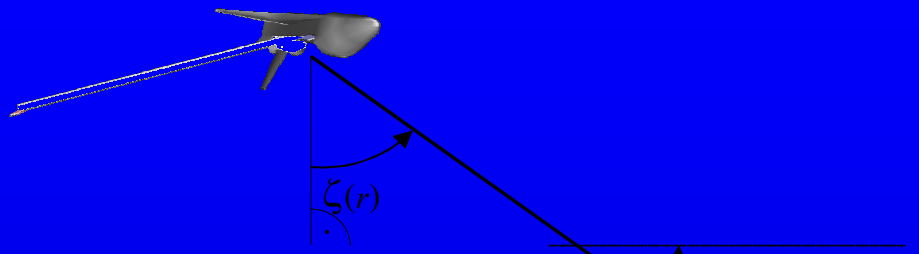
SRTM-Processing problems at Himalaya



300 km



Schadow reconstruction

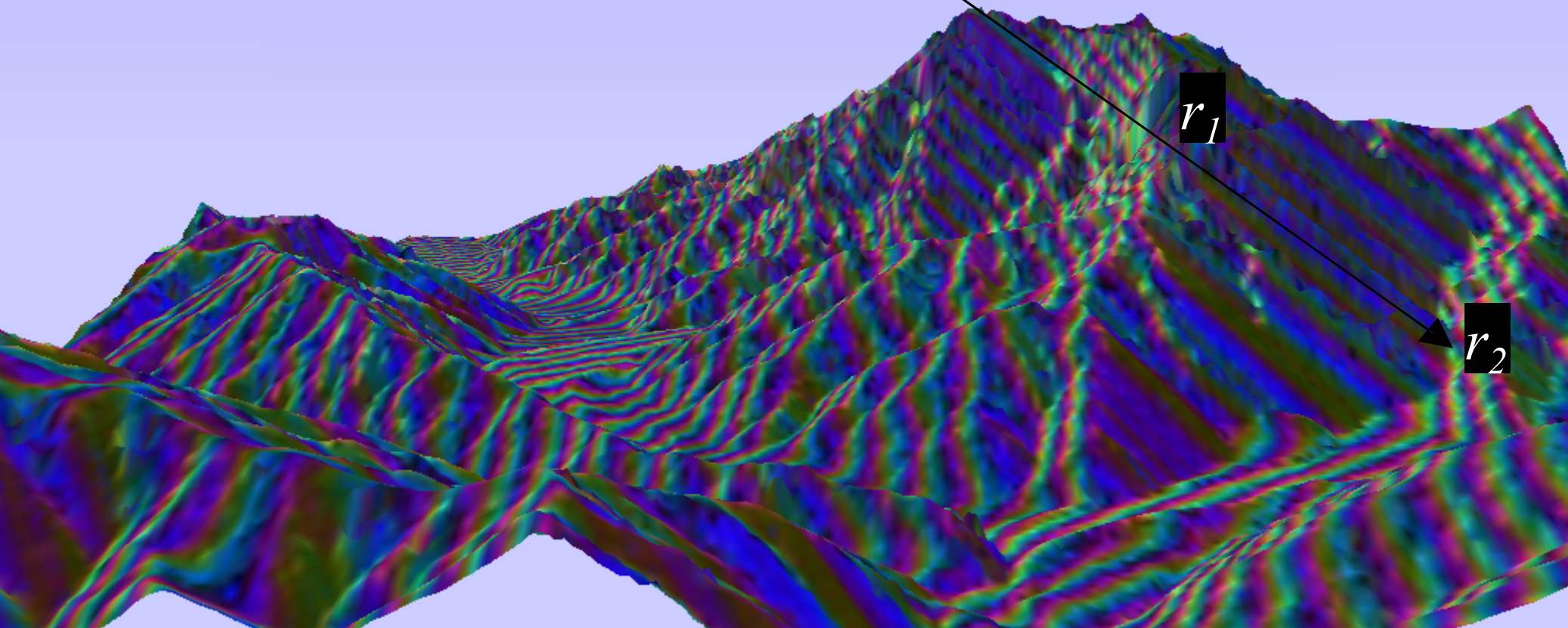


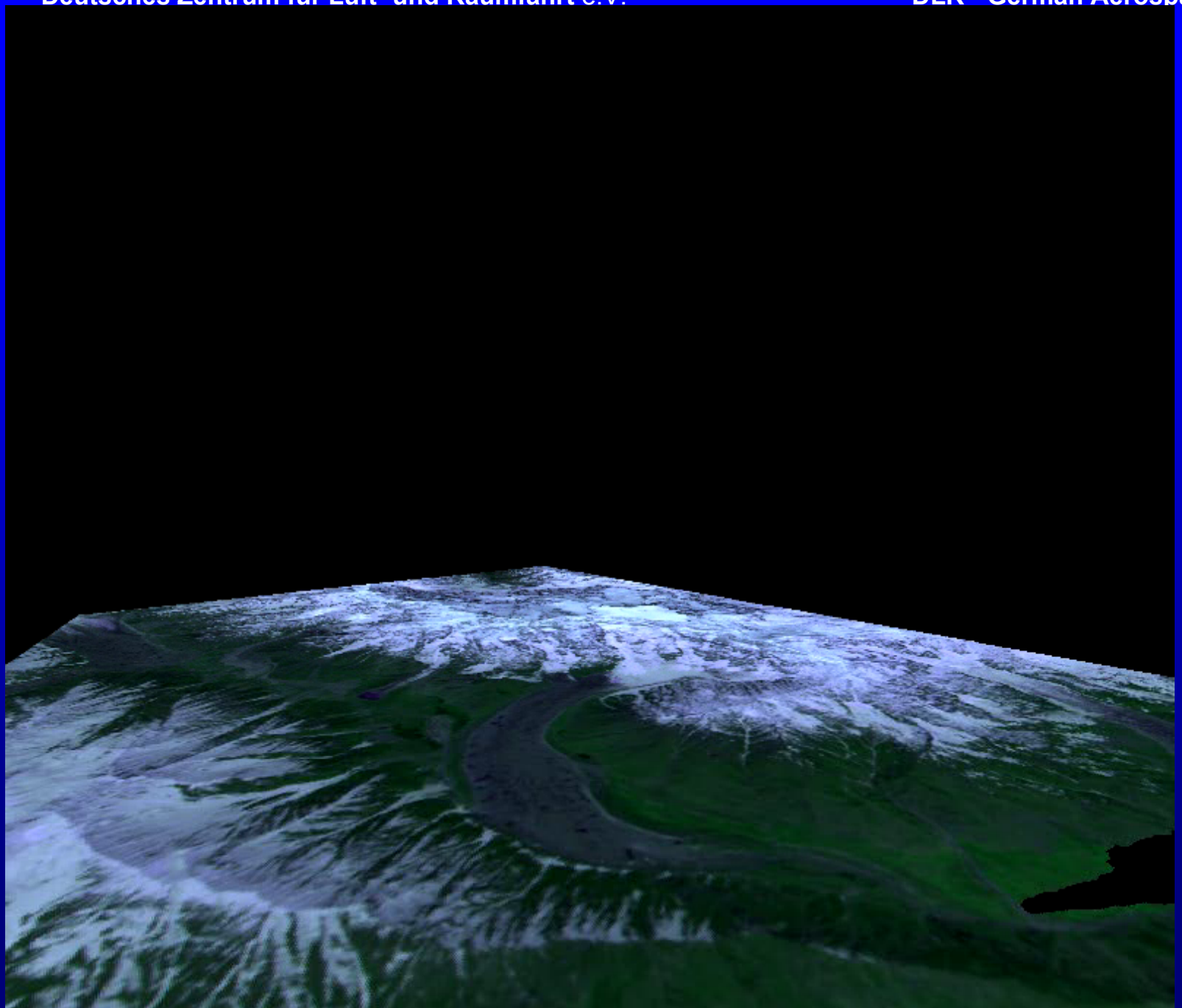
Schadowline:

$$\zeta(r_1) = \zeta(r_2)$$

$$\alpha = \zeta - 90°$$

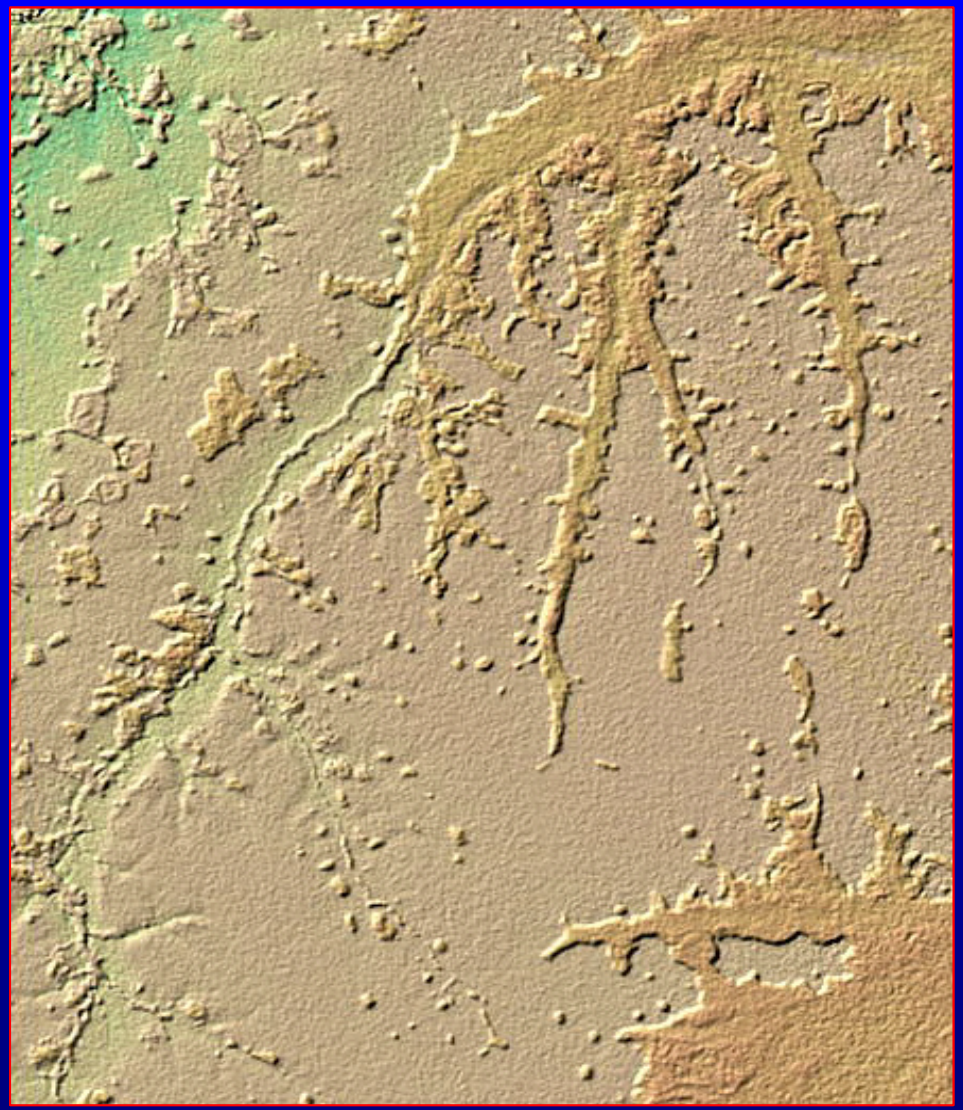
$$\frac{d\varphi}{2\pi dR} = -\frac{B_\perp}{r\lambda \tan(\zeta - \alpha)} \approx 0$$

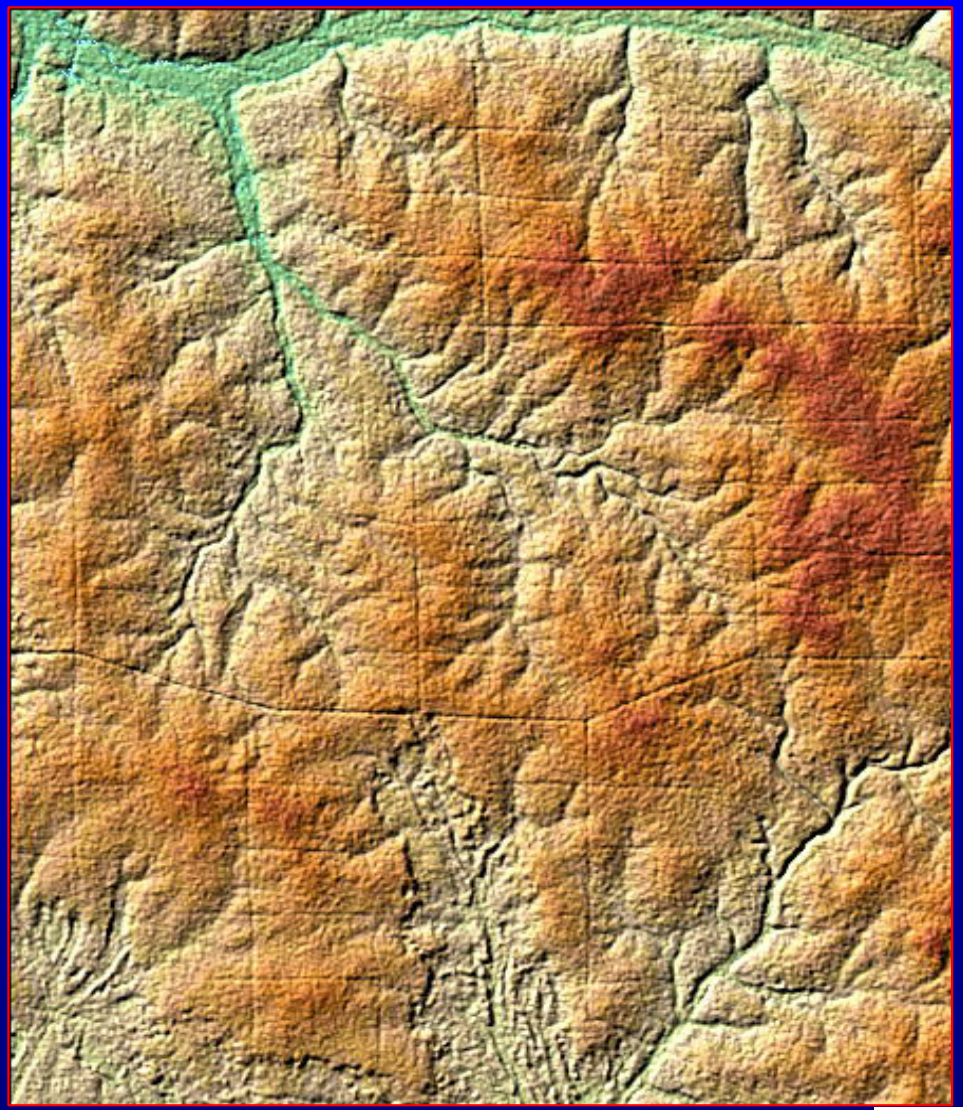




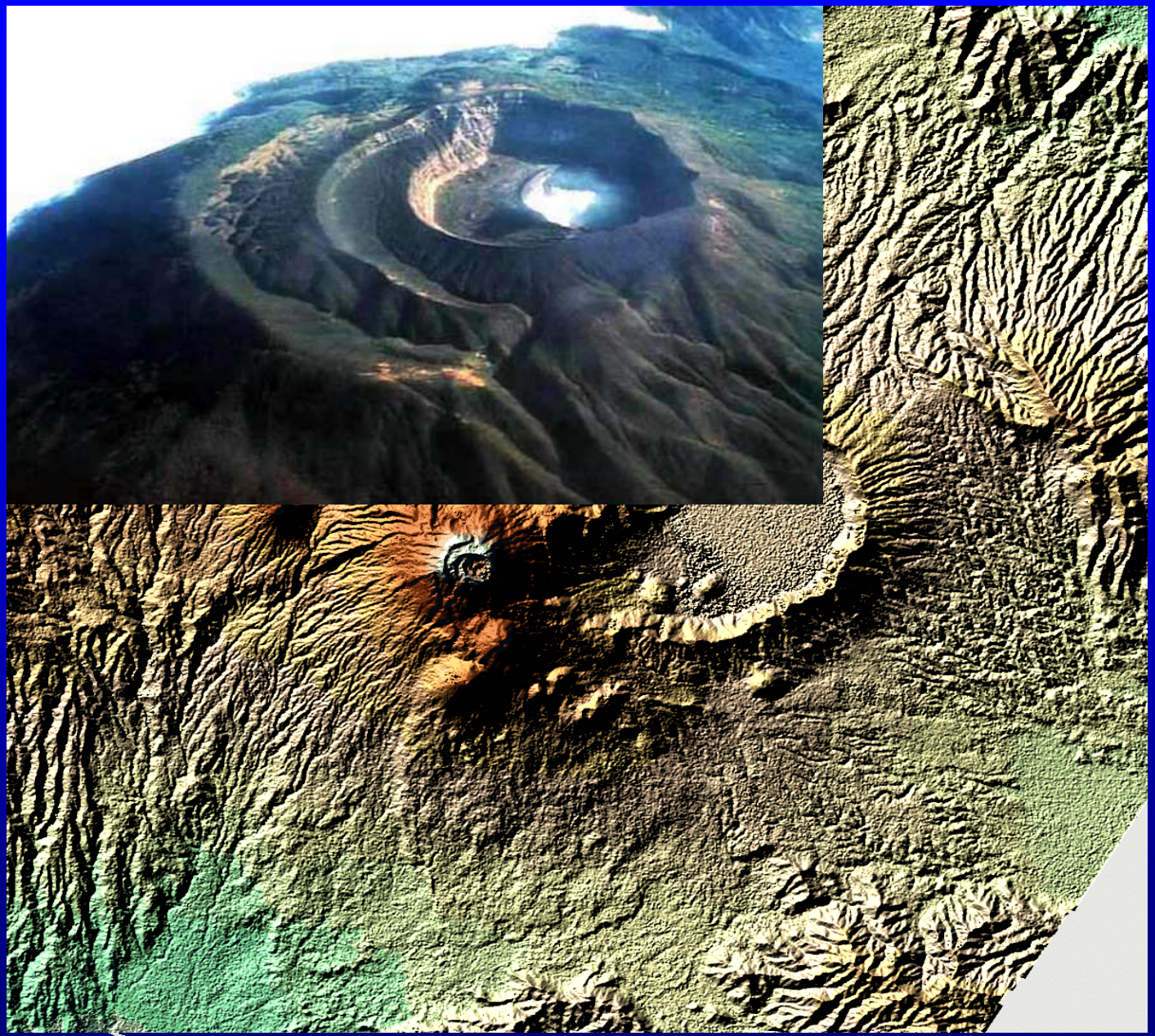
Nanga Parbat X-SAR/SRTM Overlay with SPOT

SRTM/X-SAR – Congo, Central Africa





SRTM/X-SAR – Vargeao Dome Crater, Brasil



SRTM/X-SAR – Santa Ana Volcano El Salvador

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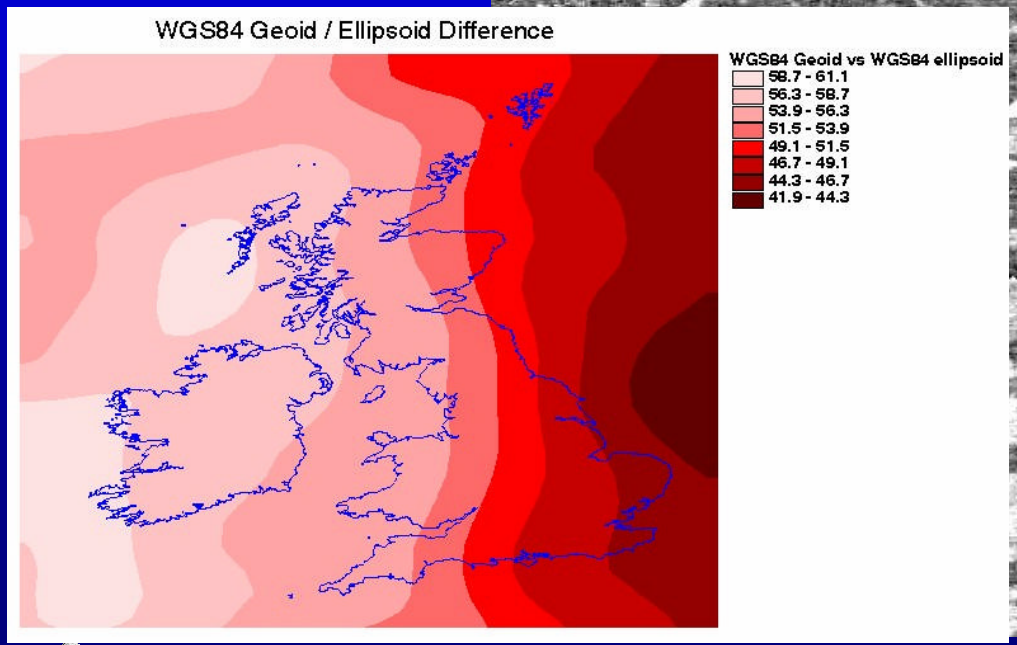
X-SAR/SRTM Scientific Investigations AO

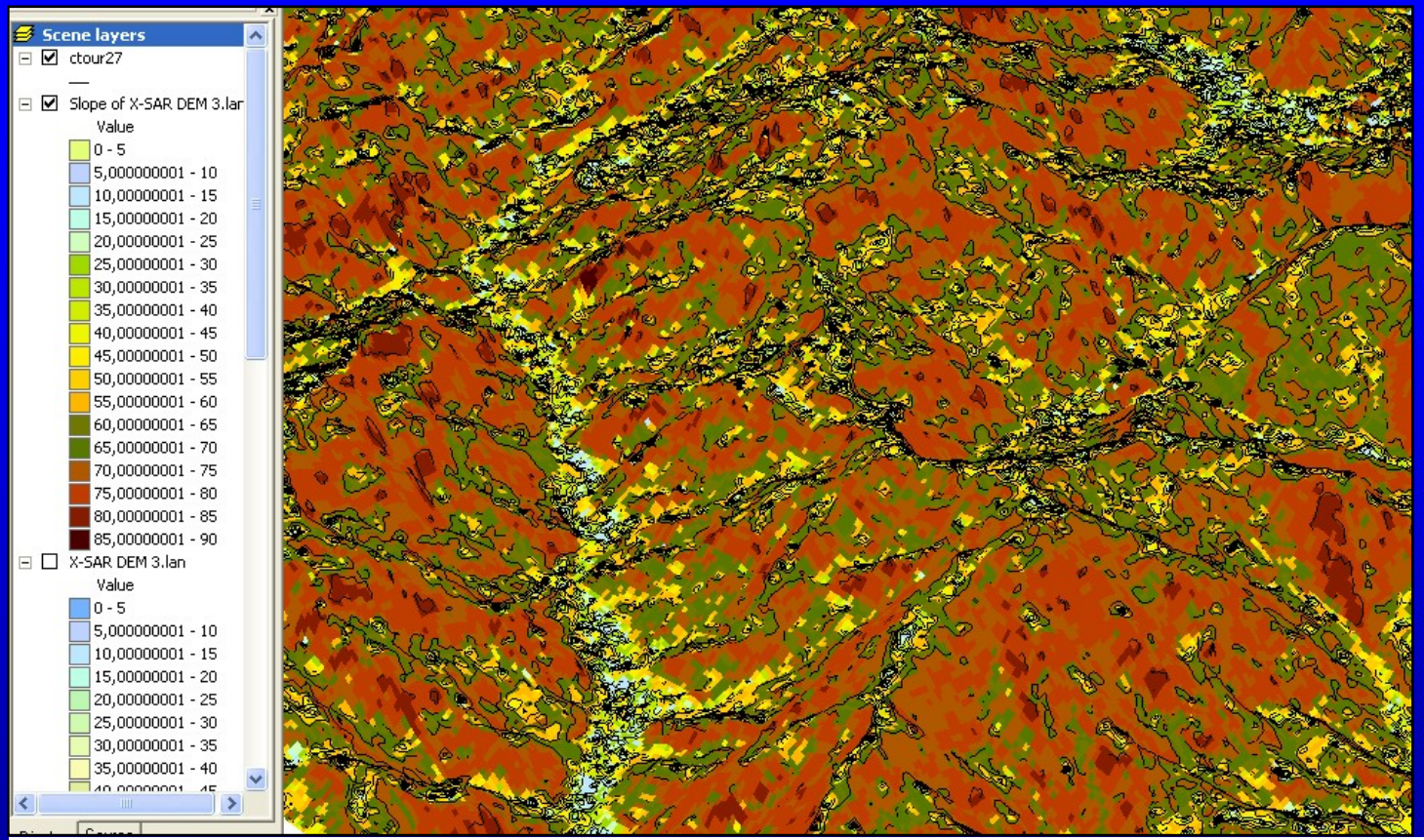
PIs	Nation	Products	Area	C-band Request	
1	Australia	9	Australia	X	
1	Austria	6	Austria, Germany	X	
1	Bulgaria	18	Bulgaria	X	
1	Canada	10	Canada		
1	China	17	China	X	
1	Finland	9	Syria		
3	France	34	France, Iran		
2	Great Britain	61	Great Britain, France, Spain		
23	Germany	458	worldwide	X	
1	Israel	28	USA, Malaysia	X	
1	Italy	14	Italy, Ethiopia	X	
1	Netherlands	21	Germany	X	
1	Norway	23	Norway	X	
1	New Zealand	40	New Zealand	X	
1	Russia	20	Russia-Elbrus	X	
1	South Africa	19	South Africa	X	
1	Sweden	20	Sweden, Poland, Estonia	X	
4	Switzerland	90	Switzerland, Bolivia, Canada		X
7	USA	159	N+S America, Africa, Malaysia	X	
53	Total	1046		no	

X-SAR/SRTM DEM- DTED2 England

From Final Report AO 051 Laycock, Qinetics

- Height offset 53m (Geoid)
- Vegetation
- Artifacts in DTED map



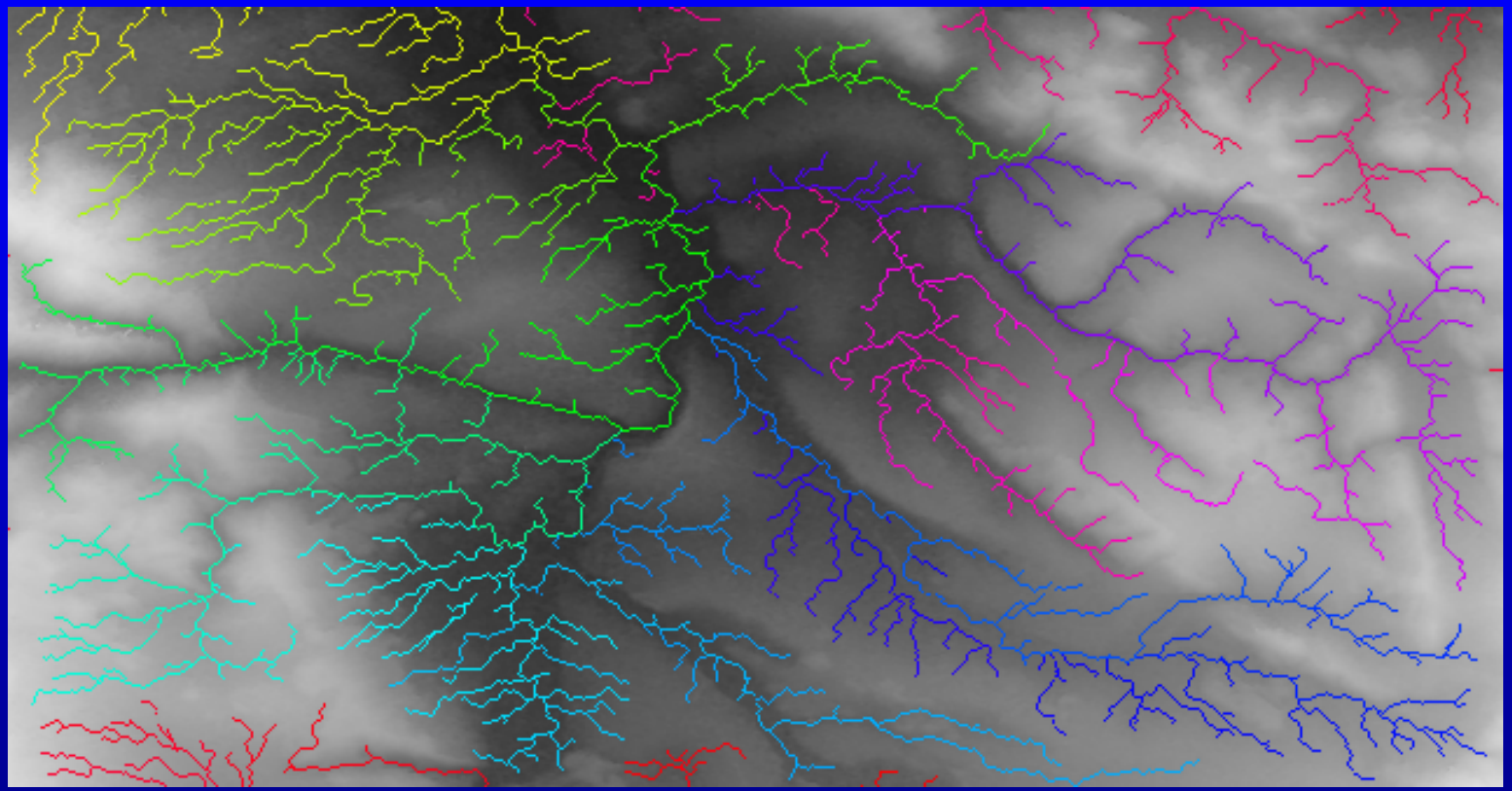


Principle Investigator:
AO 021
PD Dr.habil. Barbara Theilen-Willige
Natural Hazard IS in Venezuela

Every colour corresponds to a slope degree between 0 and 90 degrees.
The areas with the highest slope degrees (dark red) are most probable sites of slope failure.

SRTM, SRTM DEM's, ENVISAT and ERS imageries were used to create maps within an "Earthquake Hazard Information System" as important layers in a GIS data base in order to perform user-defined computations of earthquake hazard maps as required by ERDIK & SWIFT-AVCI (1997).
SRTM DEM's are of high importance and value concerning the detection and mapping of areas prone to slope failure and flooding.

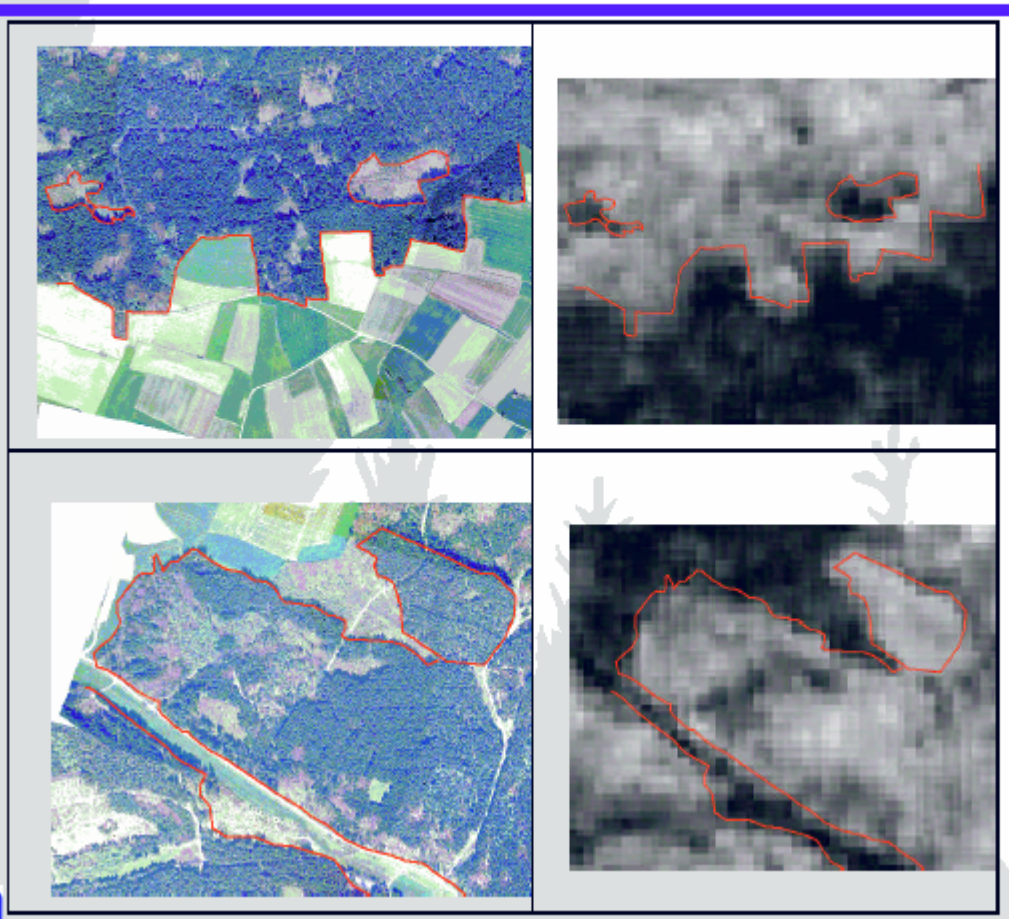
X-SAR/SRTM Height Models-Application Results



AO104 SRTM height models used for hydrological modeling for drainage systems
Example from Prof.F.Quiel (Royal Institute of Technology Stockholm, Sweden)

Characteristics of X-SAR/SRTM-Data from Forest Areas

Controll Areas taken from Orthophotos overlayed to SRTM-Surface Modell



- forest stand borders can be used to compare geometric accuracy
- In SRTM-Data there is no strong "borderline"
- typical forest struktures are somtimes smaller then the pixelsize of 25 * 25 m

SLU

Sachverständigenbüro für Luftbildauswertung und Umweltfragen, Lohenstr. 14, 82166 Gräfelfing

Characteristics of X-SAR/SRTM-Data from Forest Areas

Investigators:
Dr. K. Martin, Dr. B. Förster SLU, Sachverständigenbüro für Luftbildauswertung und Umweltfragen,

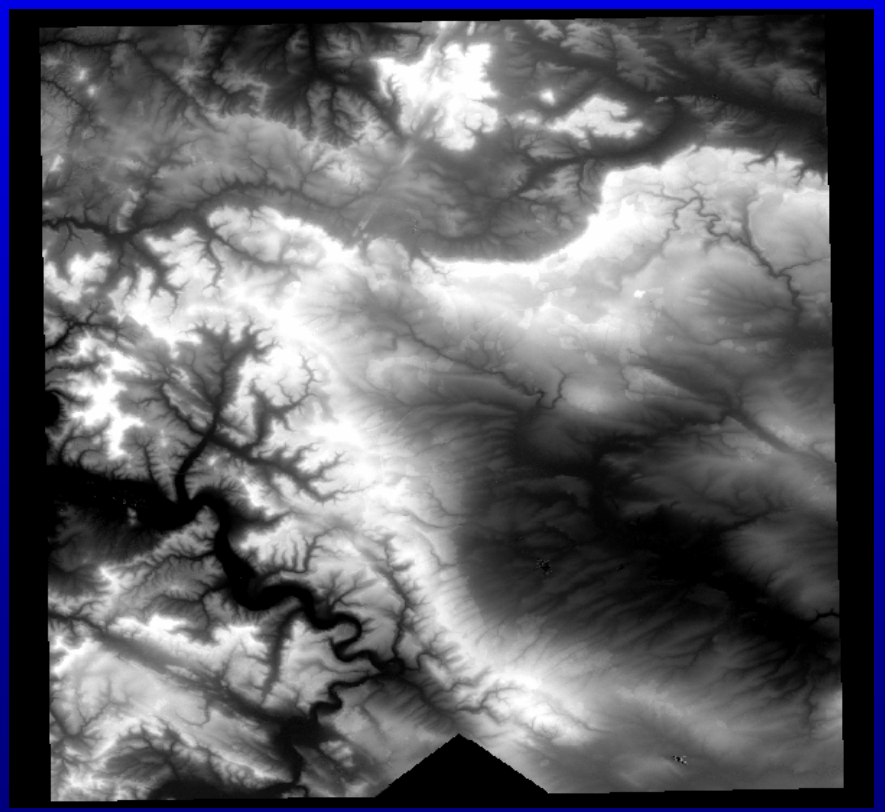
(Stands with more than 90% Crown Closure)

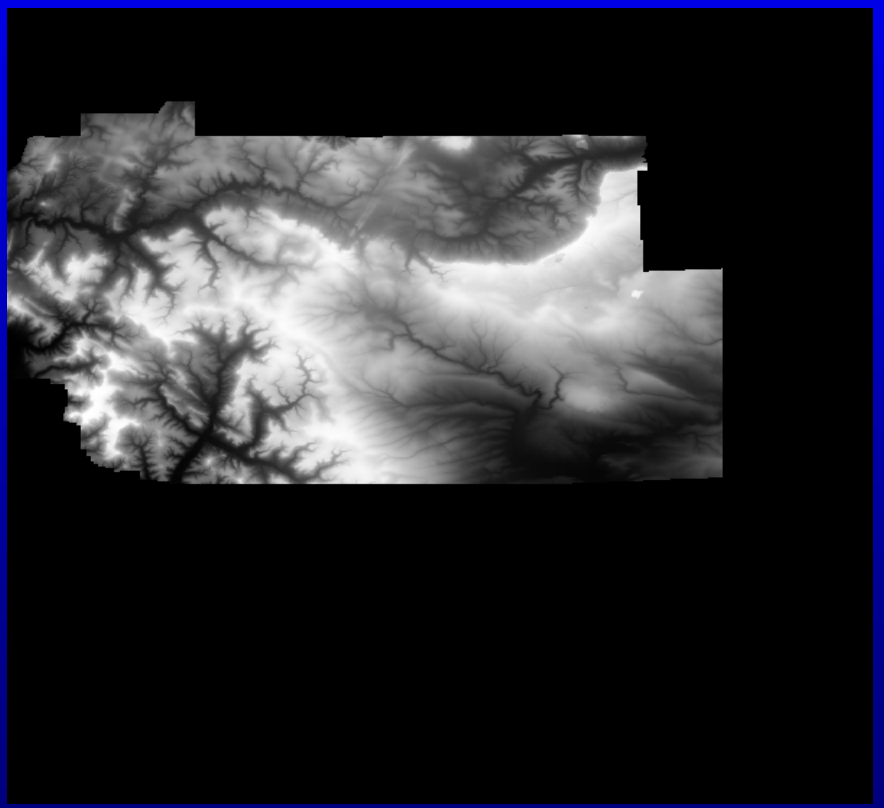
Stand type	mean tree height	Diff. mean. SRTM - DGM	Std.dev. SRTM	Difference
Spruce timber	25	21,8	5,4	3,2
Spruce timber	26	27,3	2,8	-1,3
Spruce timber	28	25,7	2,7	2,3
Spruce timber	30	25,6	2	4,5
Spruce timber	31	28,1	3,8	2,9
Spr, young-growth	5	3,3	3,1	1,7
Spr, young-growth	11	9,8	1,7	1,2
Spruce pole	18	17	4,4	1
Spruce pole	25	29,2	2,6	-4,2
Larch timber	25	20,3	3,5	4,7
Decid, timber	25	22,9	2,9	2,1
Decid, timber	30	23,2	3,1	6,8
Decid, timber	32	23,4	4,8	8,6
Decid, timber	35	17,3	4,1	17,7
Decid, pole	15	15,1	1,7	-0,1

Validation of X-SAR/SRTM DEMwith Laser Data (AO 009)

Insitute of Navigation,University of Stuttgart Dr.M.Reich,Dr.Thiel,

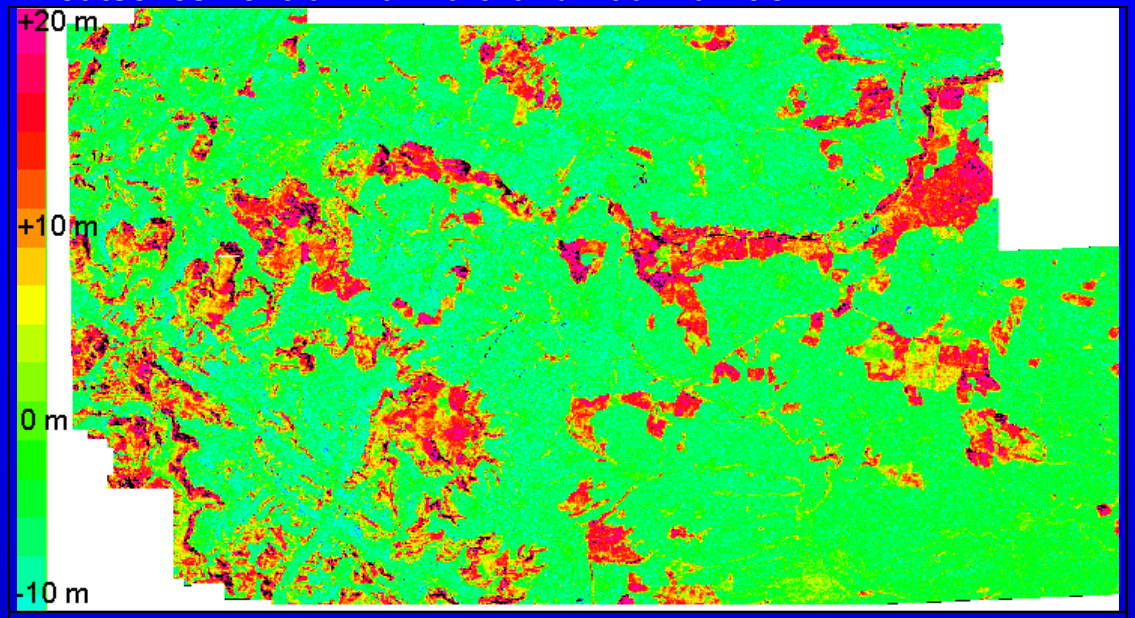
GEOCODED SRTM X-SAR DEM (LEFT) GEOCODED LASER DEM (RIGHT)
BOTH IN UTM32 with 25x25m pixel spacing



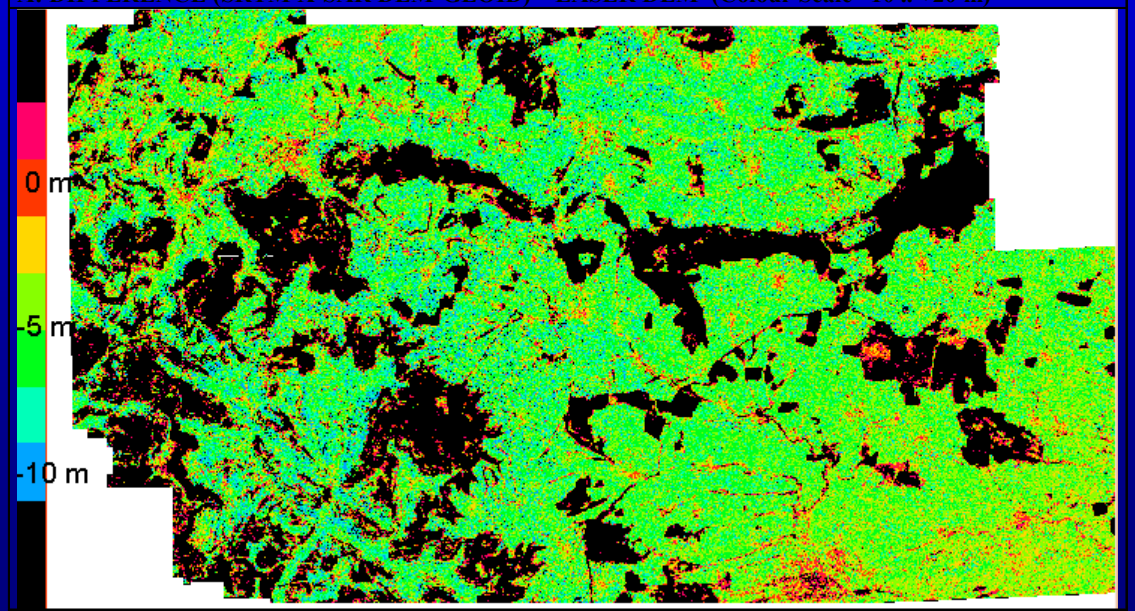


HEIGHT DIFFERENCE SRTM X-SAR DEM -LASERDEM(THÜRINGEN)

Dr.M.Reich and Dr.Thiel
from the Insitute of Navigation,
University of Stuttgart



A: DIFFERENCE (SRTM X-SAR DEM-GEOID) – LASER DEM (Colour Scale –10 .. +20 m)



B: DIFFERENCE (SRTM X-SAR DEM-GEOID) – LASER DEM (Colour Scale –10 ... 0 m)

Height Difference	Mean	Standard Deviation
SRTM DEM – Laser DEM	-5,06 m	4,38 m
LVA DEM – Laser DEM	-1,18 m	6,05 m

- Laser DEM is more accurate than existing Height Data
- For open areas the quality of SRTM Data is comparable to the quality of existing LVA DEM or better
- SRTM Data can complement and improve existing DEMs based on conventional methods
- Further analysis is necessary for forested and urban areas to deduce the terrain surface

AO 113: Along Track Interferometry Demonstration with SRTM

Principal Investigator:

H. Runge, DLR - IMF

Co-Investigators

InSAR and Traffic Monitoring:

H. Breit, M. Eineder, DLR-IMF

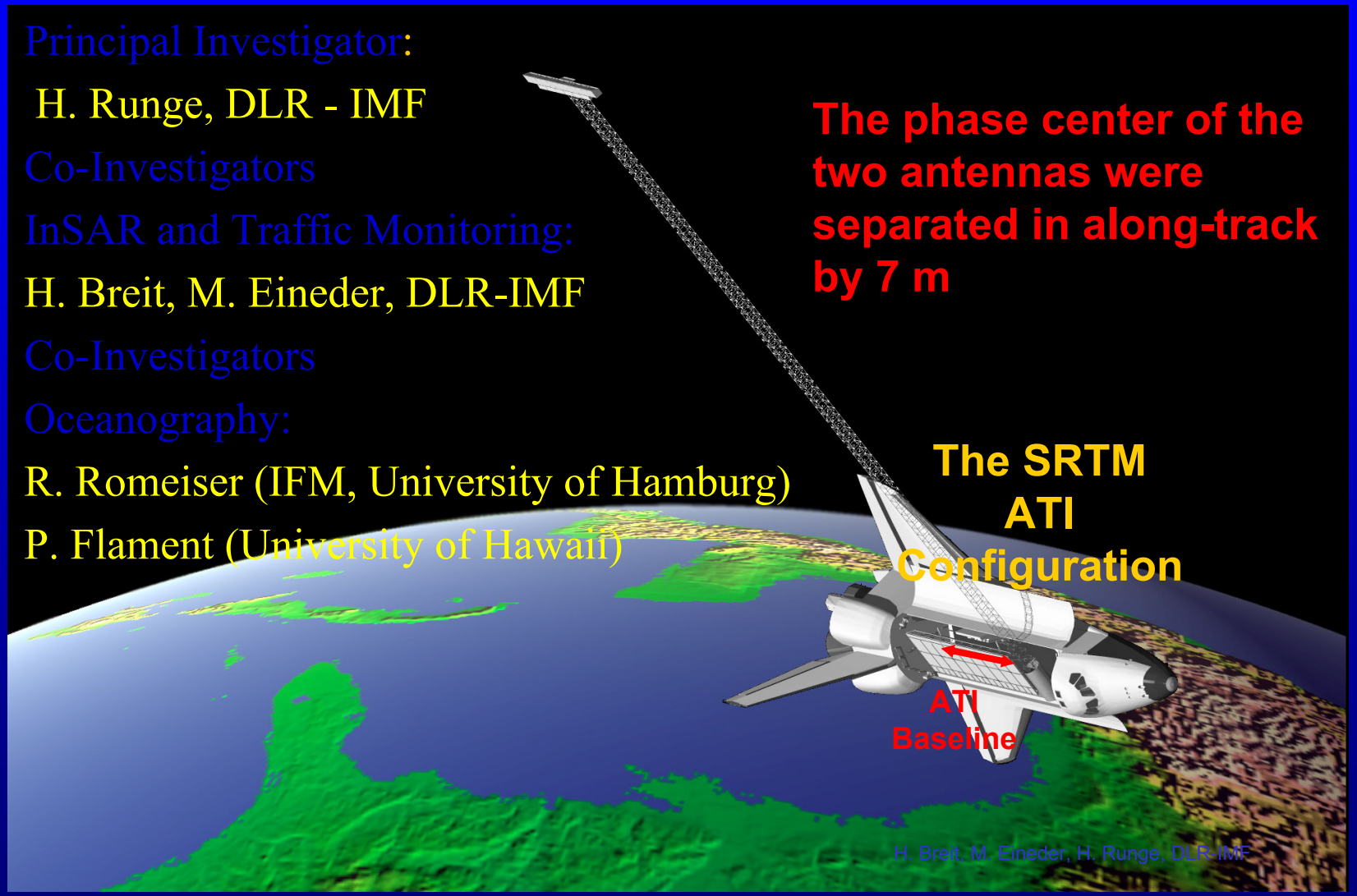
Co-Investigators

Oceanography:

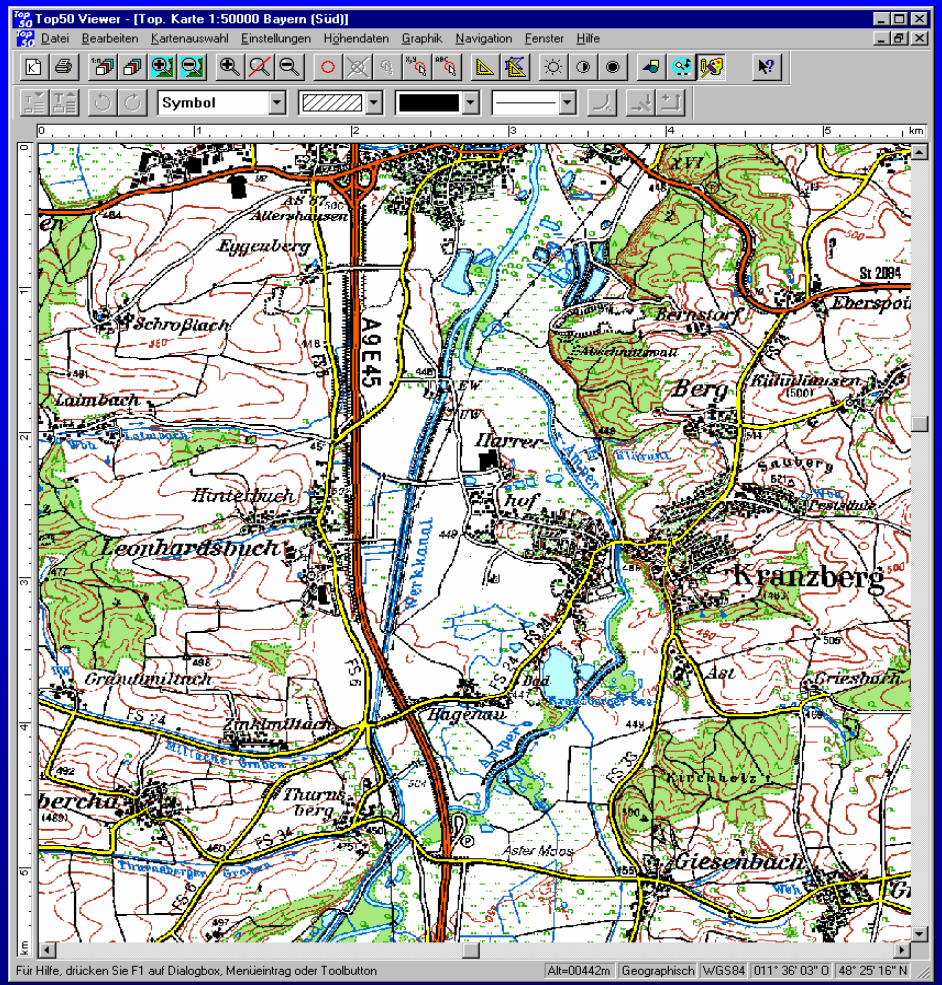
R. Romeiser (IFM, University of Hamburg)

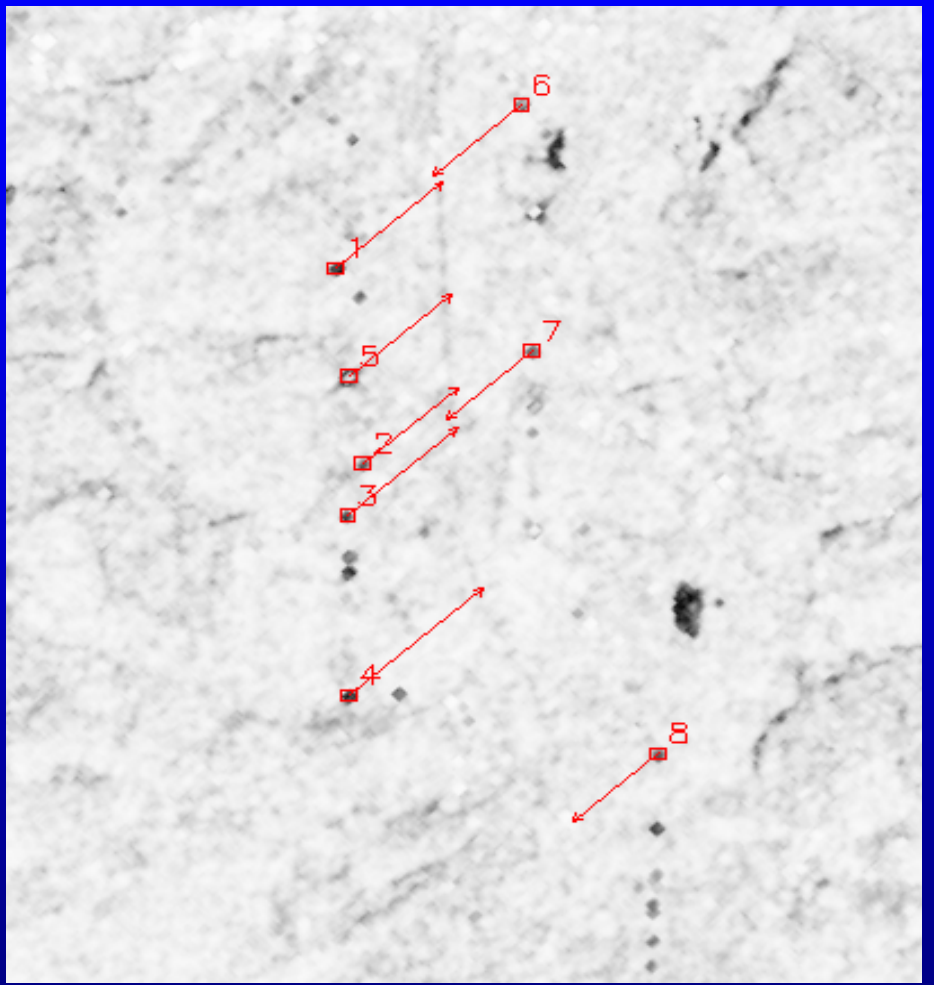
P. Flament (University of Hawaii)

The phase center of the two antennas were separated in along-track by 7 m



Truck velocity measured with SRTM





Testarea: Autobahn A9
München - Nürnberg

Radar Backscatter intensity

Detection of phase distortions in the coherence image

X-SAR/SRTM Shuttle Radar Topography Mission

Truck velocity measured with SRTM

Measurement of the displacement along track

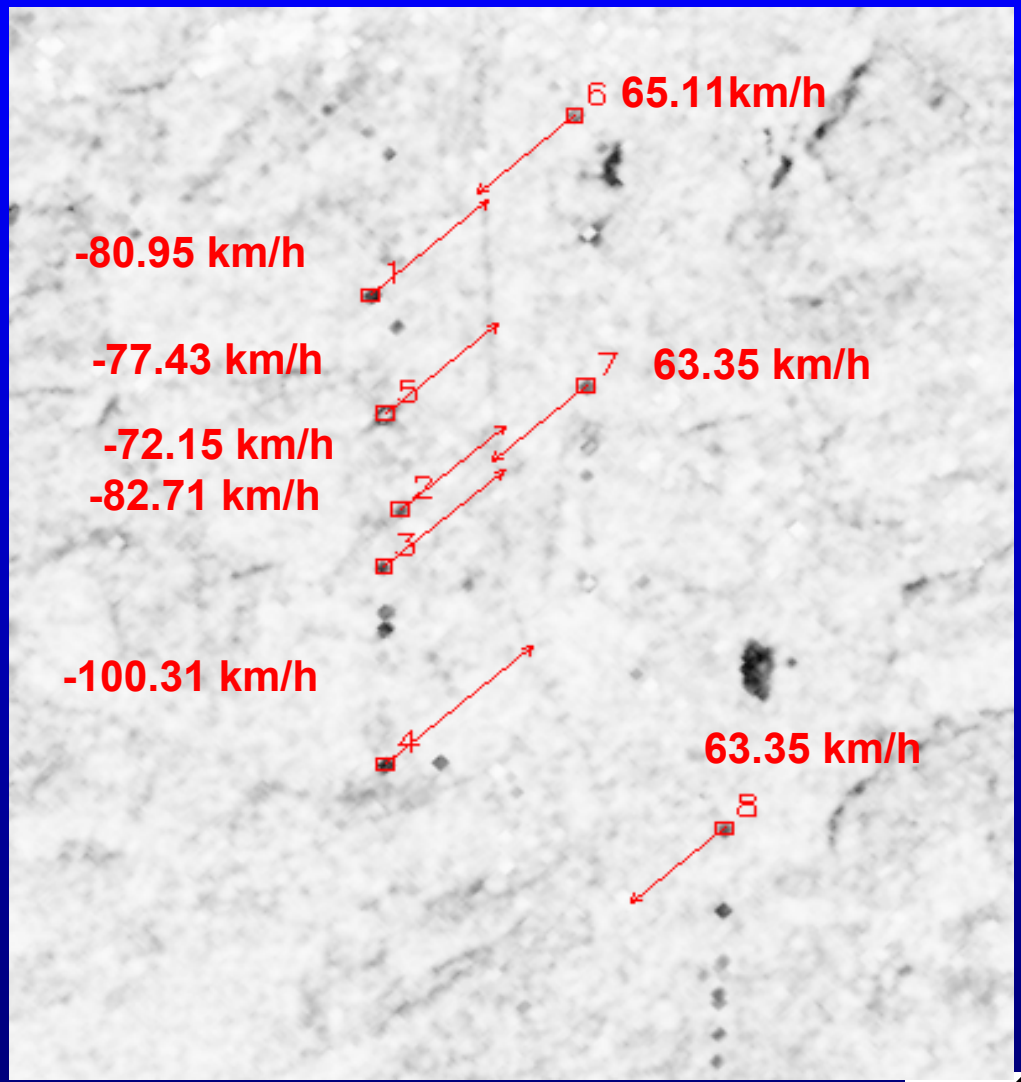
$$v_{veh} = \frac{\Delta az \cdot v_{Sat}}{R} \cdot \sin(\theta_i) \cdot \sin(\Delta\psi_{track})$$

Sensitivity:~ 1000m / 100 km/h

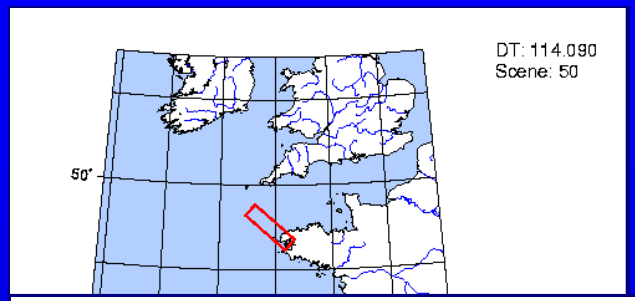
Accuracy: ~ 1 km/h !

- By Measurement of the Interferometric Phase (Along Track Interferometry ATI)

$$\Delta\varphi = 2\pi \frac{v_{rad} \cdot \Delta t}{\lambda 2}$$

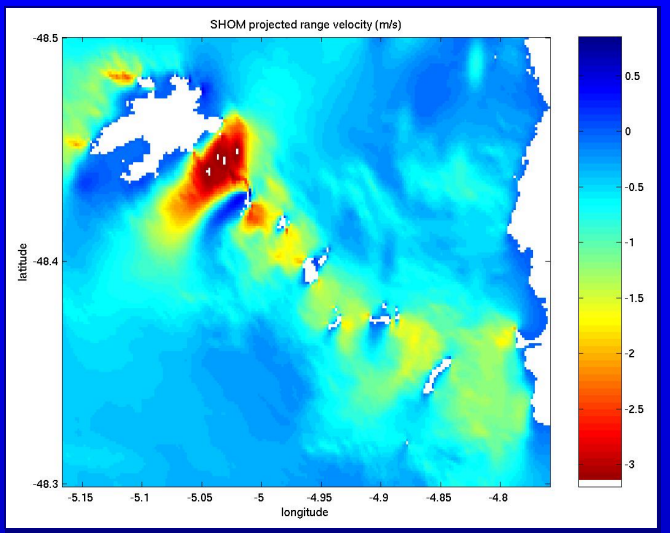


SRTM measures ocean currents at Test Site “Brest”

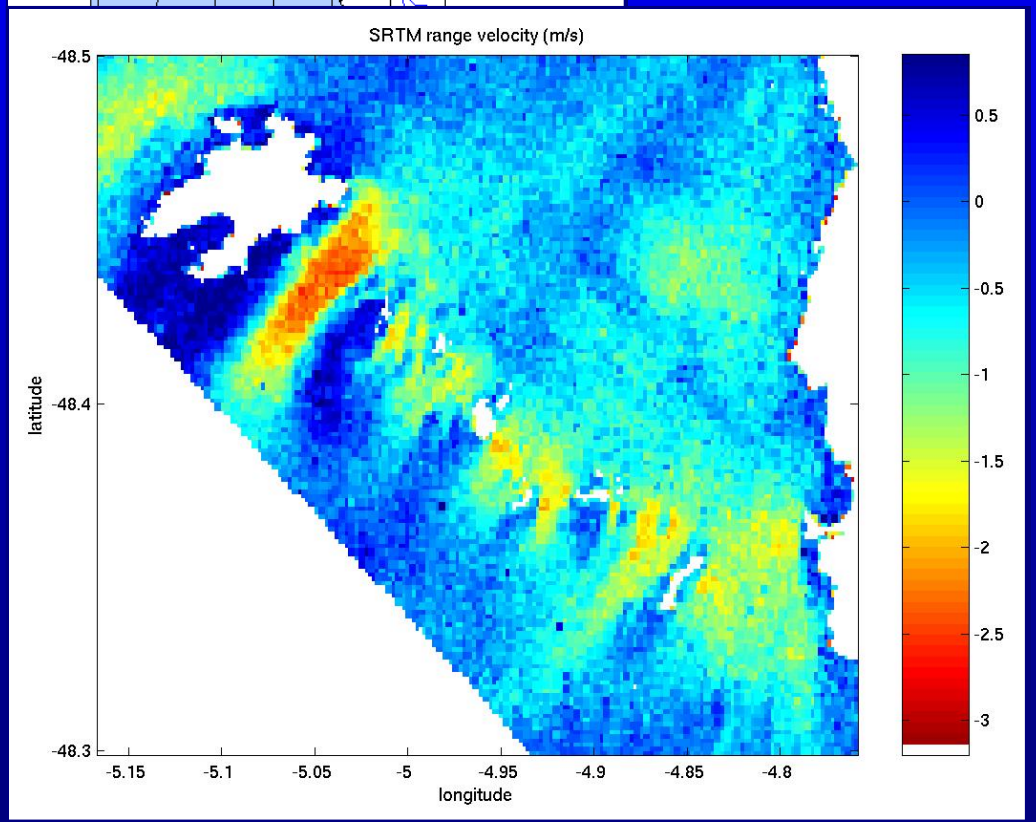


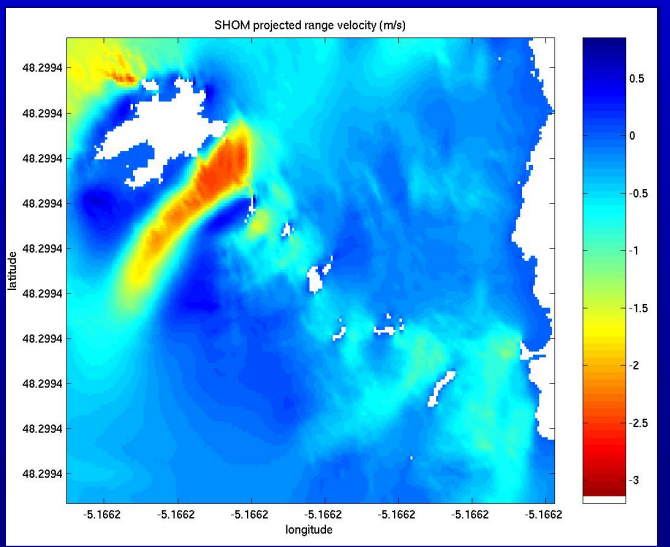
SHOM Currents

at SRTM flyover



SRTM Currents





SHOM Currents slightly after flyover

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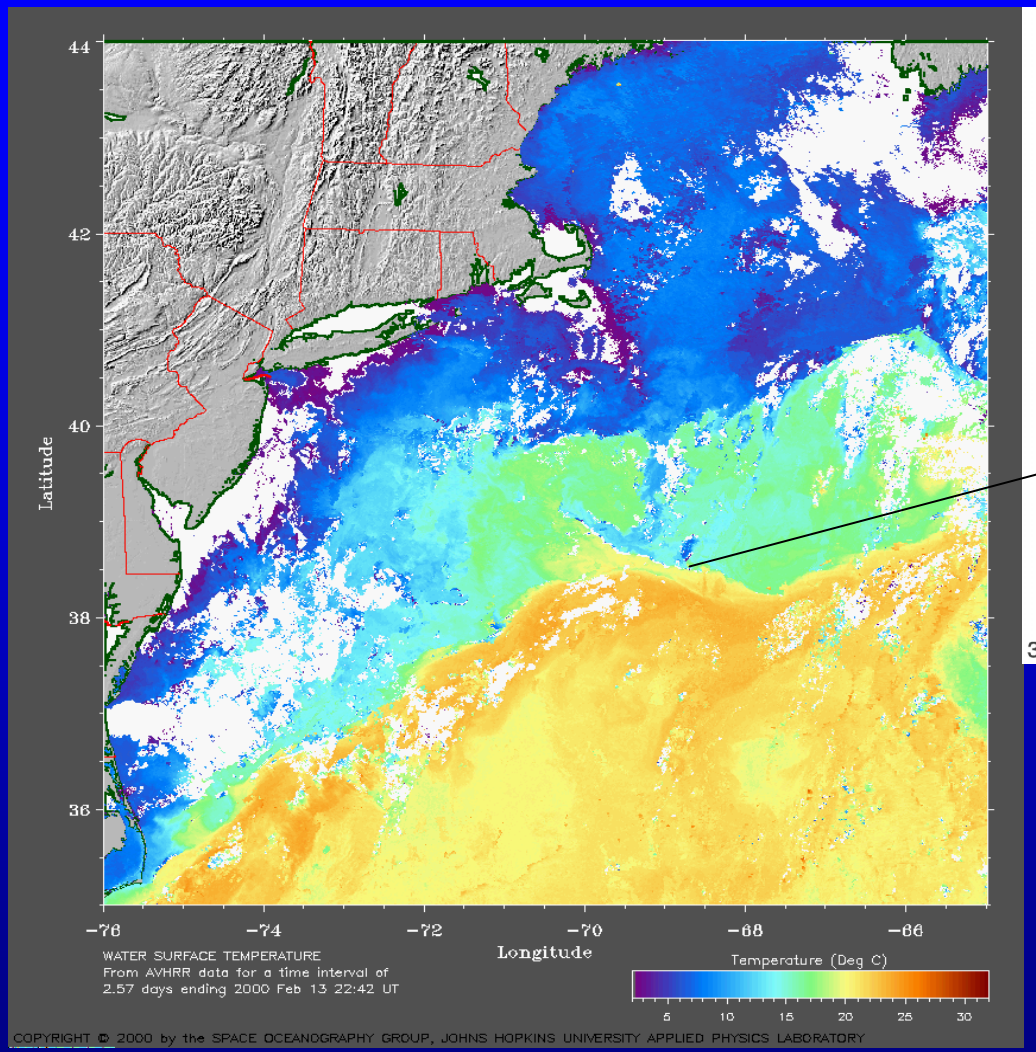
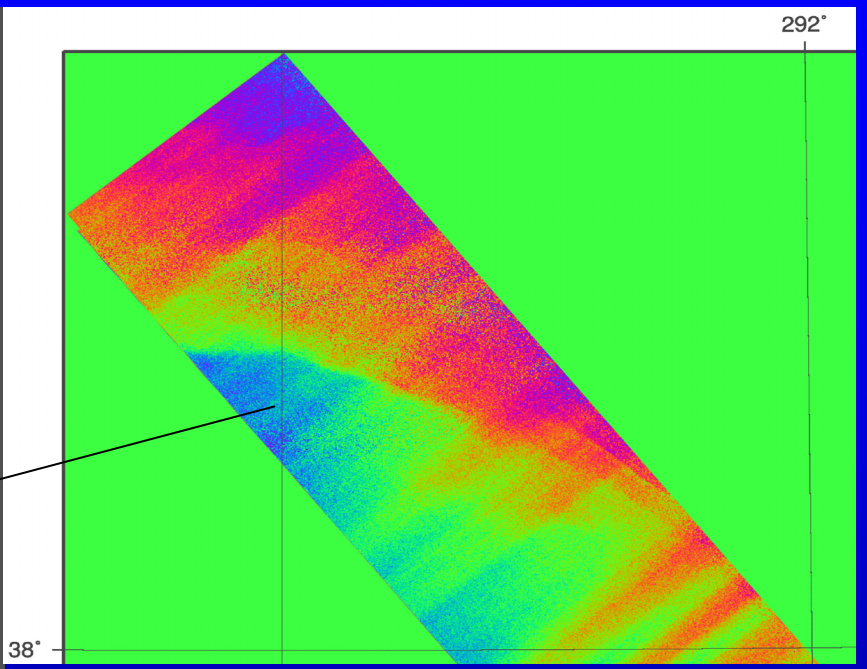
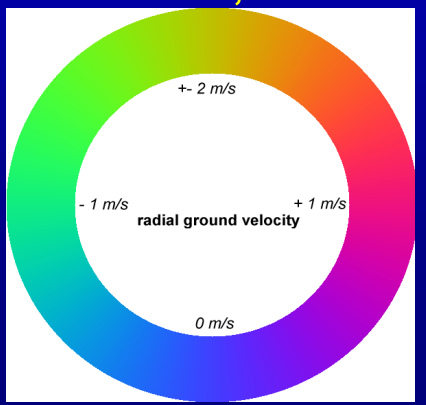
Gulf stream imaged by SRTM





SRTM Phase image of Data
Take 022.050, Scene: 0530



AVHRR image taken on Feb. 13th, 2000, the day of the SRTM fly-over

X-SAR/SRTM Shuttle Radar Topography Mission

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http://www.caf.dlr.de/srtm/

for SRTM data search go to

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