The German Radar Mission TerraSAR-X

Civil Commercial Imagery Evaluation Workshop, JACIE 2008

Fairfax March 25-27, 2008

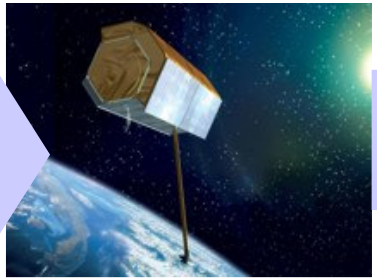
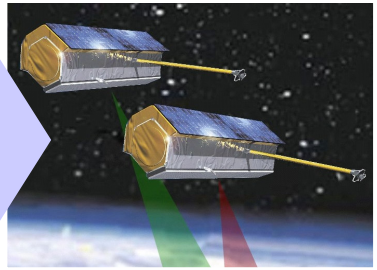
Stefan Buckreuss

TerraSAR-X Mission Manager

Microwaves and Radar Institute

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

German Spaceflight Program: SAR Road Map

SIR-C/X-SAR	SRTM	*TerraSAR-X*	TanDEM-X
			
1994 International, experimental, scientific mission	2000 International, experimental, scientific mission with operational product (DEM)	2007 National, operational mission suiting scientific and commercial markets *PPP Contract*	2009 National, operational scientific and commercial mission
• Geoscience	• Geoscience • Common public interest	• Geoscience • Commercial applications • Common public interest	• Geo/Radarscience • Commercial applications • Common public interest

"TerraSAR-X, a National Science Mission with Commercial Potential"

Public Private Partnership

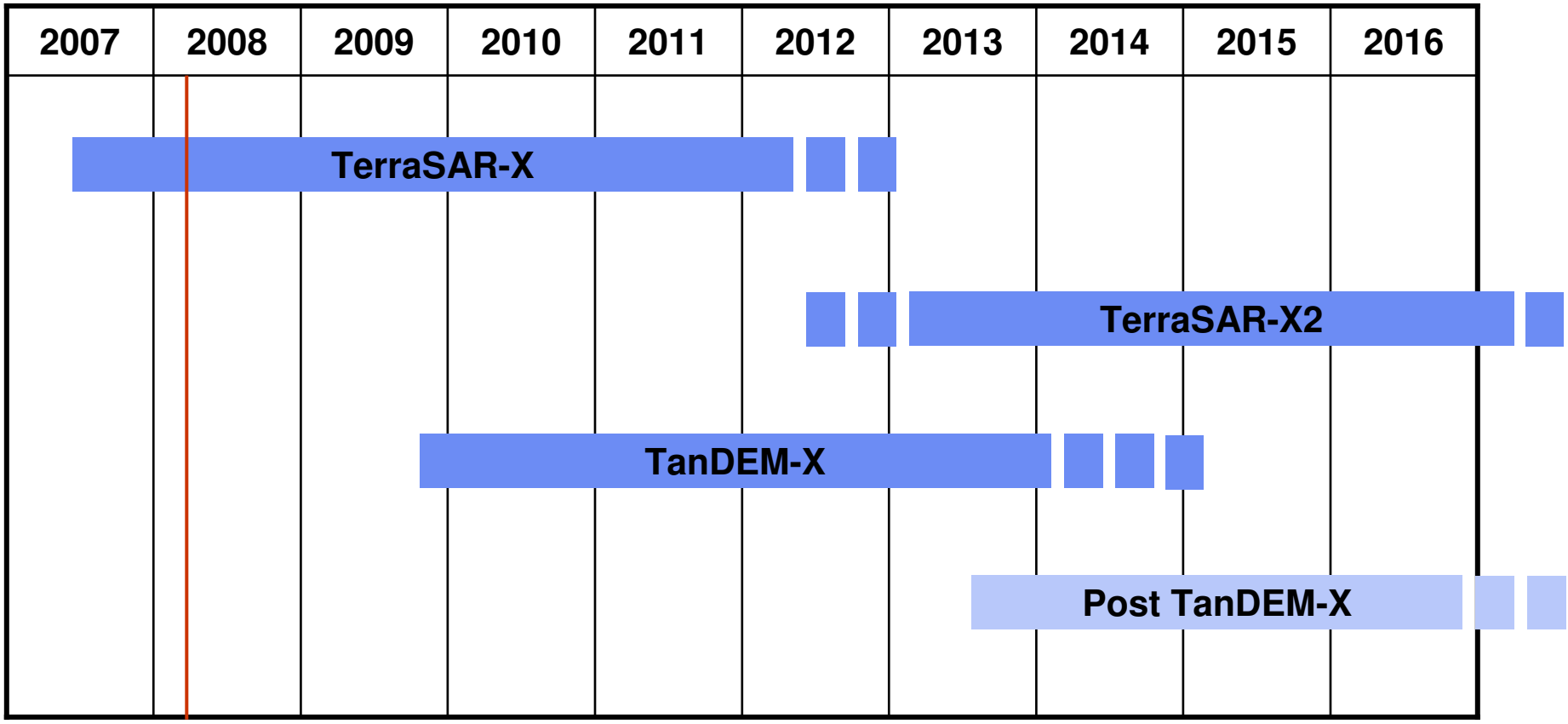
DLR
- Project & Mission Mgmt.
- G/S Development & Ops
- Science Coordination
- System Engineering Support

EADS Astrium
- Platform Development
- Instrument Development
- Launch on Dnepr-1

Infoterra
- Service Infrastructure
- Information Products
- Commercial Exploitation

- Satellite tasking will be shared equally 50/50 (scientific/commercial)
- DLR is the owner of the TerraSAR-X satellite and all data
- Nominal mission duration is 5 years
- If commercially successful → TerraSAR-X2 (to be financed by industry)

Future SAR Missions

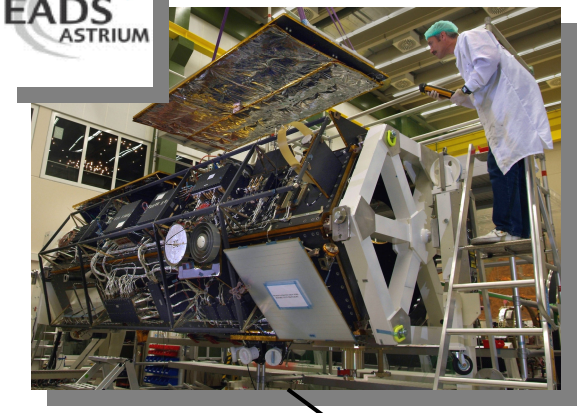


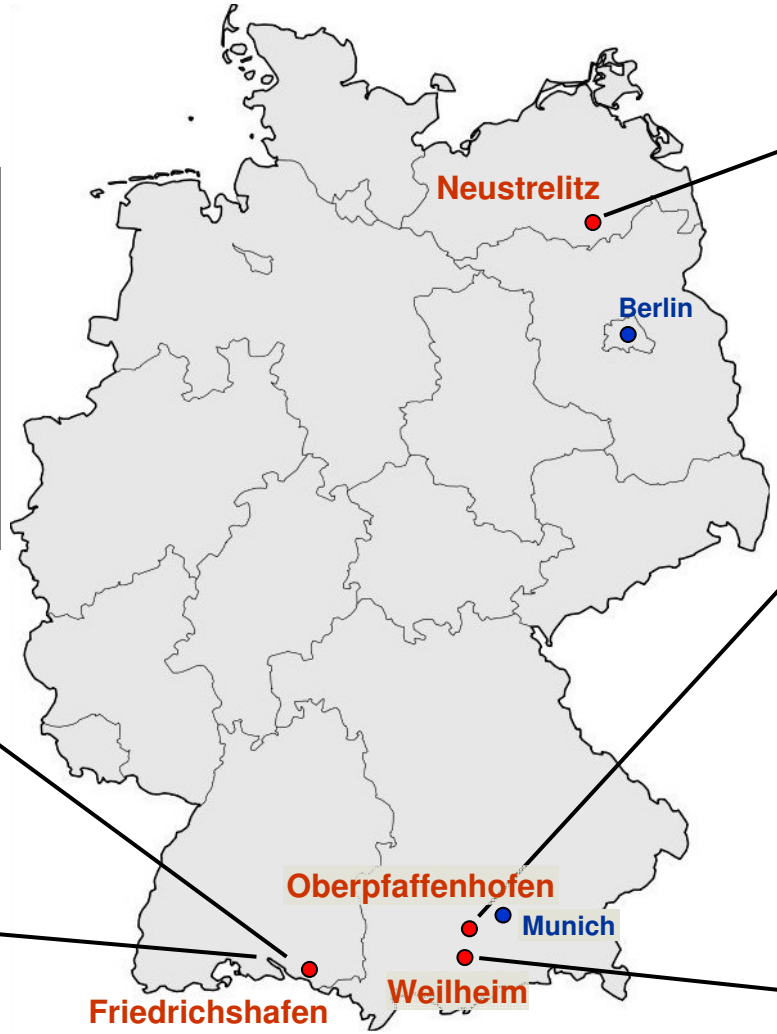
Schedule

- **August 2001** — **Space segment project kick-off**
- **May 2002** — **Ground segment project kick-off**
- **2001 - 2005** — **Space- and ground segment design and integration**
- **2006 – June 2007** — **Integrated tests, verification and validation**
  Individual and combined system tests and simulations on ground (space + ground segment)
- **June 15, 2007** — **Launch in Baikonur on a Dnepr-1**
- **June 15 – 21, 2007** — **Early Orbit Phase (7 days)**
  Check-out of bus, radar instrument and secondary payload
  All standard imaging modes (strip, spot & scan) have been exercised successfully.
- **June 22 – Dec 14, 2007** — **Commissioning Phase (5.5 months)**
  Calibration of radar data and product release, optimization of instrument settings, load tests, etc.
- **since Dec 14, 2007** — **Operational Phase**

TerraSAR-X Locations in Germany

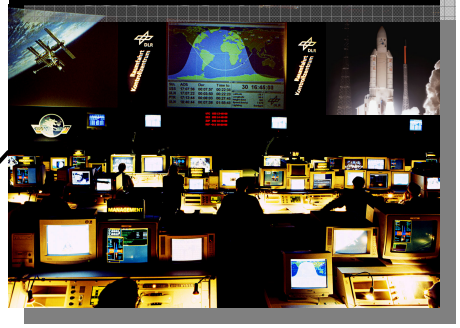
Spacecraft Development



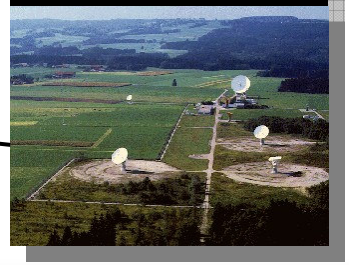


X-Band Payload Data Reception

Research Center & Mission Control

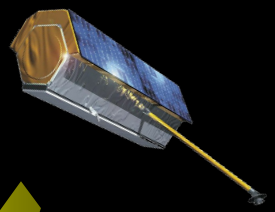


S-Band Telemetry & Telecommand



Commercial Exploitation

TerraSAR-X Mission Profile



Radar
Data Take

S-Band
Telemetry &
Telecommand

Downlink of
stored
radar data
@ 300
Mbit/sec

Ground Segment

DLR Ground Station
Weilheim

DLR-Oberpfaffenhofen:
Mission Operations/Planning, Flight Dynamics
Radar Operations, Calibration

DLR Ground Station
Neustrelitz

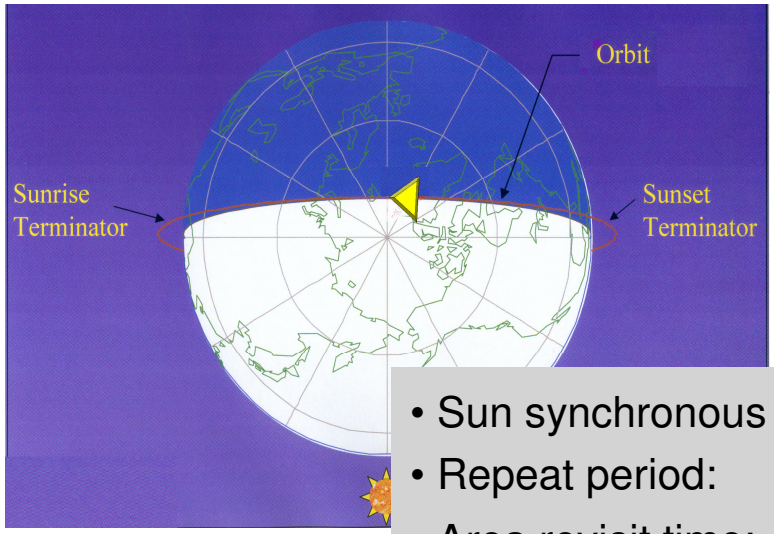
DLR-Oberpfaffenhofen
DLR-Neustrelitz:
Data Reception,
SAR-Processing,
Archiving,
Data Distribution

infoterra
an astrium company

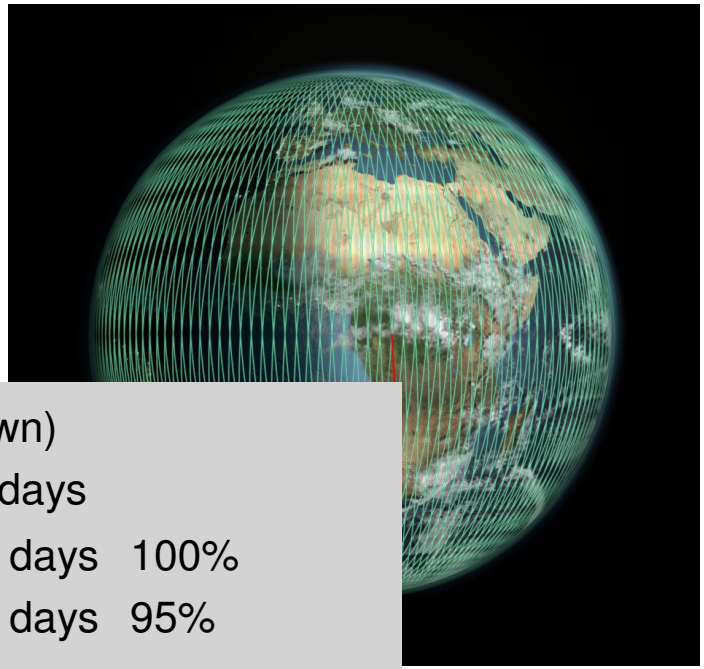
Commercial Exploitation

Science Coordination

TerraSAR-X Orbit



Sun-Synchronous 11-Days Repeat Orbit



Ground Track After 11 Days

- Sun synchronous orbit (dusk/dawn)
- Repeat period: 11 days
- Area revisit time: 4.5 days 100%
  (with left & right looking) 2.5 days 95%
- Orbits per day: 15
- Orbits per repeat cycle: 167
- Equatorial crossing time: 18:00h ascending pass
- Inclination: 97.44 °
- Altitude at equator: 514.8 km
- Velocity: 7.6 km/sec = 27.360 km/h

TerraSAR-X Ground Segment

Mission Operations Segment (MOS)
Provided by *German Space Operations Center (GSOC)*

- Mission Control (Oberpfaffenhofen)
- Mission Planning
- Satellite Operations
- Satellite Control (Weilheim G/S)
- Monitoring
- Flight Dynamics

Payload Ground Segment (PGS)
Provided by *Remote Sensing Technology Institute (IMF)*
German Remote Sensing Data Center (DFD)

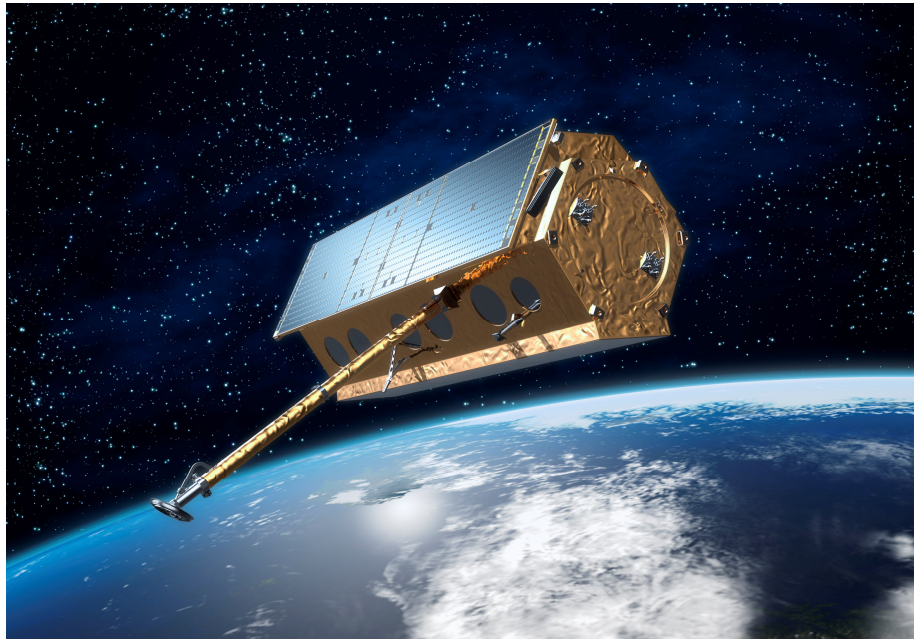
- Ordering
- Radar Data Reception (Neustrelitz G/S)
  SAR-Processor Development, SAR-Processing, Archiving
- Product Distribution

Instrument Operations & Calibration Segment (IOCS)
Provided by
Microwaves and Radar Institute (HR)

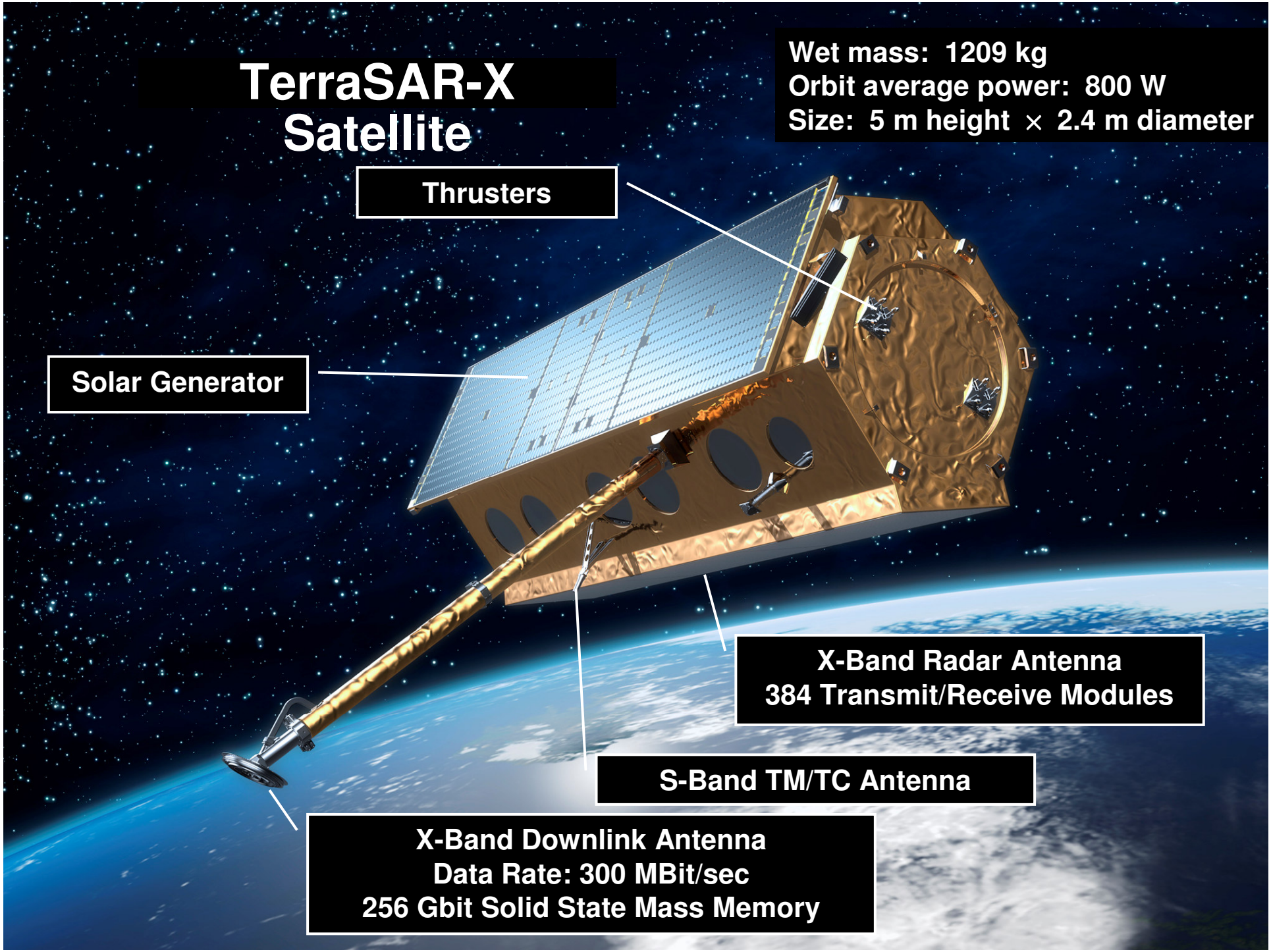
- SAR System Engineering
- Radar Operations
- SAR Calibration
- SAR Processing Algorithms

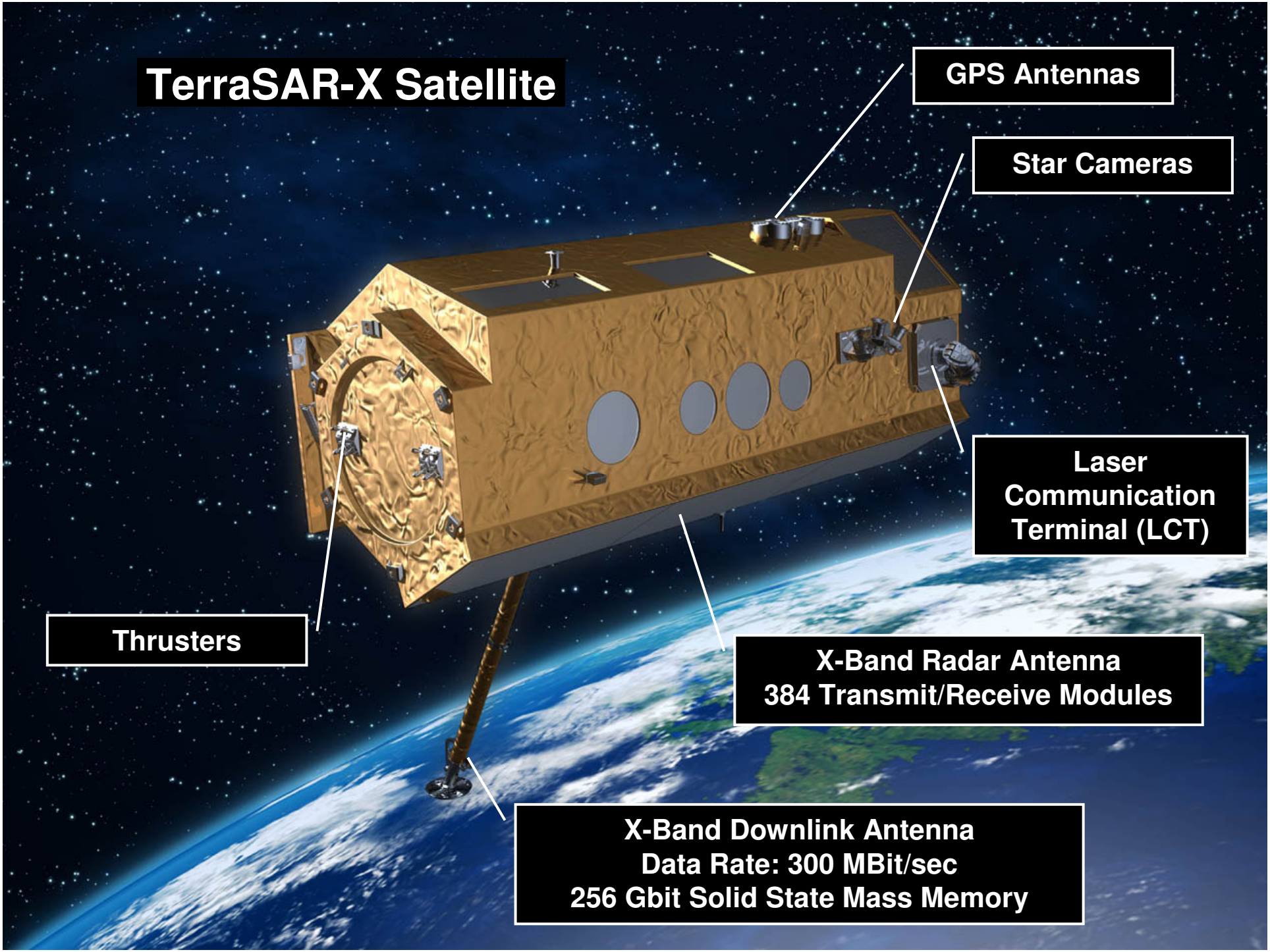
TerraSAR-X Satellite

- High resolution in SpotLight mode
- Possibility of large area coverage by utilizing ScanSAR mode
- Multi-polarization capability
- Left Looking Mode (roll maneuver of S/C)
- Dual Receive Antenna (DRA) Mode (ATI, MTI, Quad. Pol.)

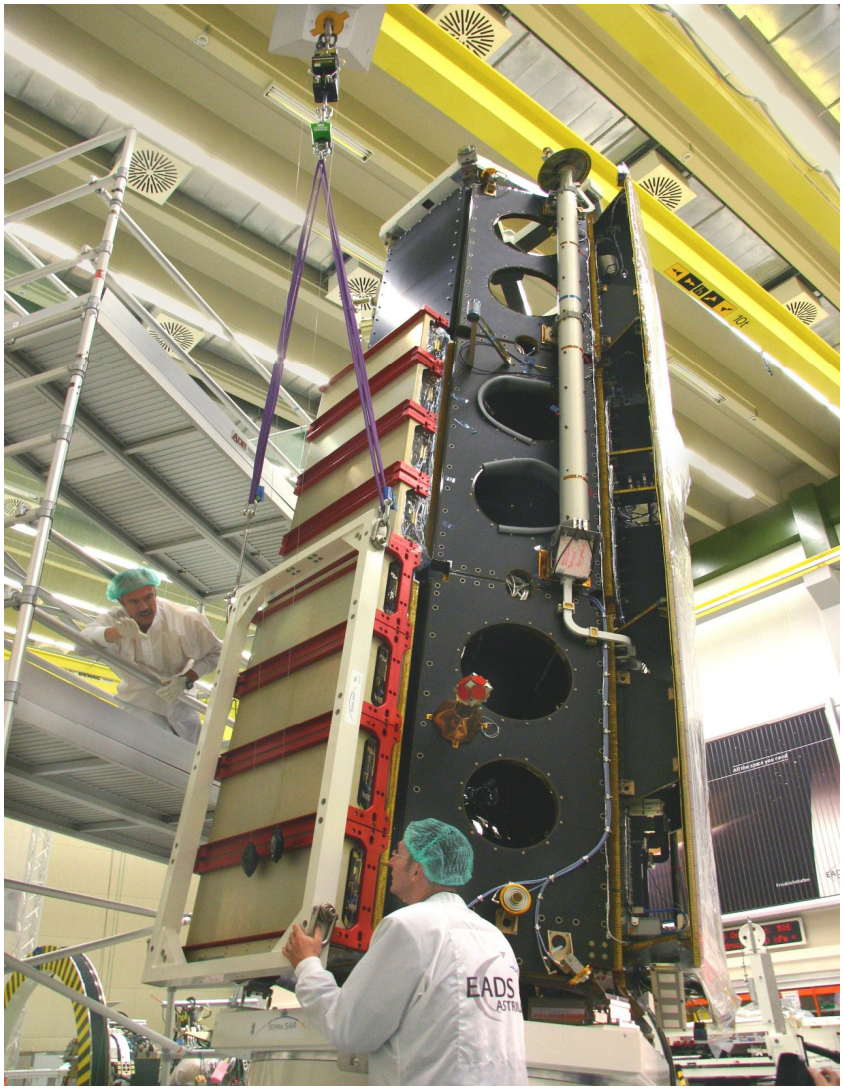


- 300 MHz transmit bandwidth (1 m range resolution)
- Repeat Pass Interferometry (±250 m orbit tube)
- Secure operation by encryption of commands and data downlink
- Prepared for TanDEM-X operation (synchronization)


TerraSAR-X
Satellite
Wet mass: 1209 kg
Orbit average power: 800 W
Size: 5 m height × 2.4 m diameter
Thrusters
Solar Generator
X-Band Radar Antenna
384 Transmit/Receive Modules
S-Band TM/TC Antenna
X-Band Downlink Antenna
Data Rate: 300 MBit/sec
256 Gbit Solid State Mass Memory


TerraSAR-X Satellite
GPS Antennas
Star Cameras
Laser Communication Terminal (LCT)
Thrusters
X-Band Radar Antenna
384 Transmit/Receive Modules
X-Band Downlink Antenna
Data Rate: 300 MBit/sec
256 Gbit Solid State Mass Memory

SAR Antenna Leaf Integration

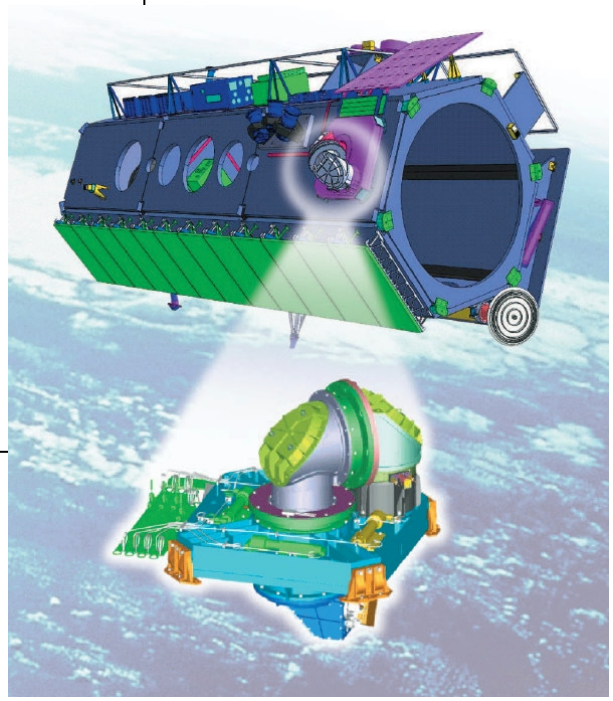


Acoustic Noise Test

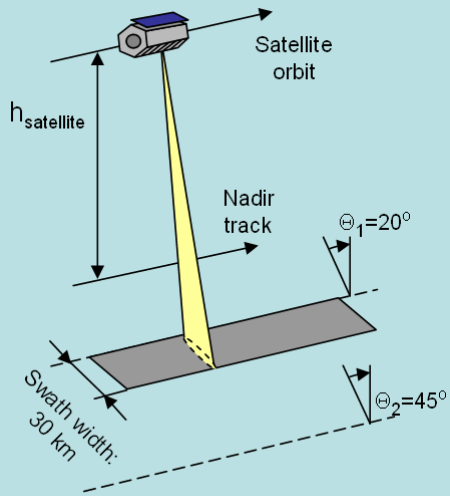
Secondary Payloads

- **LCT: Laser Communication Terminal**
  - DLR → TESAT
  - Technology-Demonstrator for Intersatellite Communication

- **TOR: Tracking, Occultation and Ranging Instrument Package**
  - Contribution of GFZ / University of Texas
  - Two-frequency GPS Receiver and Laser Reflector
  - High-precise Orbit determination for TerraSAR-X

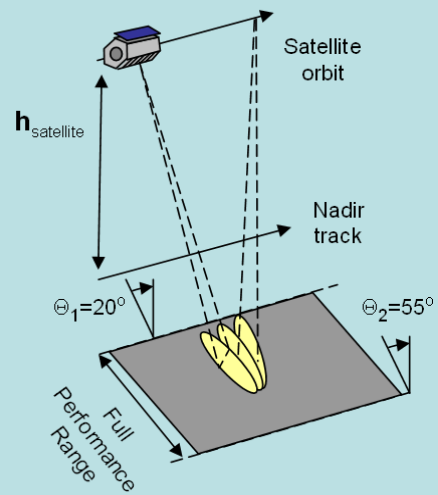


TerraSAR-X Nominal Imaging Modes



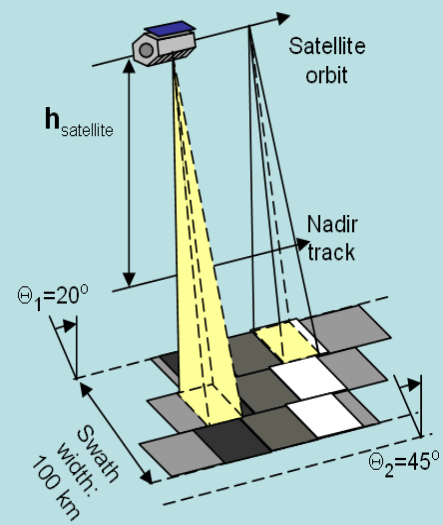
StripMap Mode

Resolution: 3 m × 3 m
Scene Size: 30 km × 50 km
[Range × Azimuth]



SpotLight Mode

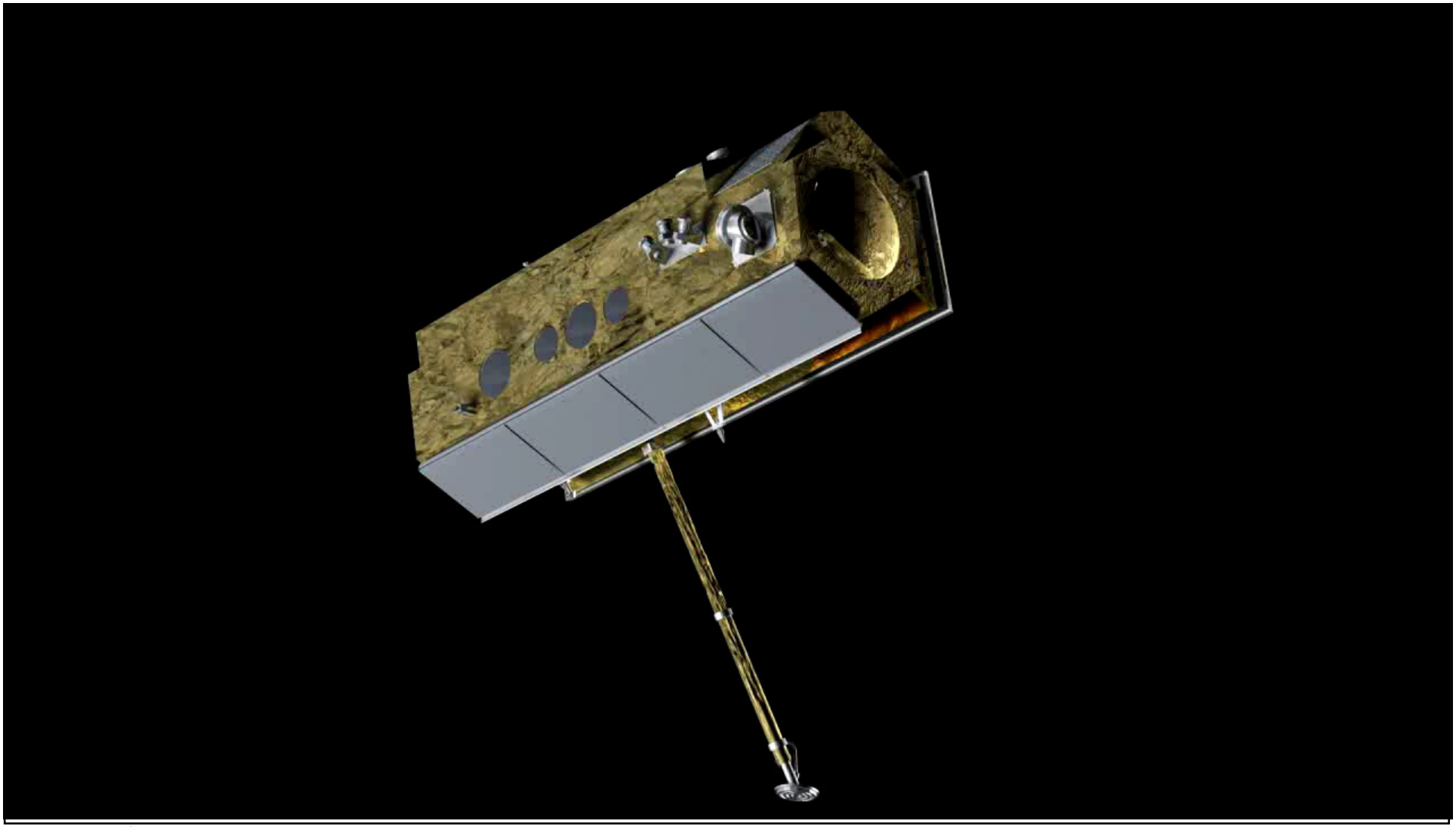
Resolution: 1 m × 1,5... 3,5 m
Scene Size: 10 km × 5...10 km
[Range × Azimuth]



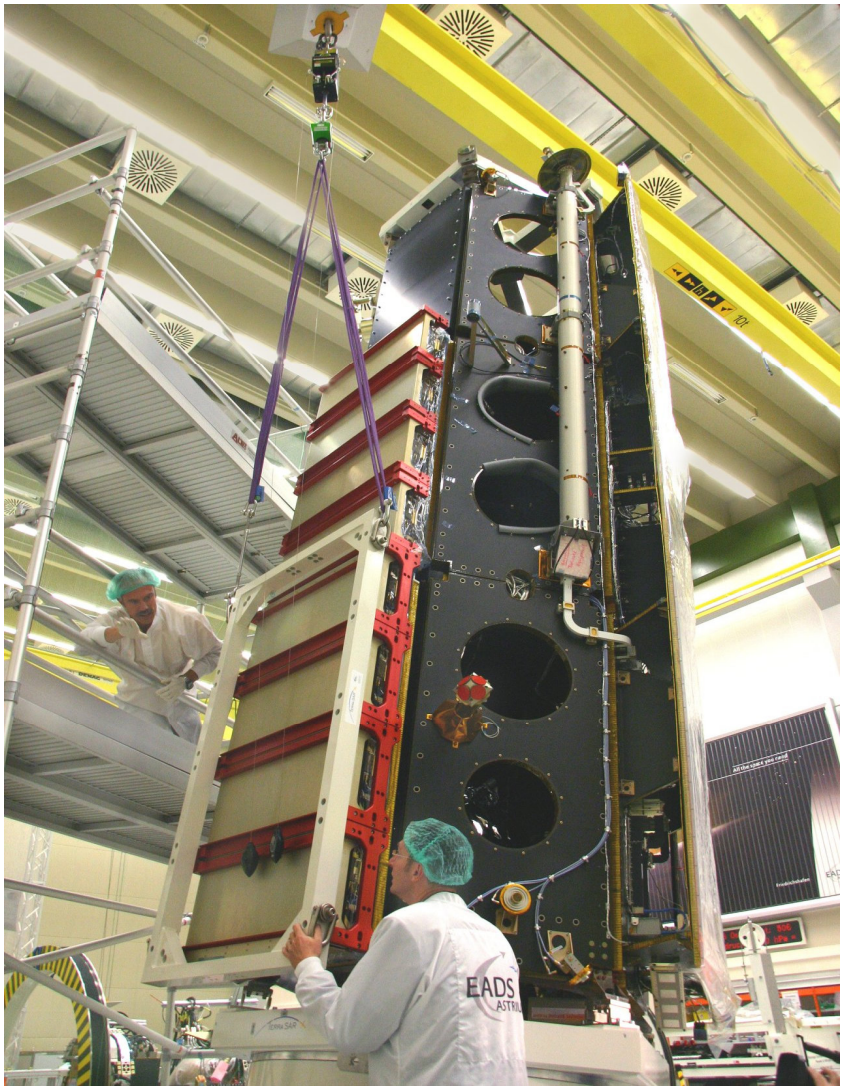
ScanSAR Mode

Resolution: 16 m × 16 m
Scene Size: 100 km × 150 km
[Range × Azimuth]

TerraSAR-X Imaging Modes



SAR Antenna Leaf Integration



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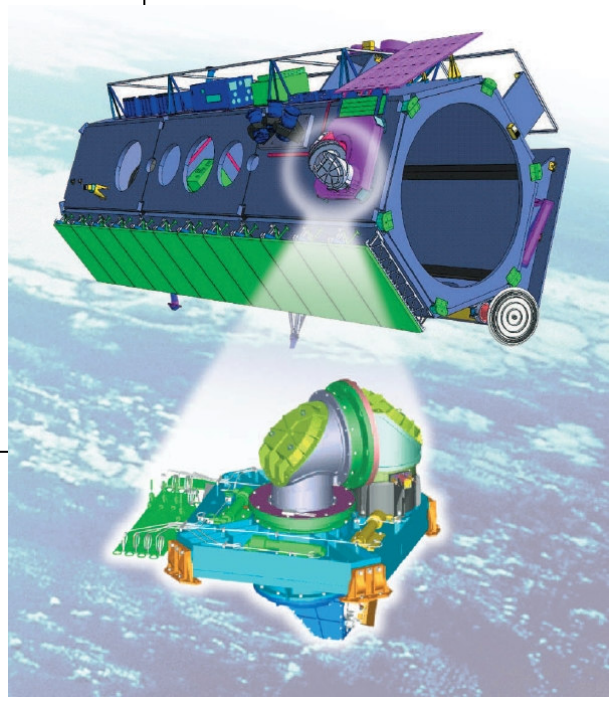


Dnepr-1 Launch

in Baikonur, Kasachstan

June 15th, 2007

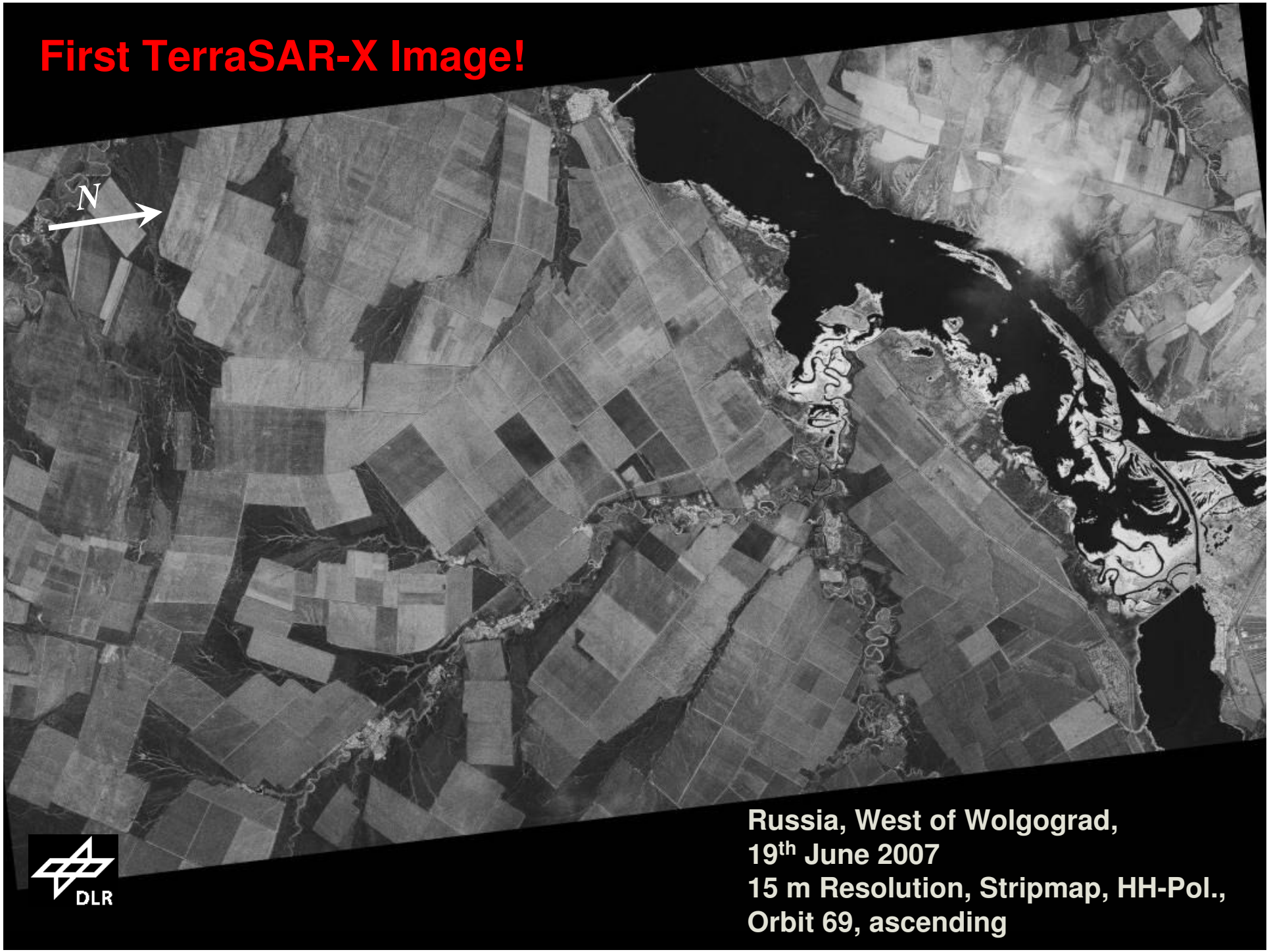
4:14 MESZ (2:14 UTC)

- Only 87 m deviation from target altitude!

LEOP: Launch and Early Orbit Phase

- First acquisition 15 minutes after launch over ESA G/S in Malindi / Kenia
- Satellite and SAR-Instrument are operational and working well
  - Imaging capacity well above specification
  - SAR performance is excellent
- 2-frequency GPS Receiver IGOR of GFZ is operational
- Check-Out of LCT completed. First Satellite-to-Ground Link successful
- All standard imaging modes (strip, spot & scan) have been exercised
- LEOP successfully completed on June 21st, 2007

First TerraSAR-X Image!



Russia, West of Wolgograd,
19th June 2007
15 m Resolution, Stripmap, HH-Pol.,
Orbit 69, ascending

„Rain“

Russia, West of Wolgograd,
19th June 2007
15 m Resolution,
Stripmap, HH-Pol.,
Orbit 69, ascending

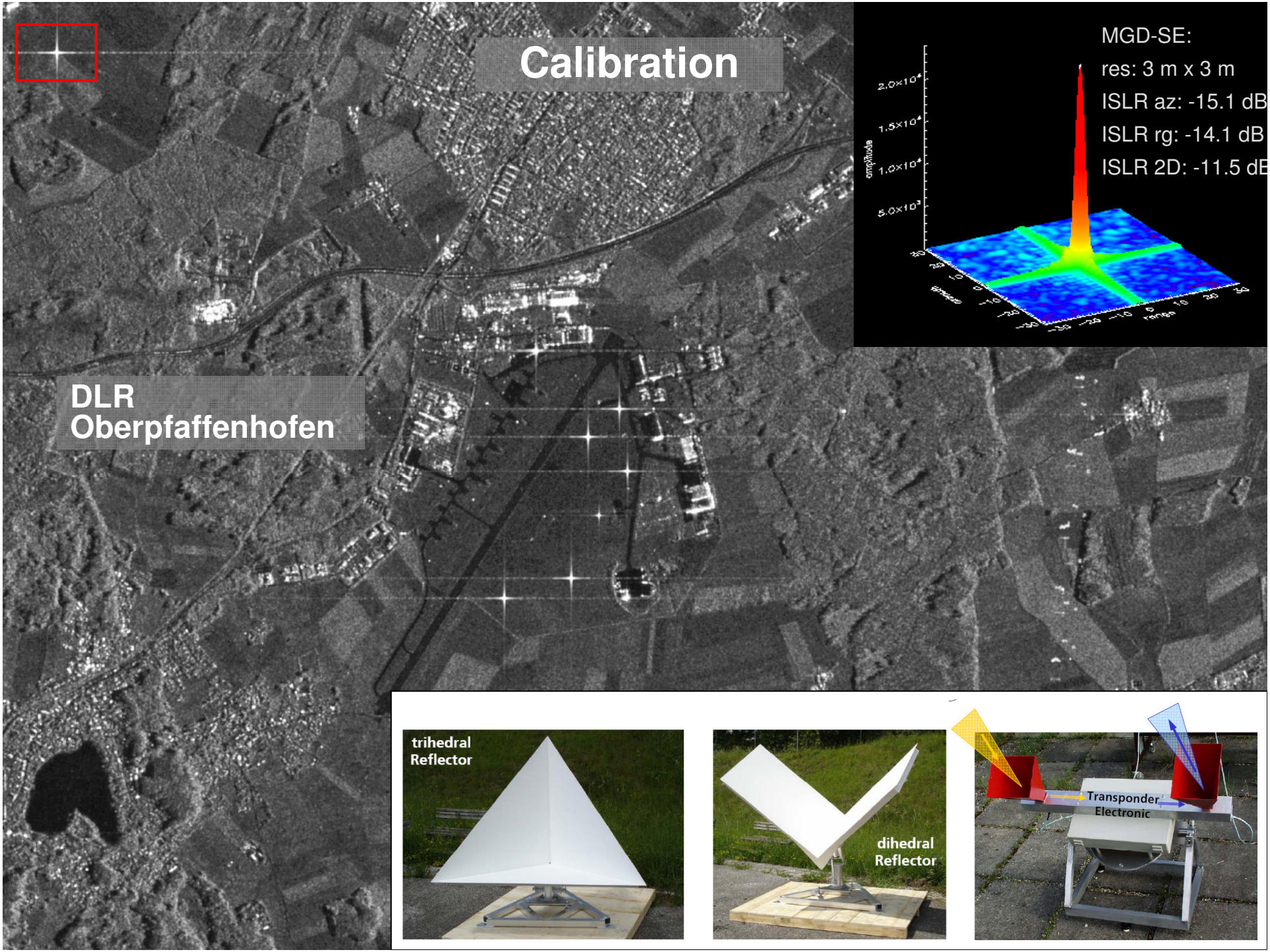
„Train off Track“

Russia, West of Wolgograd,
19th June 2007
15 m Resolution,
Stripmap, HH-Pol.,
Orbit 69,
ascending

Commissioning Phase

- Orbit and attitude verification
- Radar instrument characterization/verification
- Overall SAR system performance characterization
- Calibration of the radar data including calibration campaigns
- Check-out of receiving station and processing system
- SAR product verification and release of the basic products
- Check out of Direct Access Stations operated by Infoterra GmbH
- Load tests including the commercial service segment
- Interferometric processing
- Repeat pass interferometry
- Persistent scatterer potential
- Along track interferometry utilizing the aperture switching mode
- TOPSAR mode (improved ScanSAR)

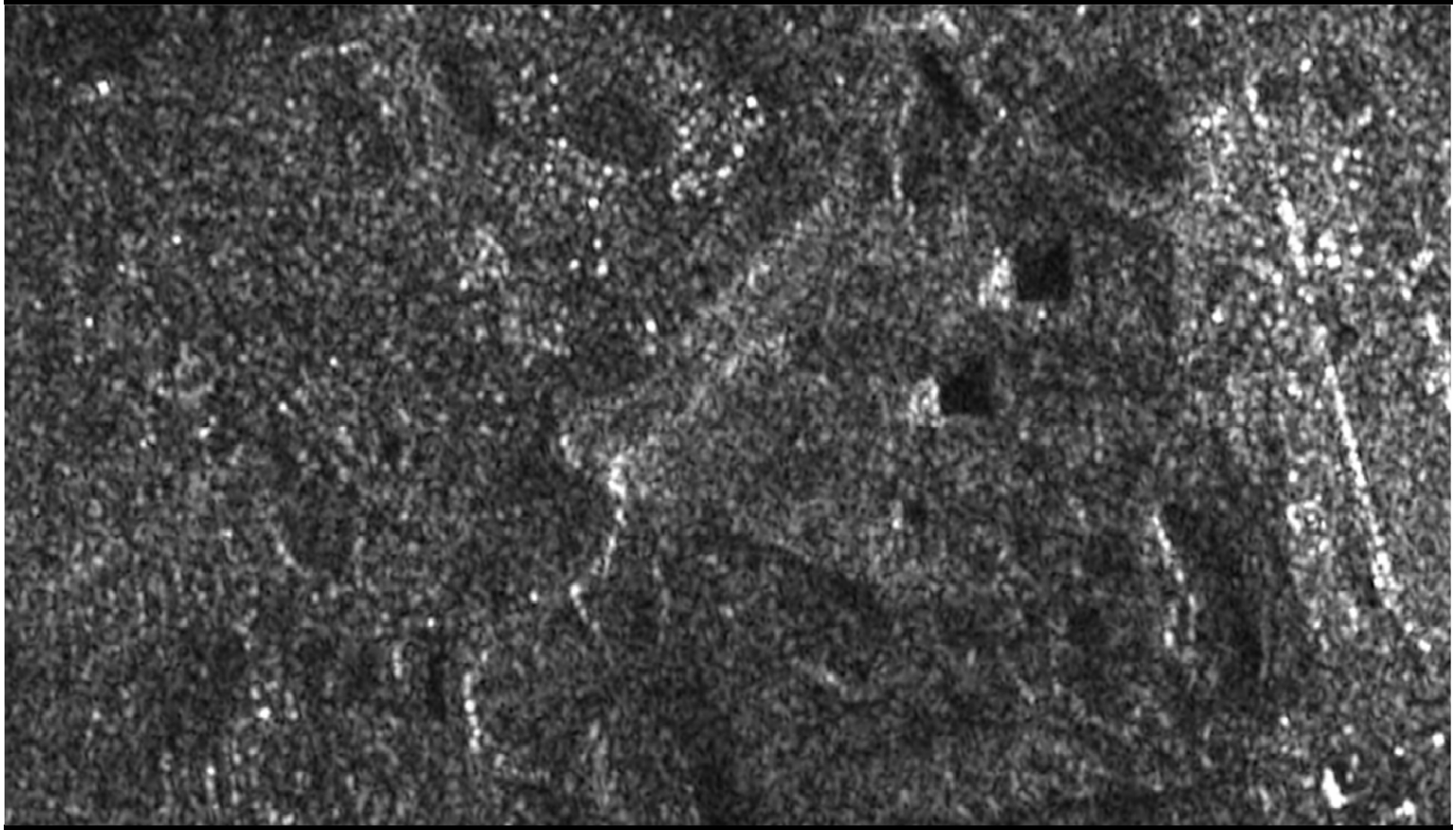
Calibration



Egypt, Pyramids of Gizeh
High Resolution Spotlight
HH-Pol.
150 MHz
DLR
TerraSAR-X

Previous SAR Image Quality of Civilian SAR Sensors

ca. 20 m $\times$ 20 m Resolution

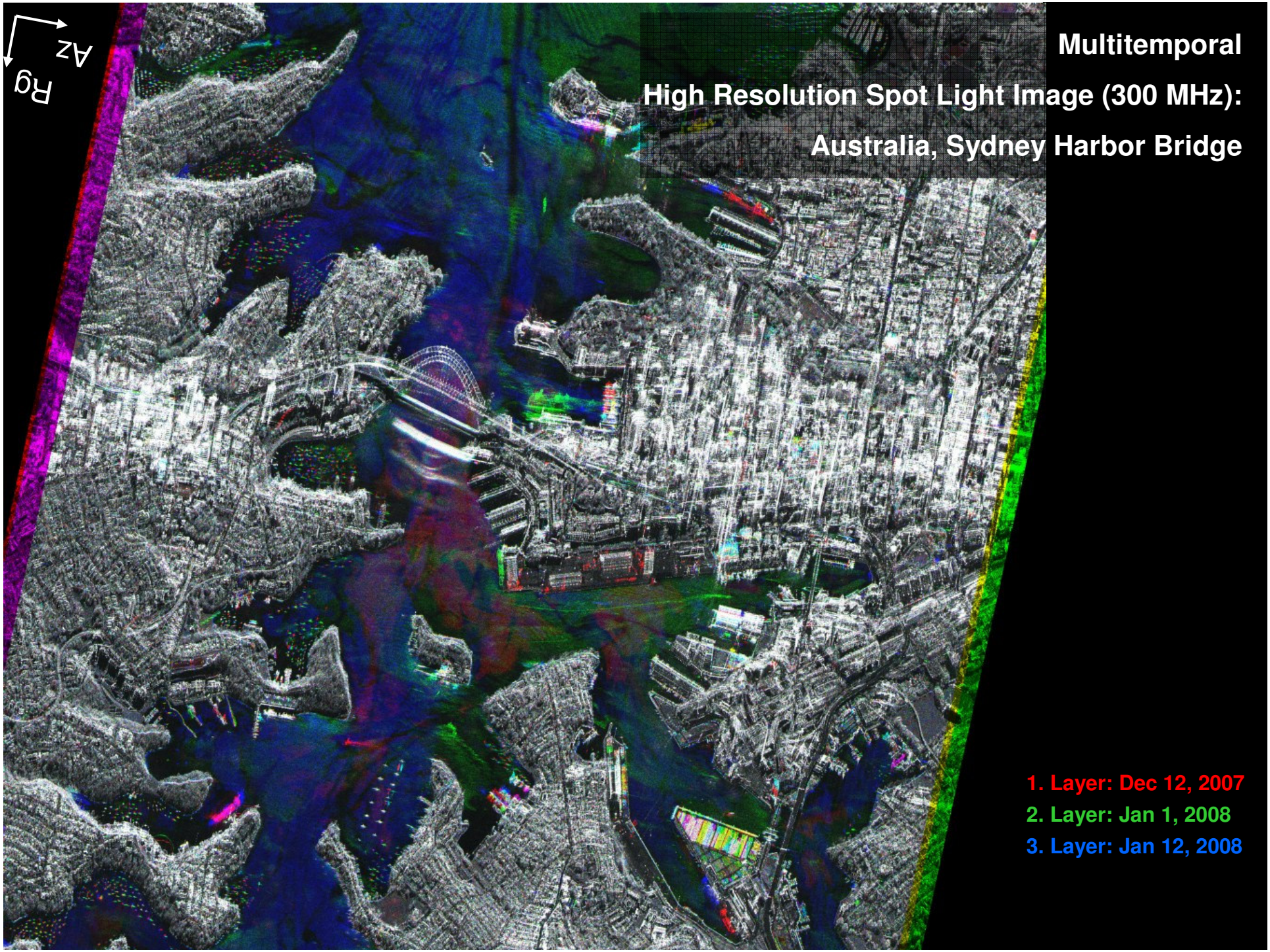


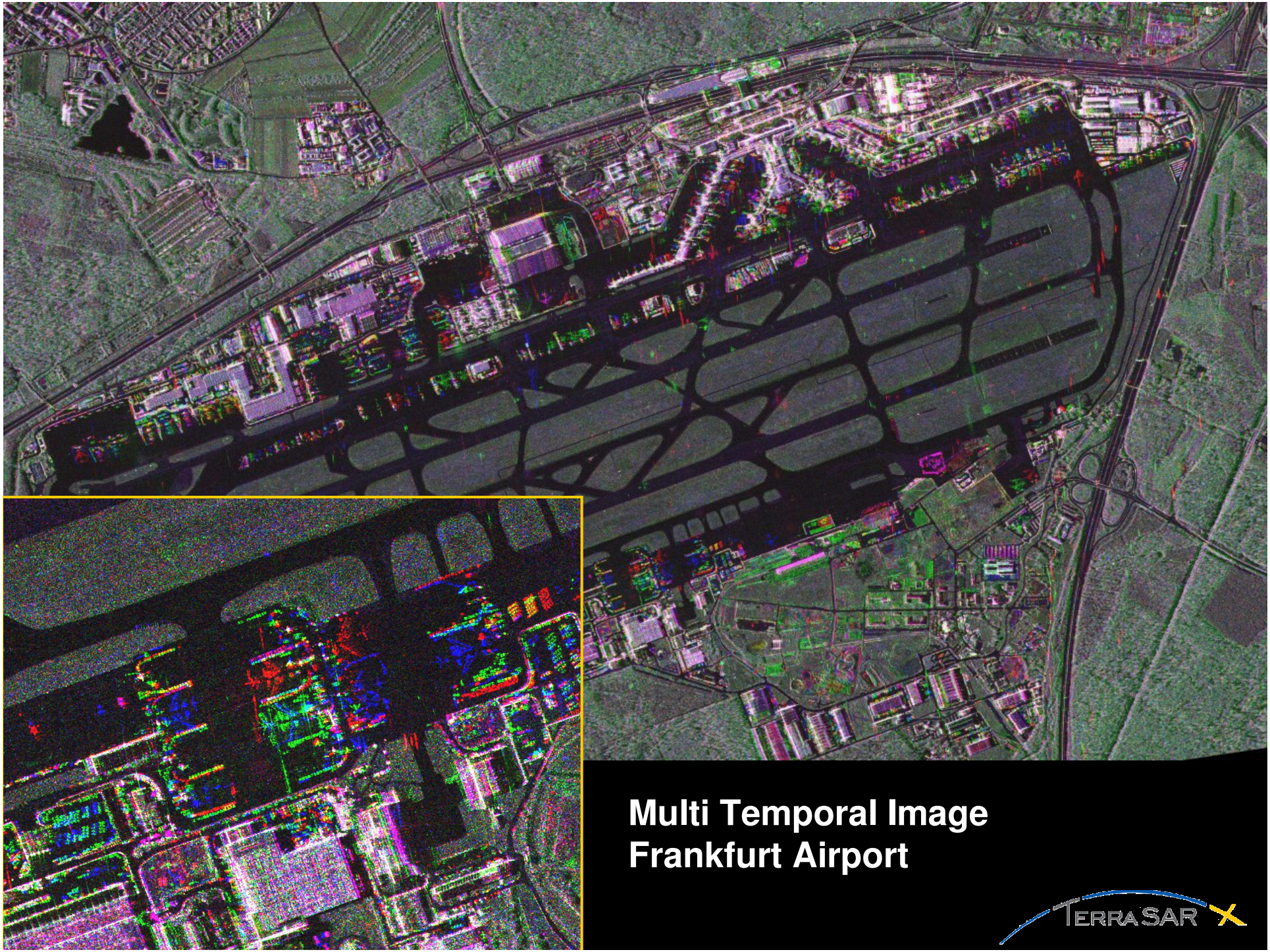
High resolution Spot Light Image (300 MHz):

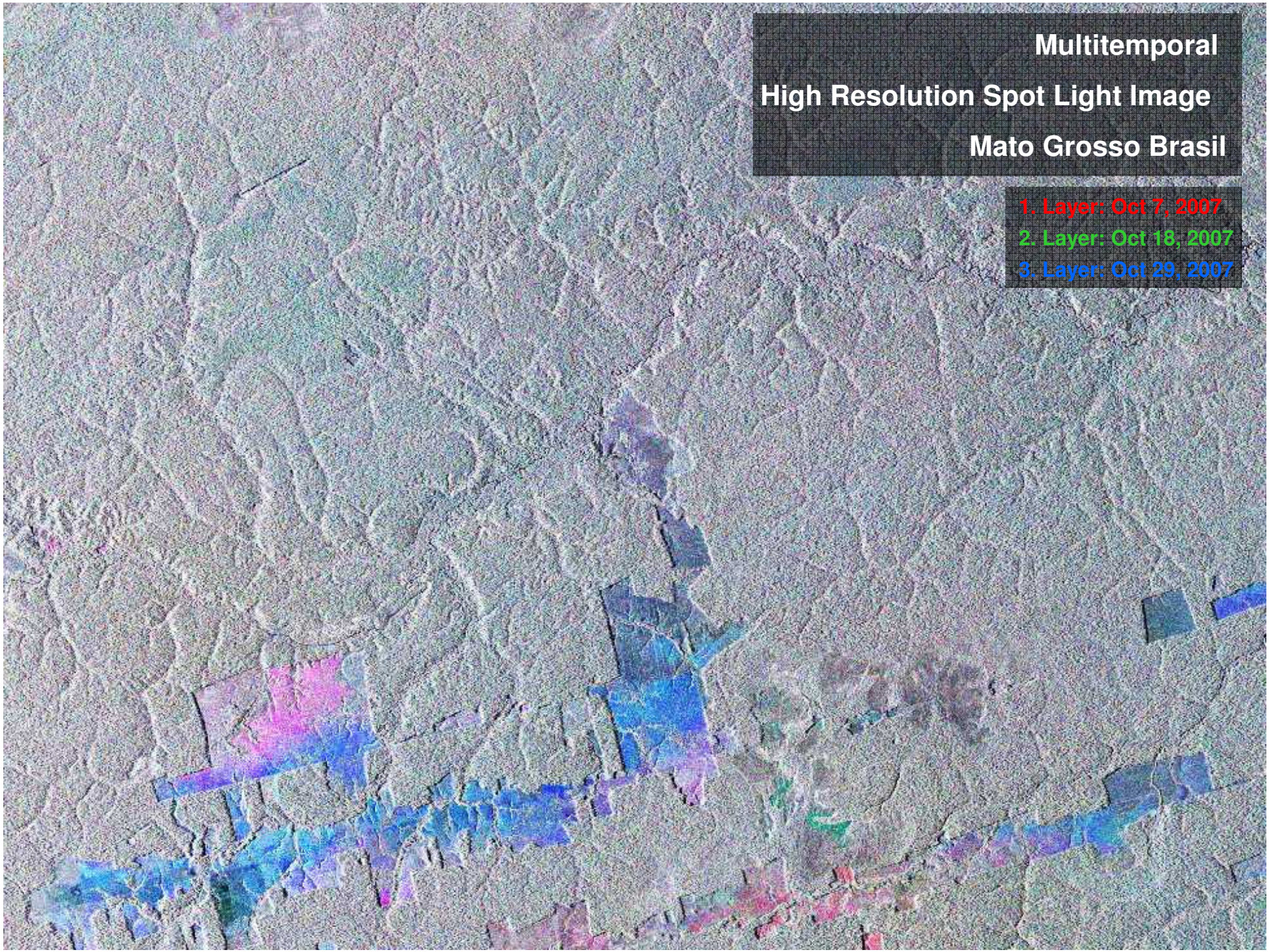
Australia, Sydney Harbor Bridge

DLR

TerraSAR-X

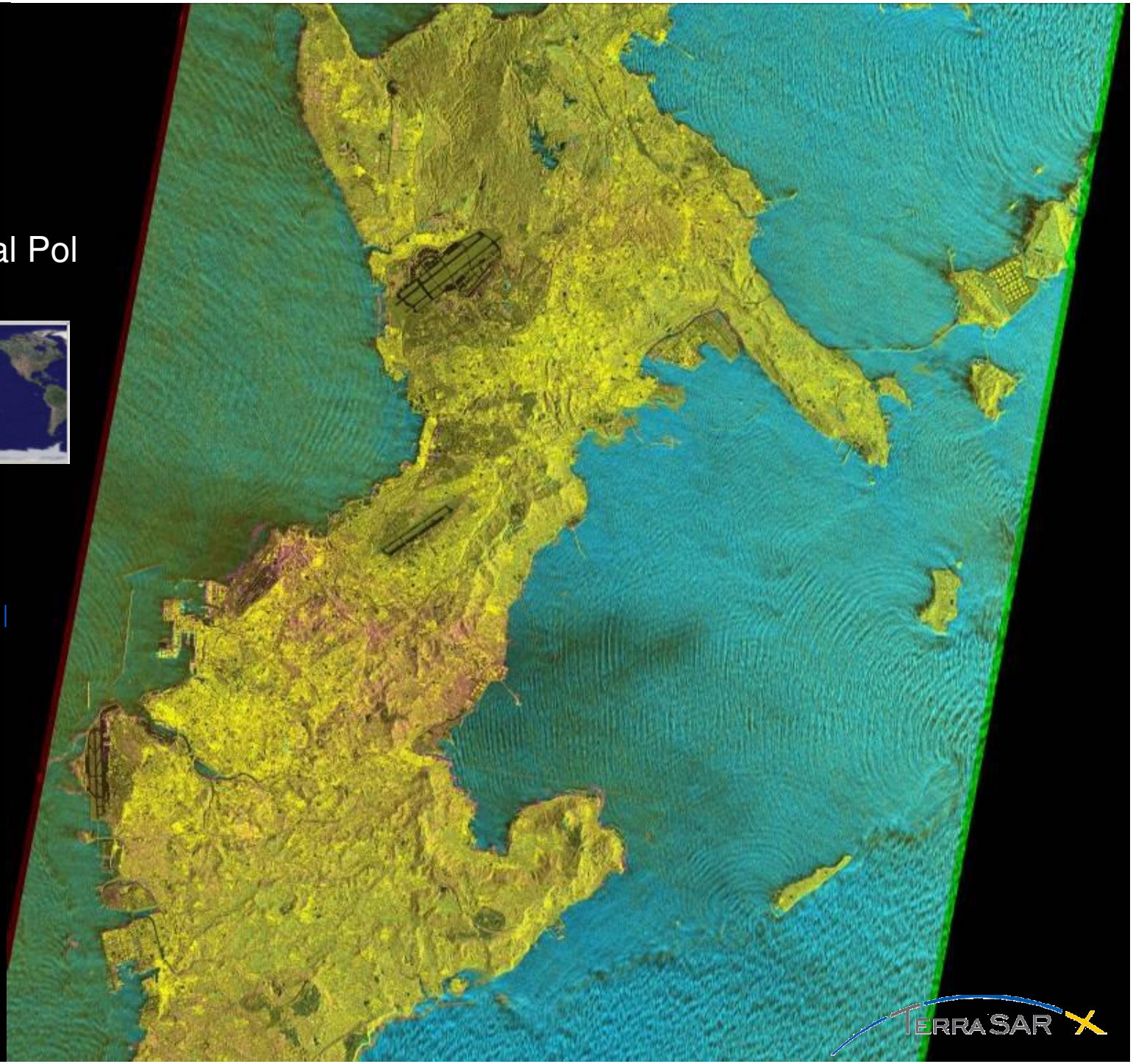

Rg
Az
Multitemporal
High Resolution Spot Light Image (300 MHz):
Australia, Sydney Harbor Bridge
1. Layer: Dec 12, 2007
2. Layer: Jan 1, 2008
3. Layer: Jan 12, 2008


Multi Temporal Image
Frankfurt Airport
TerraSAR X


Multitemporal
High Resolution Spot Light Image
Mato Grosso Brasil
1. Layer: Oct 7, 2007
2. Layer: Oct 18, 2007
3. Layer: Oct 29, 2007

Okinawa
Stripmap Dual Pol
12.07.2007

1. Layer: HH
2. Layer: VV
3. Layer: | HH – VV |

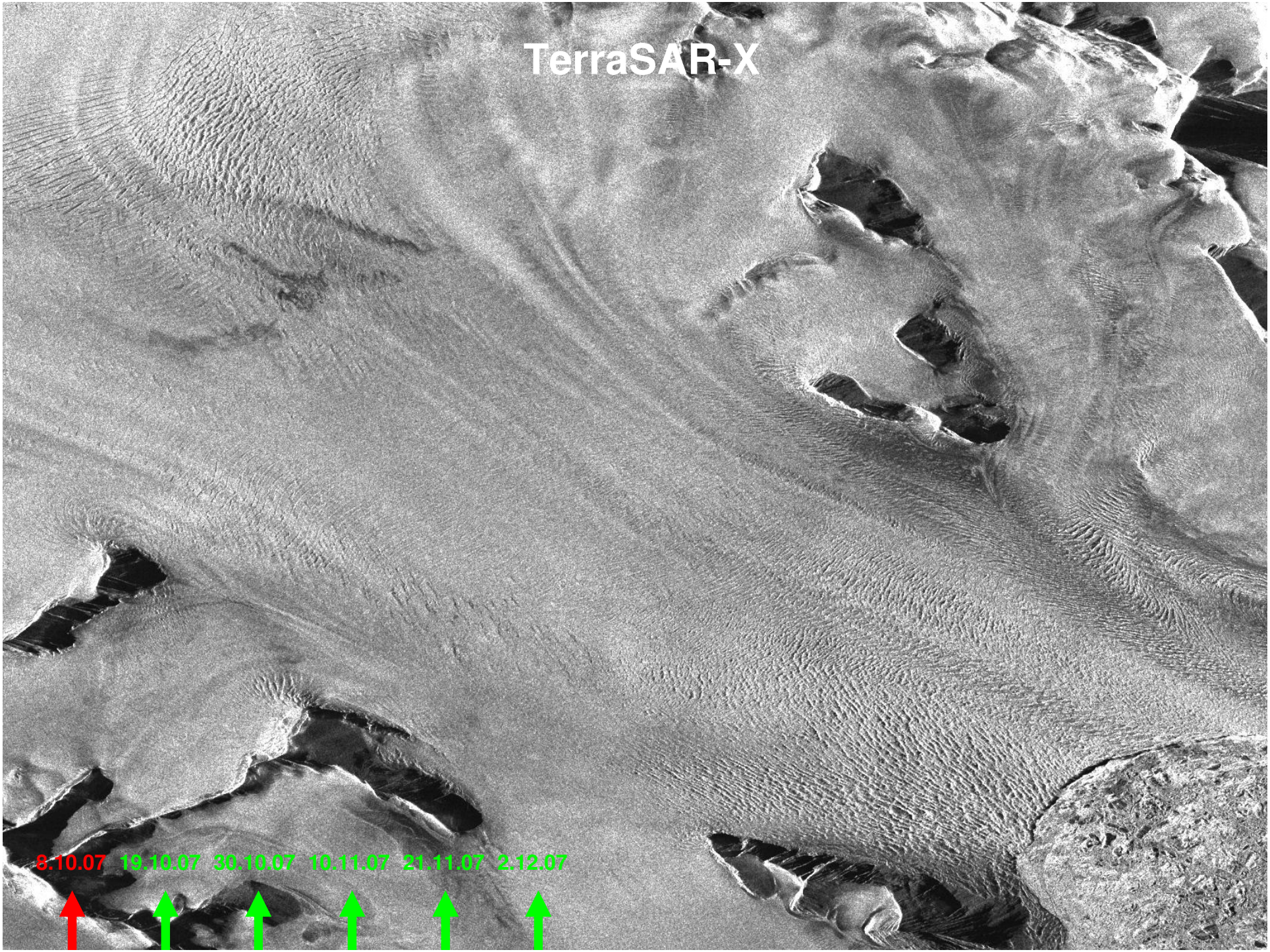


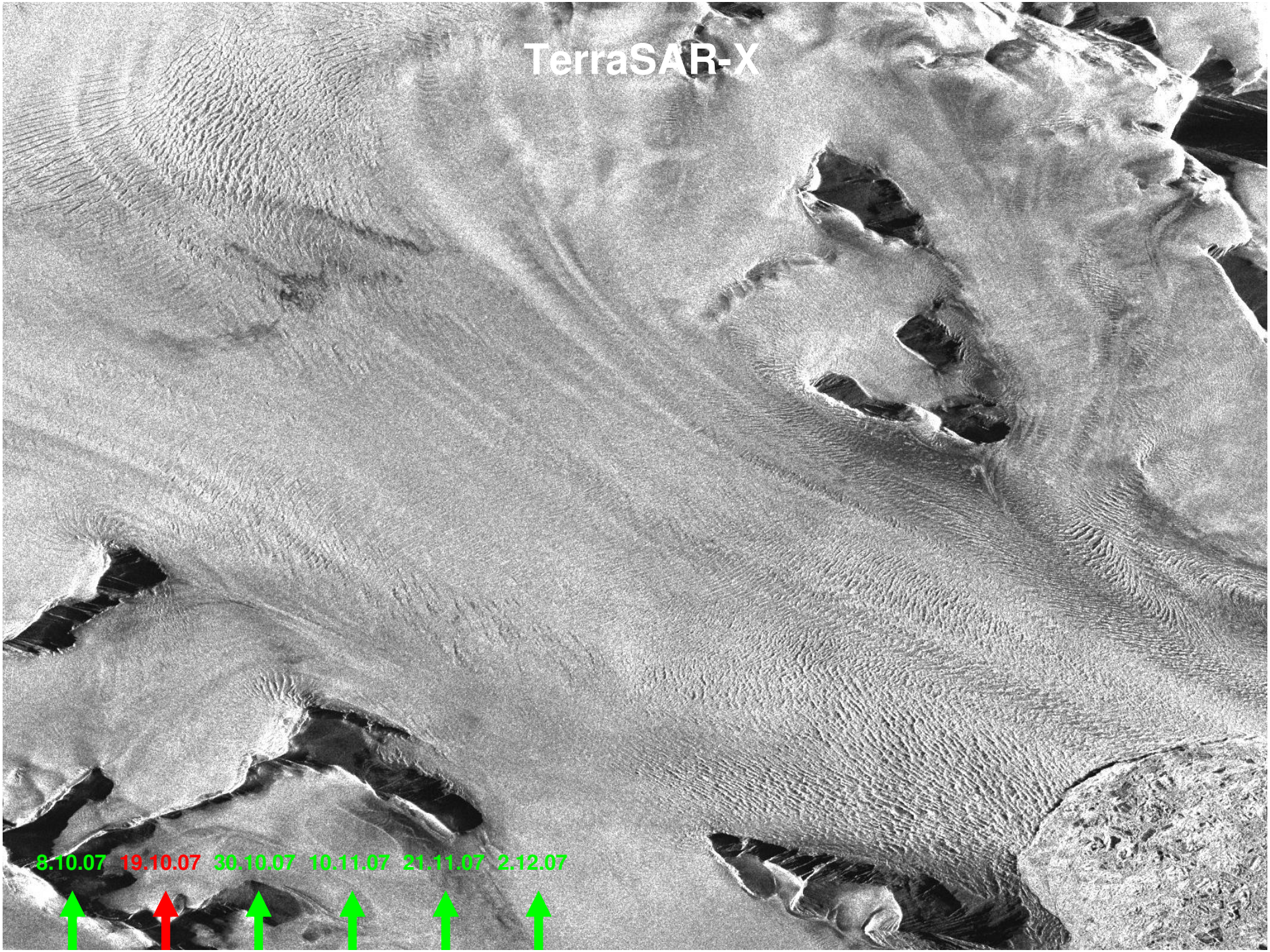
ScanSAR

Japan

DLR

TerraSAR-X


TerraSAR-X
8.10.07
19.10.07
30.10.07
10.11.07
21.11.07
2.12.07


TerraSAR-X
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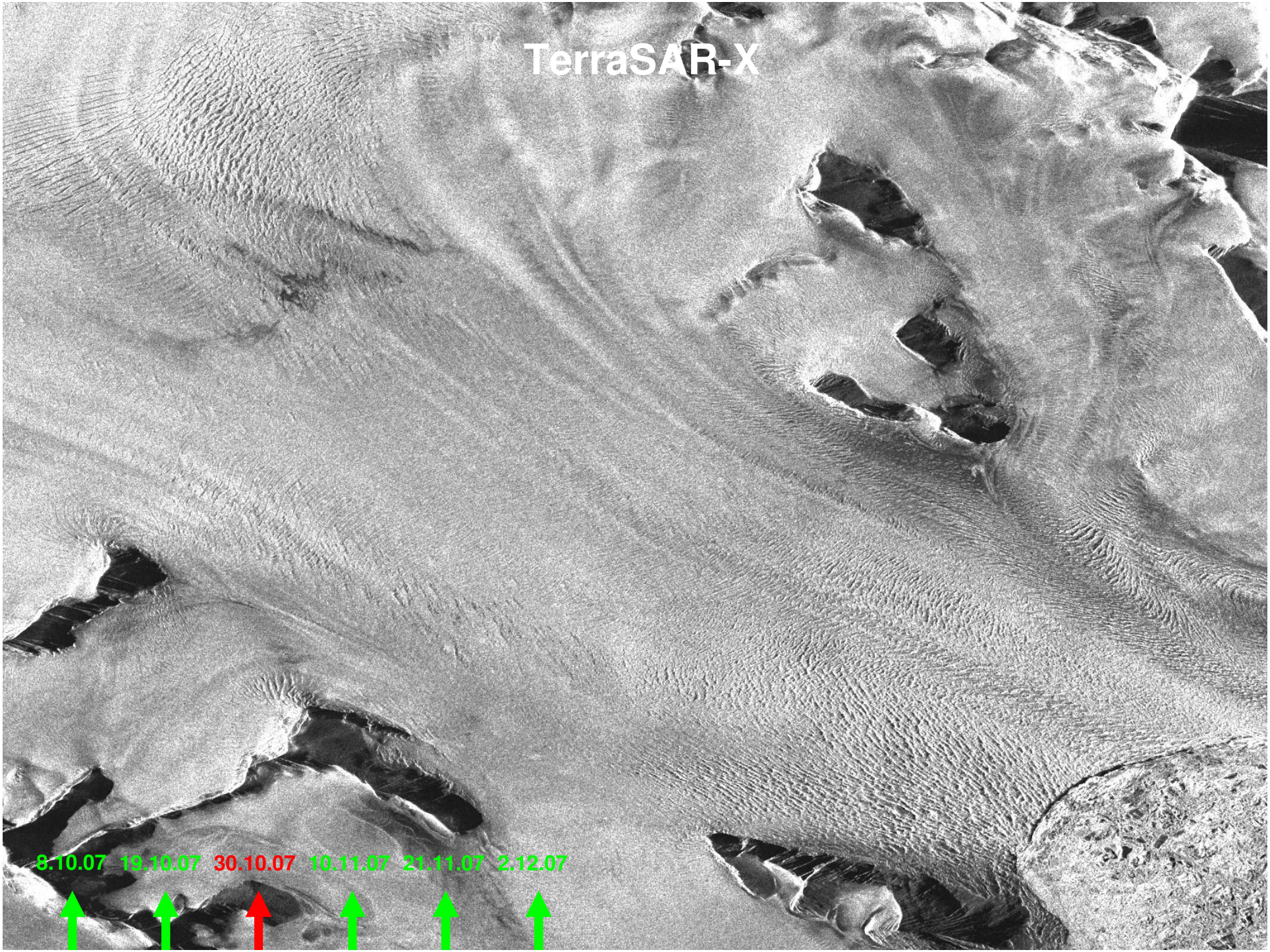
TerraSAR-X
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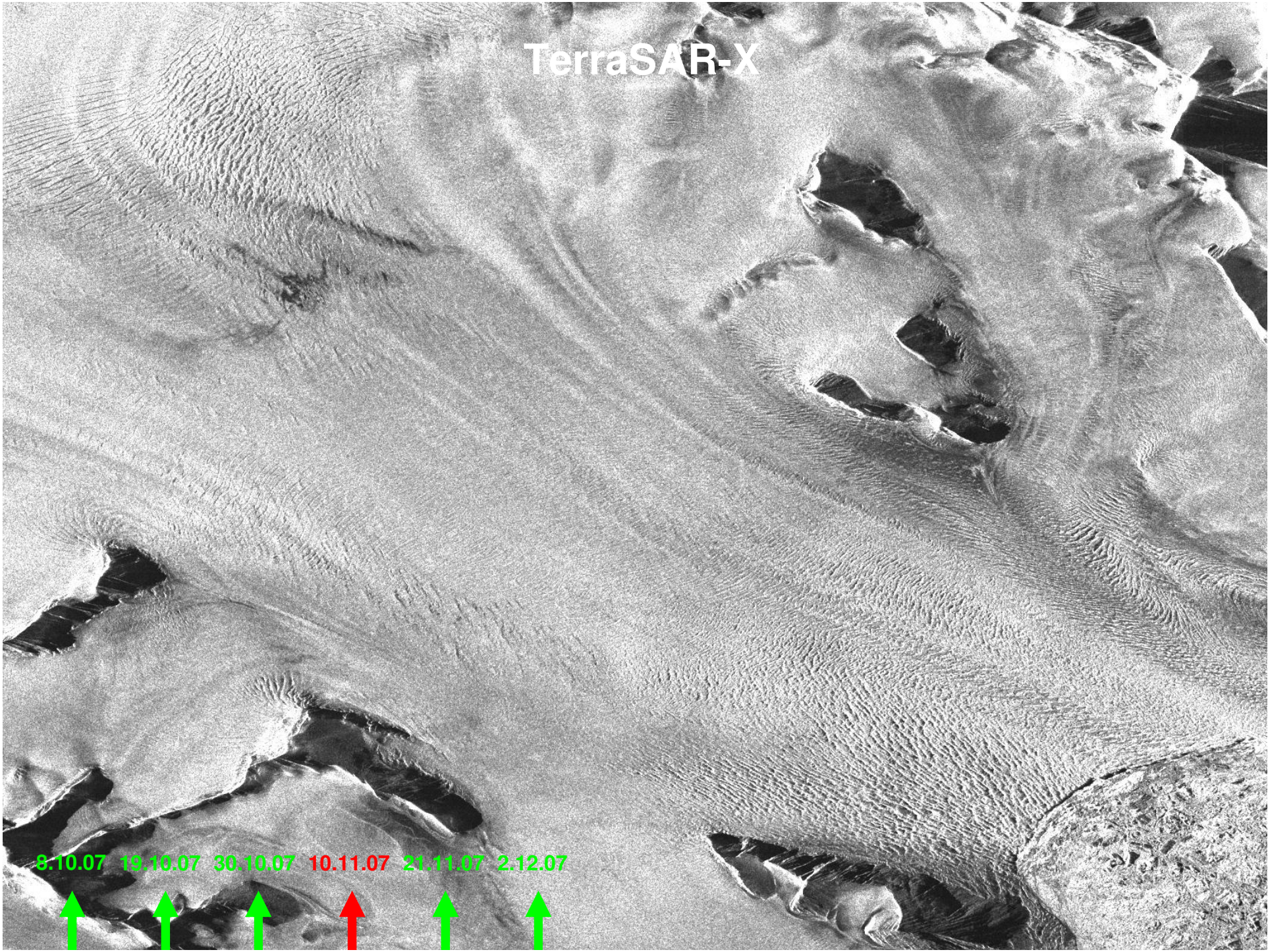
10.11.07
21.11.07
2.12.07


TerraSAR-X
8.10.07
19.10.07
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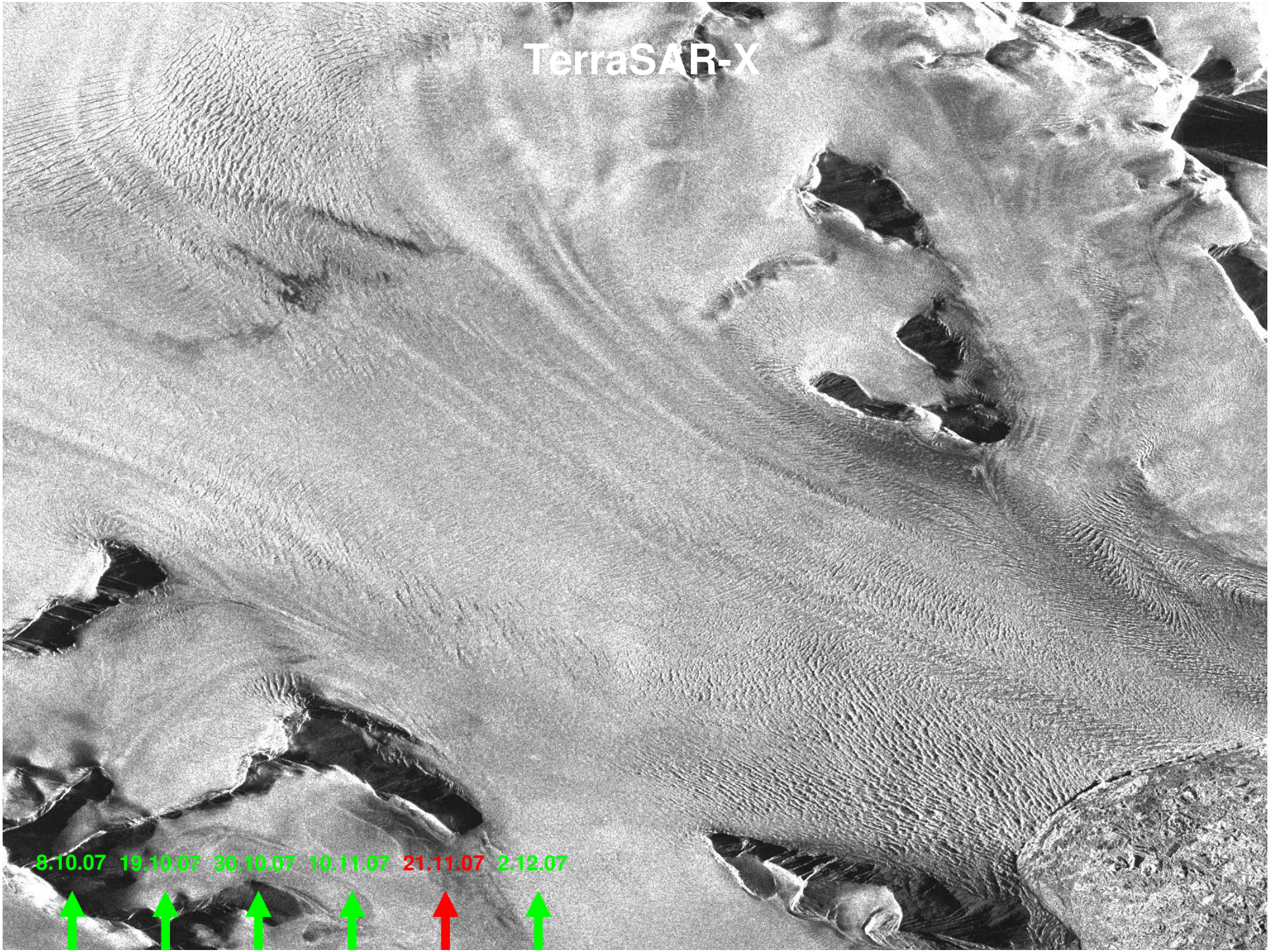
10.11.07
21.11.07
2.12.07


TerraSAR-X
8.10.07
19.10.07
30.10.07
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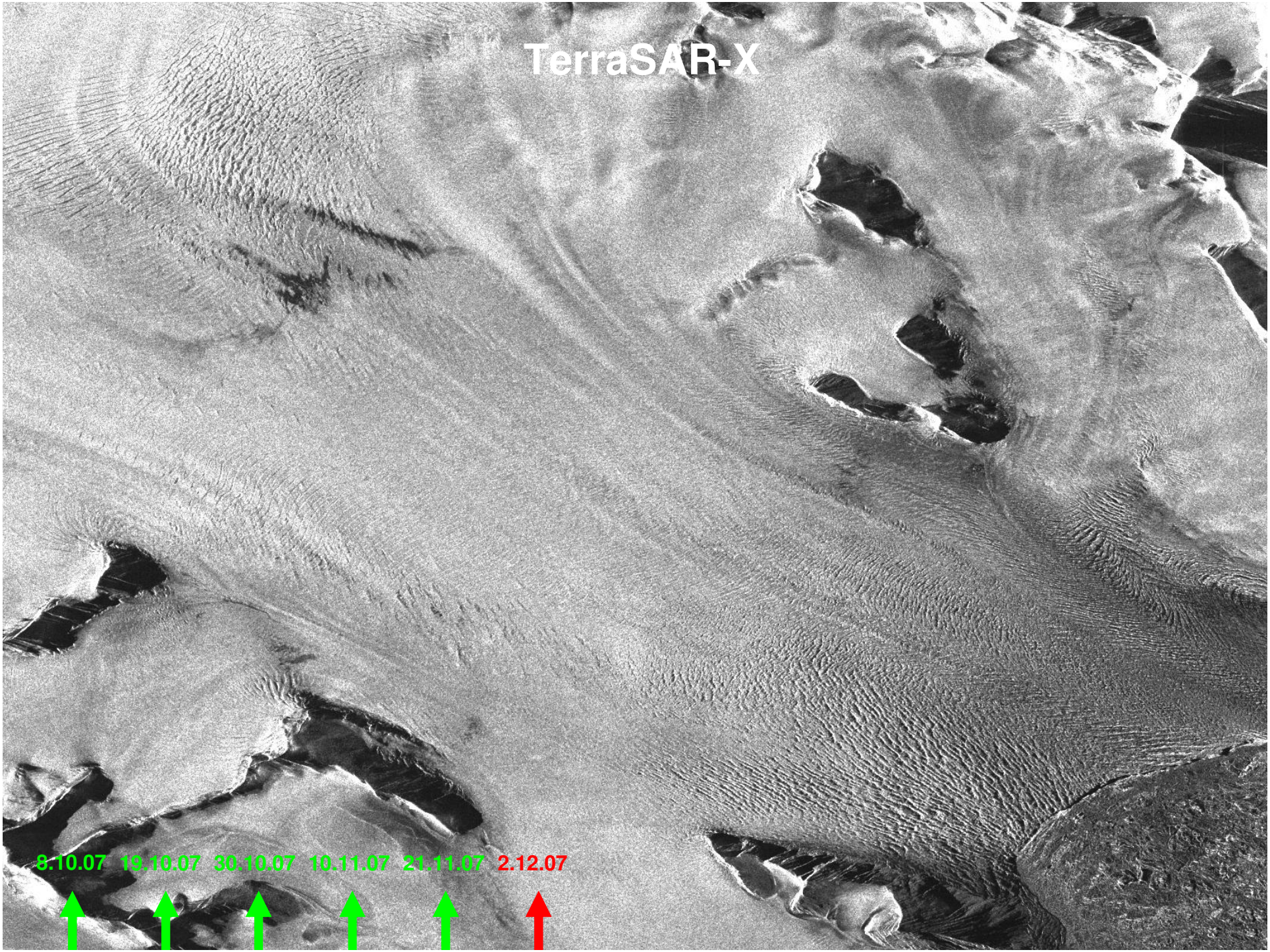
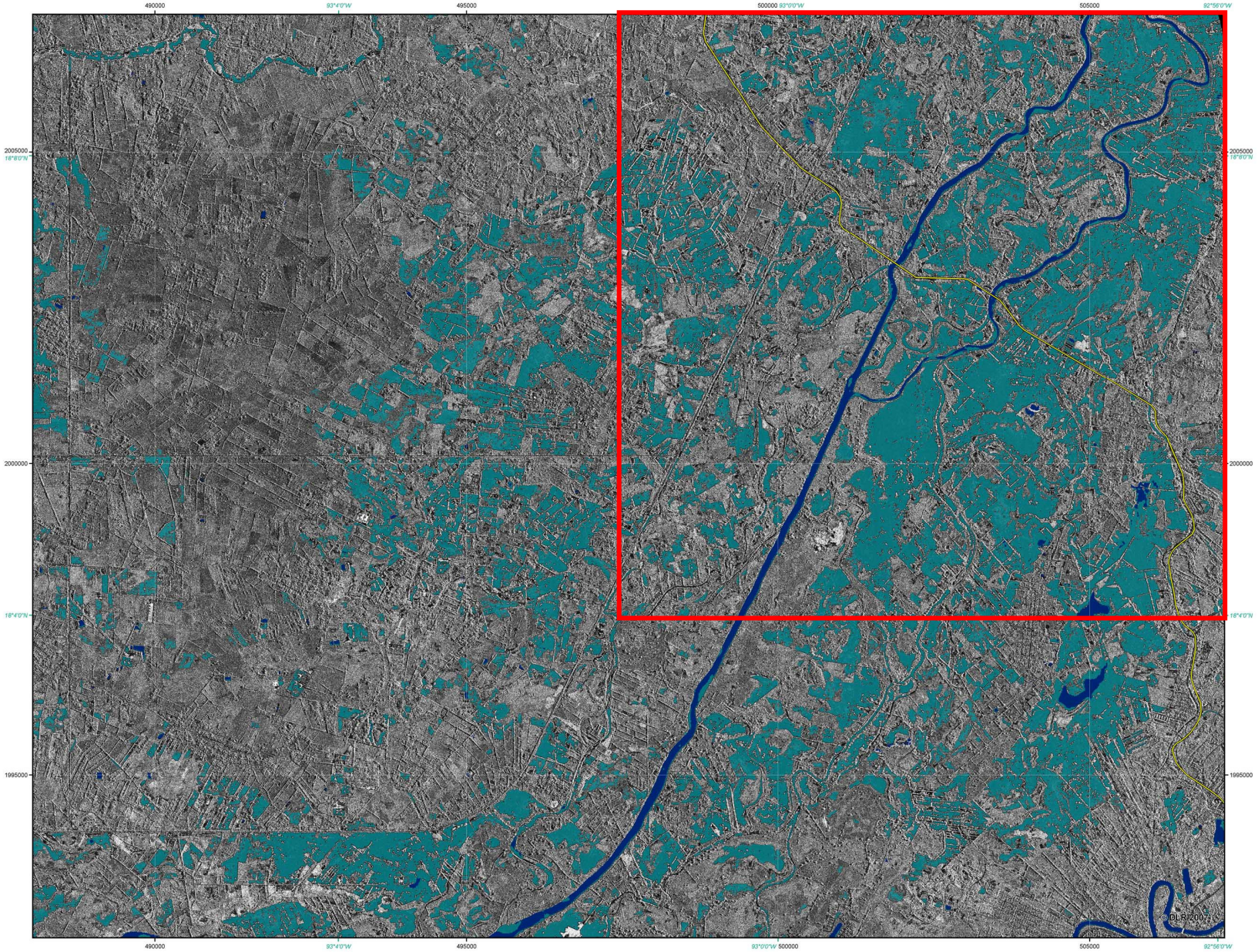
21.11.07
2.12.07


TerraSAR-X
8.10.07
19.10.07
30.10.07
10.11.07
21.11.07
2.12.07

MEXICO - Tabasco - Flood Situation around Villahermosa - November 6, 2007 - Map 1 (North)

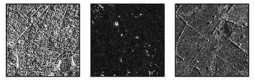
1:30.000



Center for Satellite Based Crisis Information
– Emergency Mapping & Disaster Monitoring –
a service of DFD

German Remote Sensing Data Center
German Aerospace Center

Legend



Settlement | Vegetation/Swamp | Agriculture

Flood situation (Nov 6, 2007):
- Water surface
- Normal water level

Infrastructure:
- Major roads

Interpretation

A week of heavy rains caused rivers to overflow, submerging major parts of the state of Tabasco and the neighbouring state of Chiapas. The city of Villahermosa, with a population of more than half a million people, has been most severly hit by the flood event.

This map shows the extent of the flood situation in the region of Villahermosa, Tabasco, Mexico as mapped by the German TerraSAR-X radar satellite on November 6, 2007. TerraSAR-X is jointly operated by the German Aerospace Center (DLR) and Infoterra GmbH, Germany. Please note that the flood extent in urban areas may not be detected properly due to radar geometry.

The map was produced in order to support the Mexican civil protection agency (CENAPRED).

Scale

0 490 980 1,470 1,960 m

Scale: 1:30.000 for DinA1 printing

N

Reference coordinate system:		Geographic coord. info:
Projection:	UTM Zone 15 N	Geographic (DMS)
Spheroid:	WGS 84	WGS 84
Datum:	WGS 84	WGS 84

Data Sources

SPOT5 © CNES 2007
TerraSAR-X © German Aerospace Center (DLR) 2007
Commercial exploitation rights:
infoterra

Processing/Analysis

Image processing and map creation by DLR:

- Derivation of normal water areas from SPOT
- Derivation of flooded water areas from TerraSAR-X

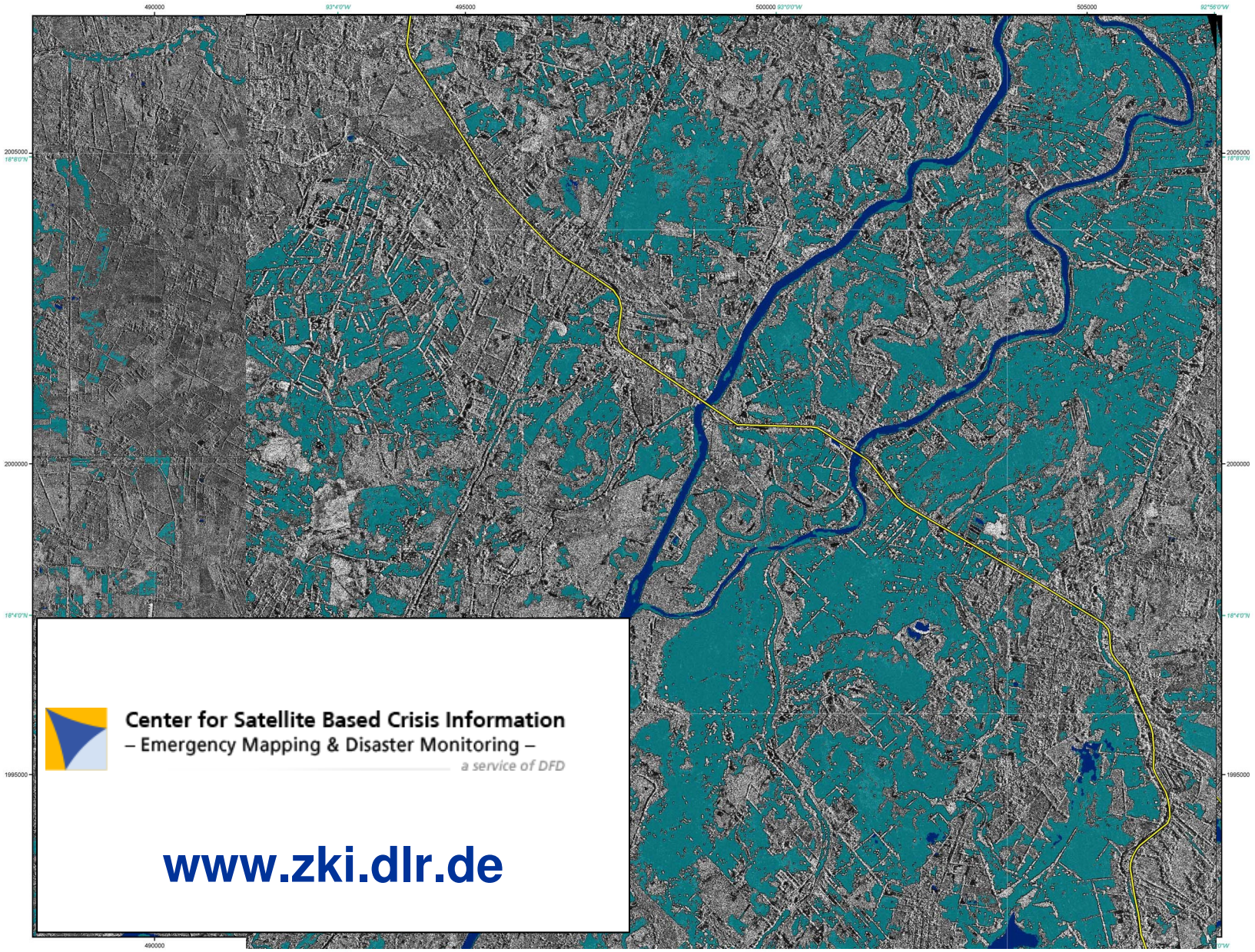
Map created November 8, 2007 by zki@dlr.de

For more information visit: http://www.zki.dlr.de

TerraSAR-X

MEXICO - Tabasco - Flood Situation around Villahermosa - November 6, 2007 - Map 1 (North)

1:30.000

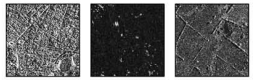


Center for Satellite Based Crisis Information
– Emergency Mapping & Disaster Monitoring –
a service of DFD

German Remote Sensing Data Center
German Aerospace Center

DLR

Legend



Settlement | Vegetation/Swamp | Agriculture

Flood situation (Nov 6, 2007):
- Water surface
- Normal water level

Infrastructure:
- Major roads

Interpretation

A week of heavy rains caused rivers to overflow, submerging major parts of the state of Tabasco and the neighbouring state of Chiapas. The city of Villahermosa, with a population of more than half a million people, has been most severly hit by the flood event.

This map shows the extent of the flood situation in the region of Villahermosa, Tabasco, Mexico as mapped by the German TerraSAR-X radar satellite on November 6, 2007. TerraSAR-X is jointly operated by the German Aerospace Center (DLR) and Infoterra GmbH, Germany. Please note that the flood extent in urban areas may not be detected properly due to radar geometry.

The map was produced in order to support the Mexican civil protection agency (CENAPRED).

Scale

0 490 980 1,470 1,960 m

N

Scale: 1:30.000 for DinA1 printing

Reference coordinate system:		*Geographic coord. info:*
Projection:	UTM Zone 15 N	*Geographic (DMS)*
Spheroid:	WGS 84	*WGS 84*
Datum:	WGS 84	*WGS 84*

Data Sources

SPOT5 © CNES 2007
TerraSAR-X © German Aerospace Center (DLR) 2007
Commercial exploitation rights:
infoterra

Processing/Analysis

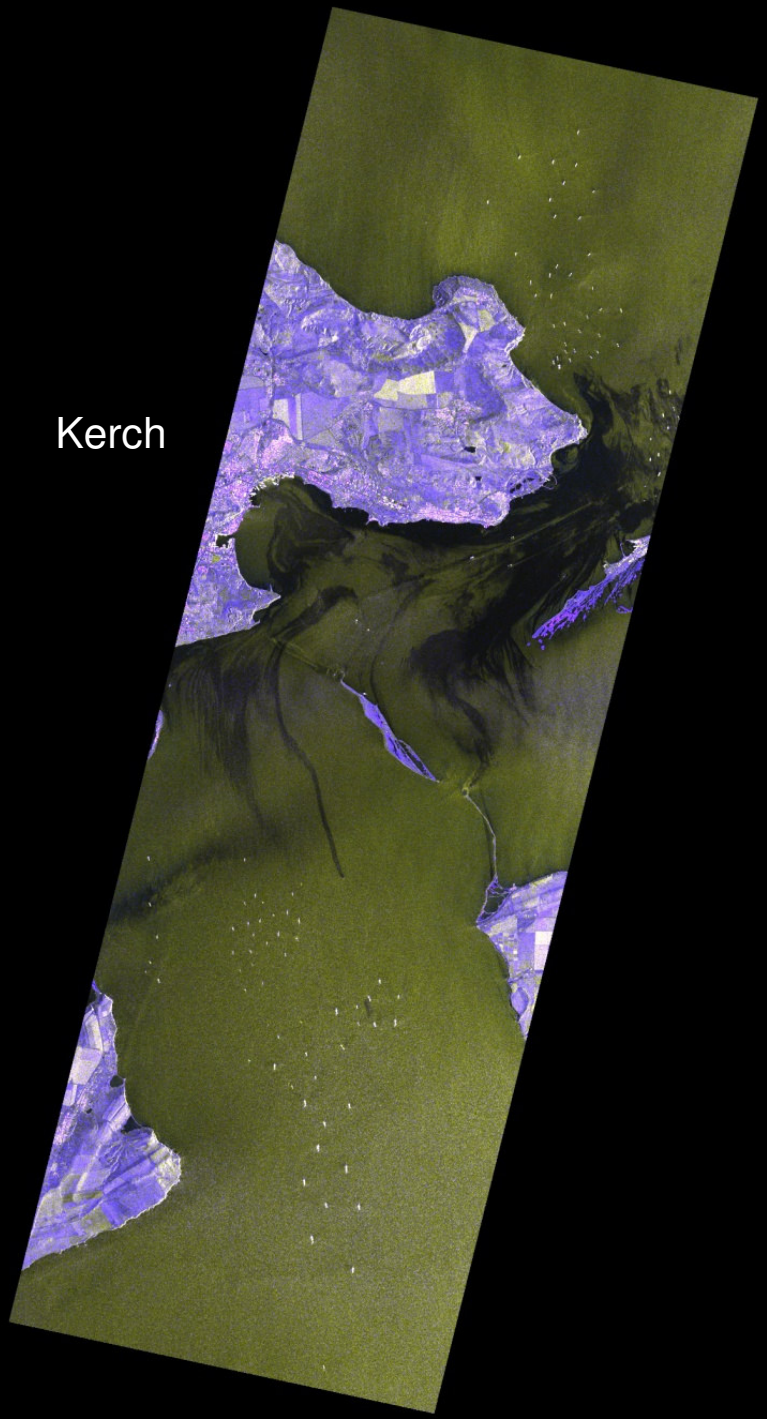
Image processing and map creation by DLR:

- Derivation of normal water areas from SPOT
- Derivation of flooded water areas from TerraSAR-X

Map created November 8, 2007 by zki@dlr.de

For more information visit: http://www.zki.dlr.de

TERRASAR-X



Oil Spill Black Sea

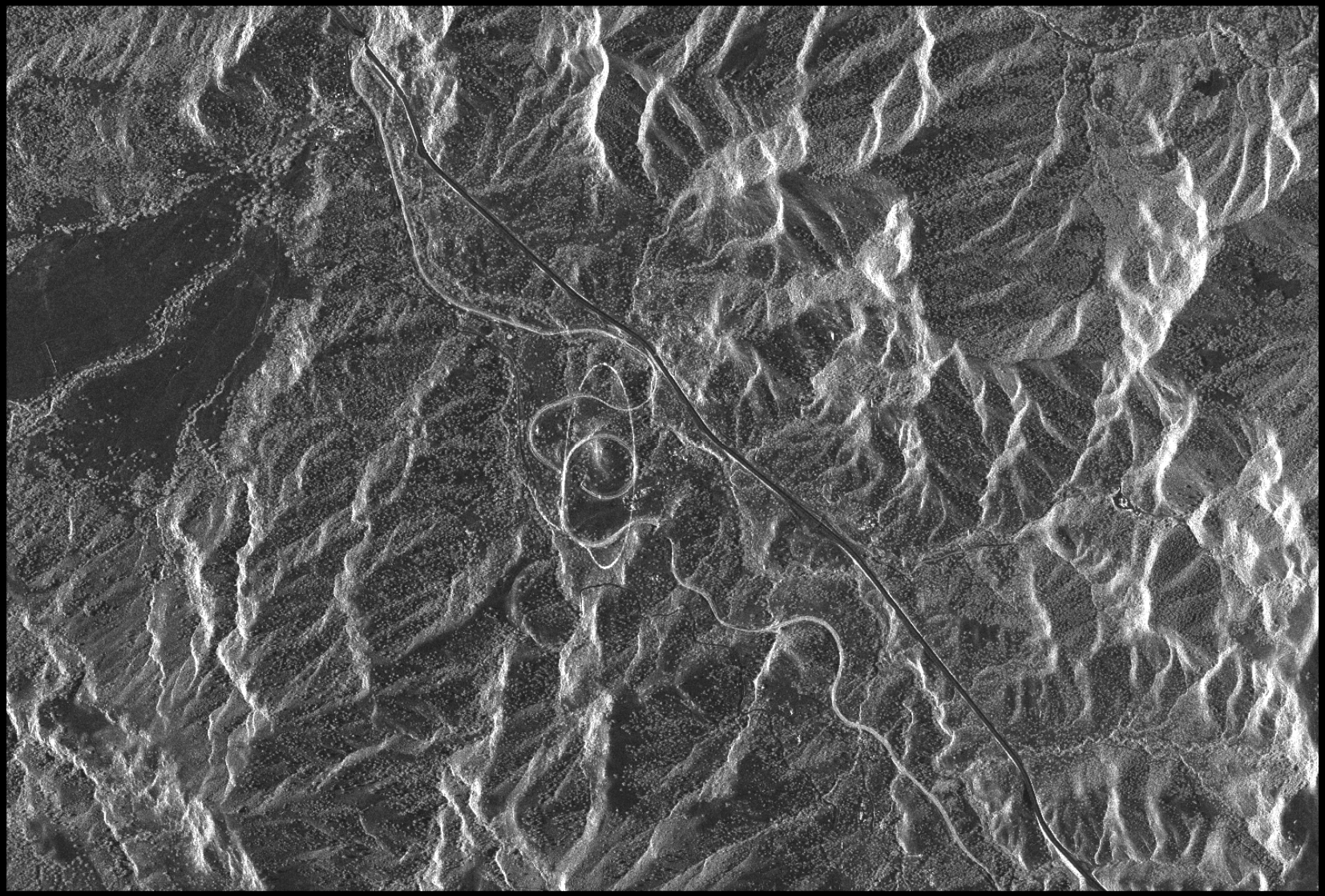
TerraSAR-X Stripmap

16.11.2007, 3:52 UTC.

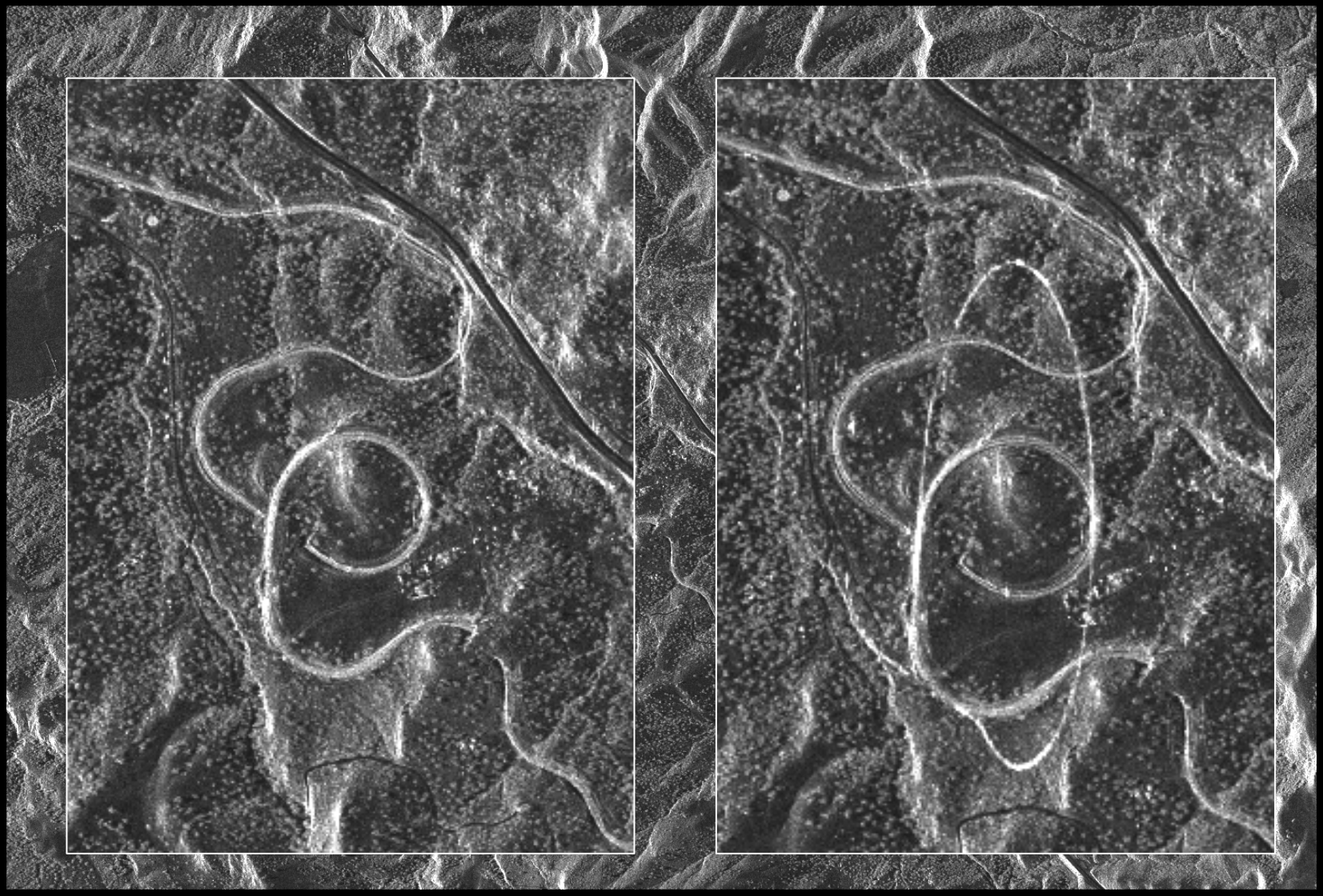
Dual polarization

1. Layer: HH
2. Layer: VV
3. Layer: | HH – VV |

One Thing You Have Most Probably Never Seen Before in a SAR Image

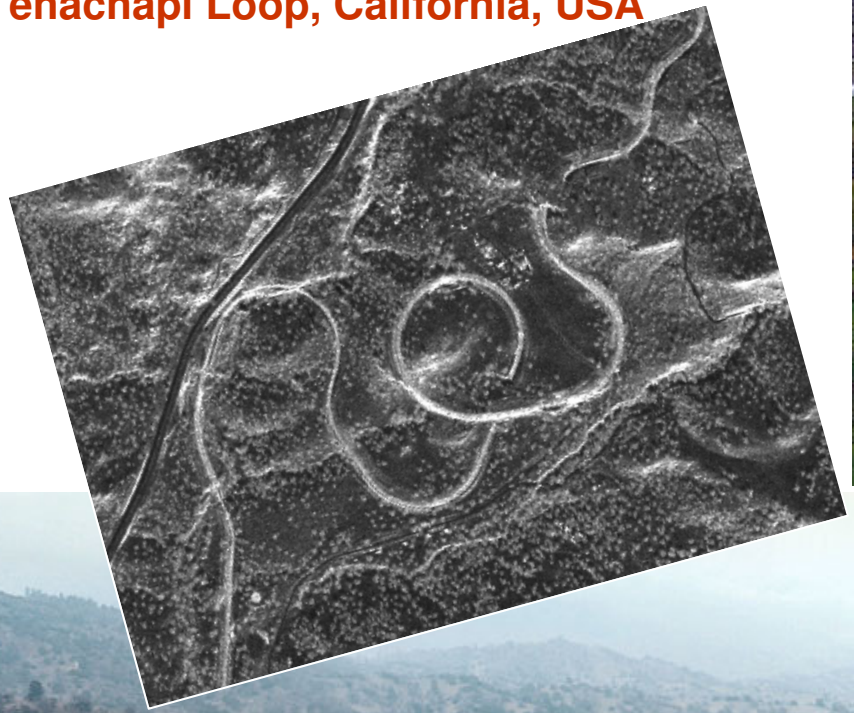


One Thing You Have Most Probably Never Seen Before in a SAR Image

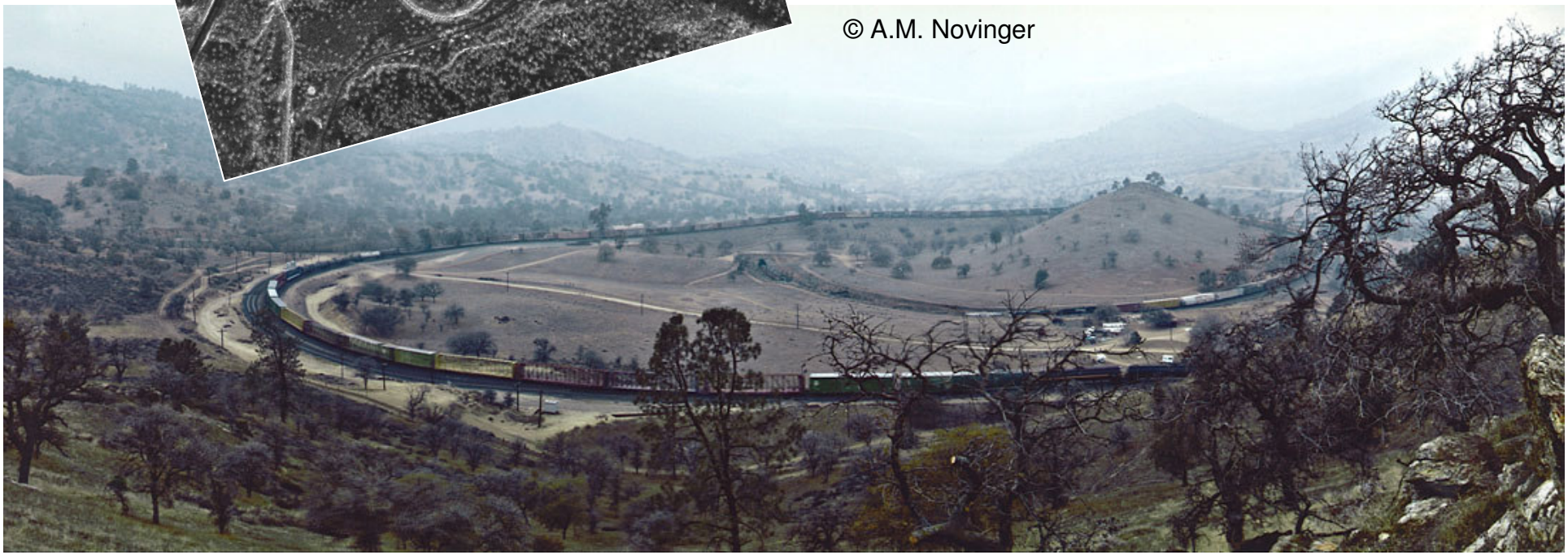


TerraSAR-X

Tehachapi Loop, California, USA



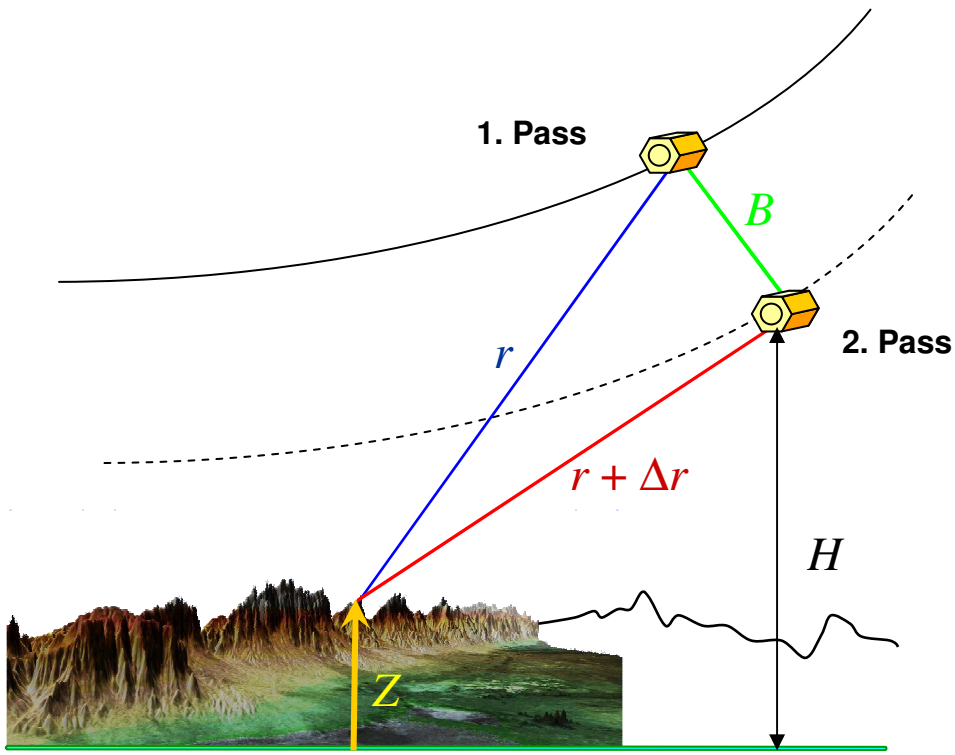
© A.M. Novinger

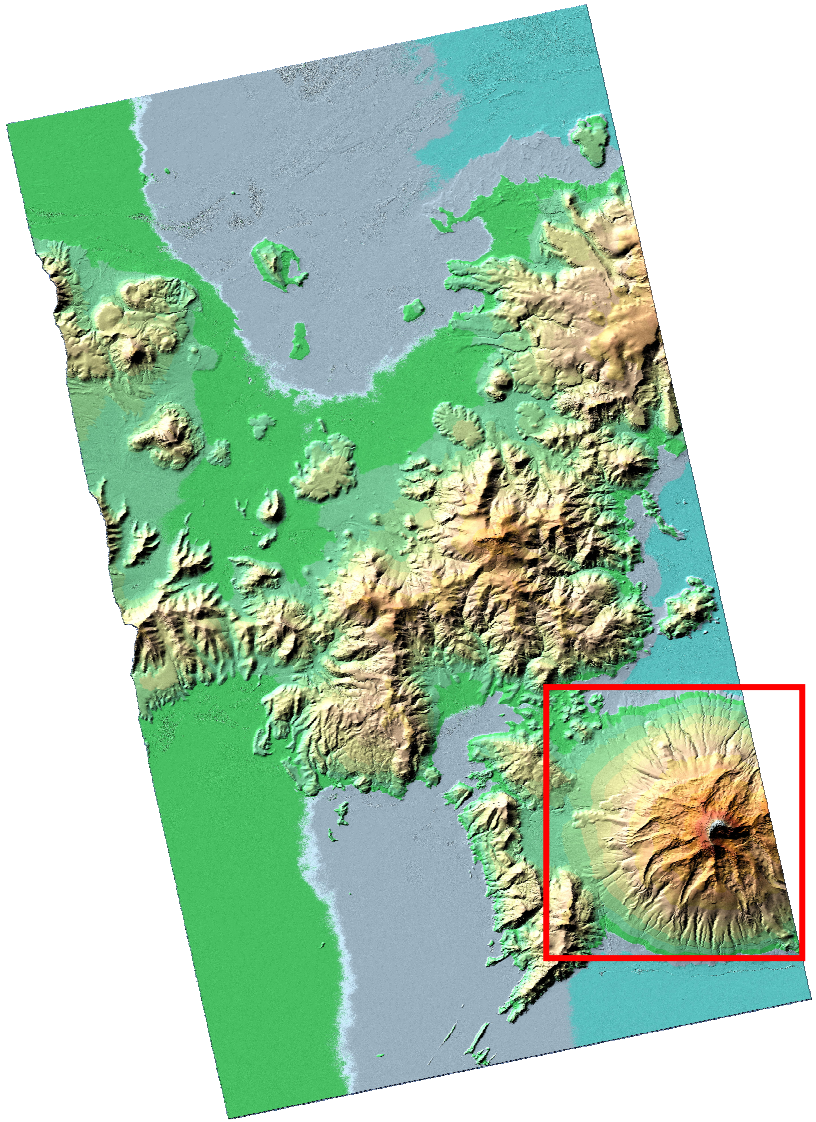


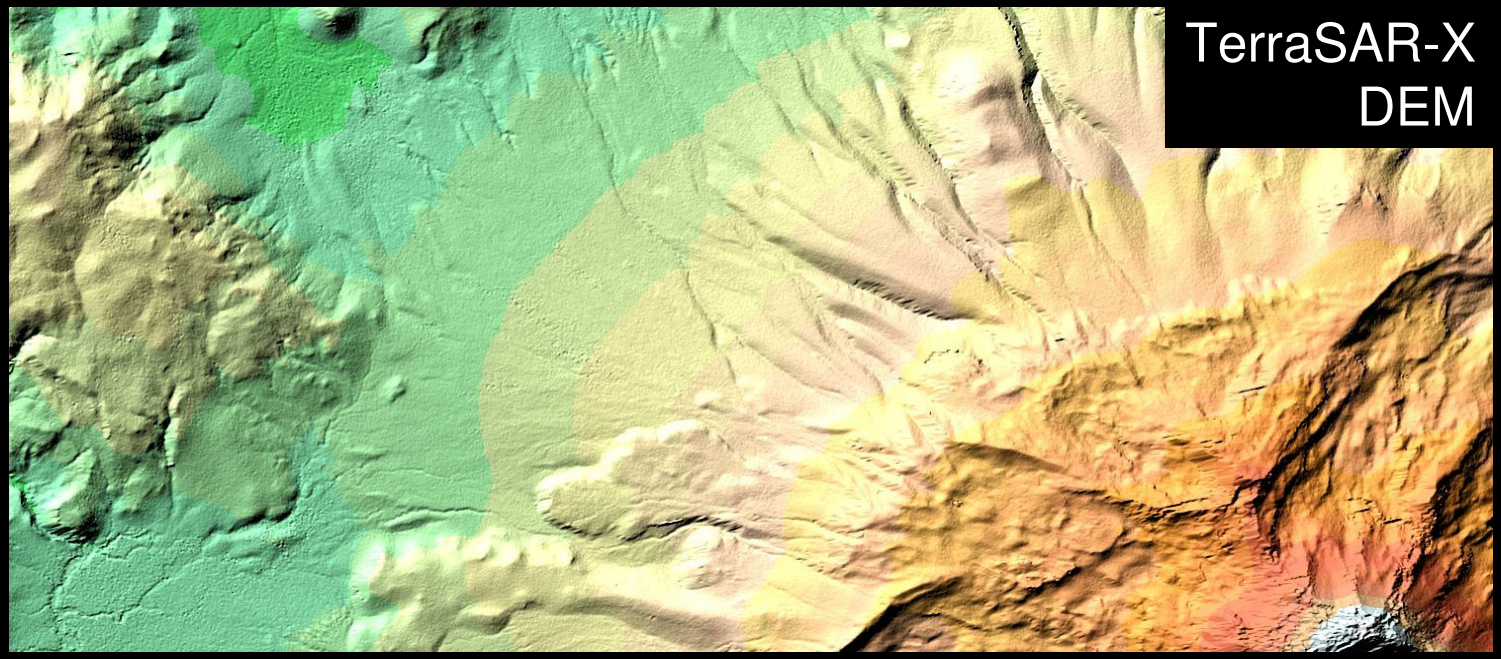
© Wikipedia

Digital Elevation Model: Salar Uyuni & Mt. Tunupa

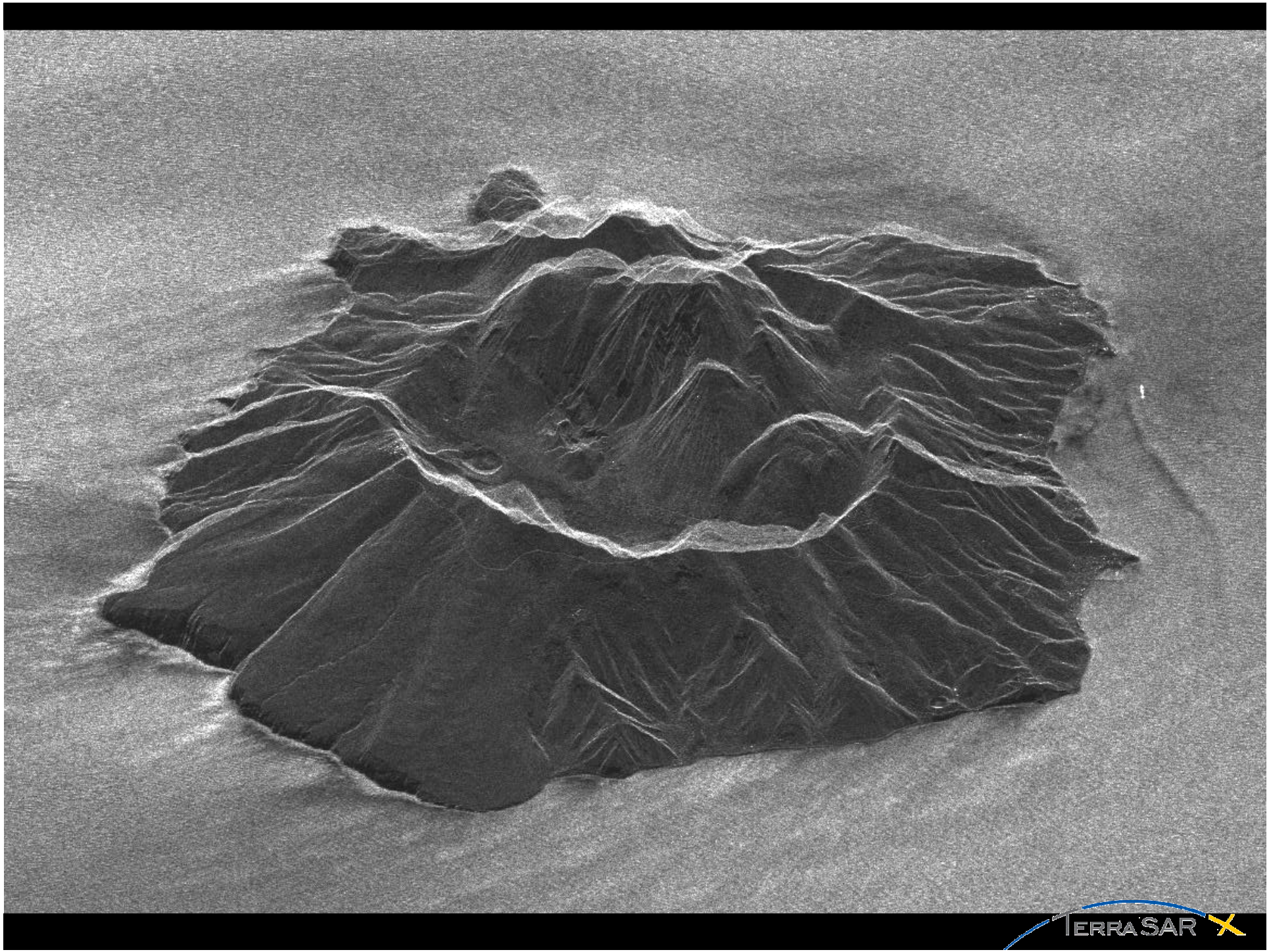
Repeat Pass Interferometry

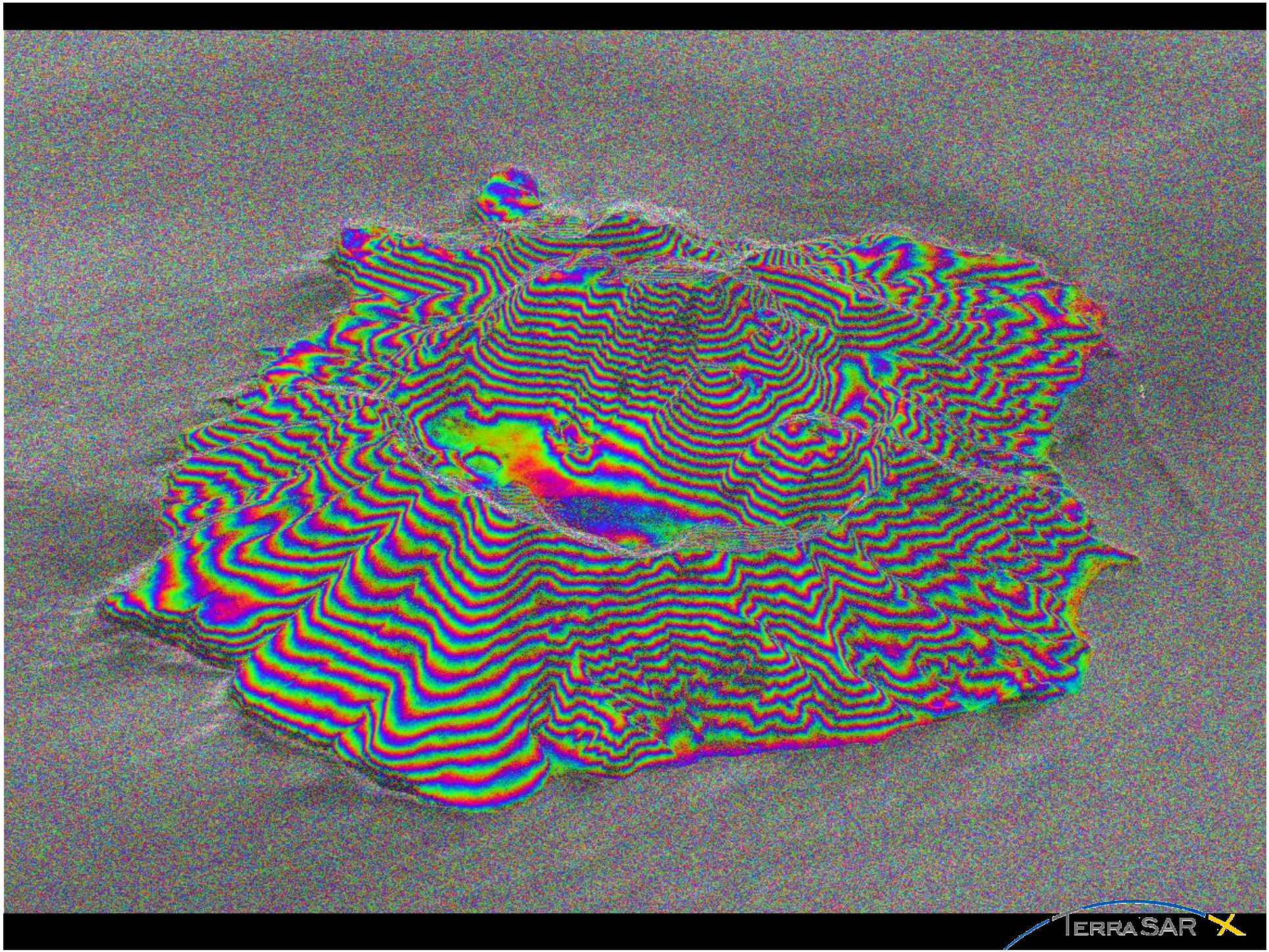





TerraSAR-X
DEM

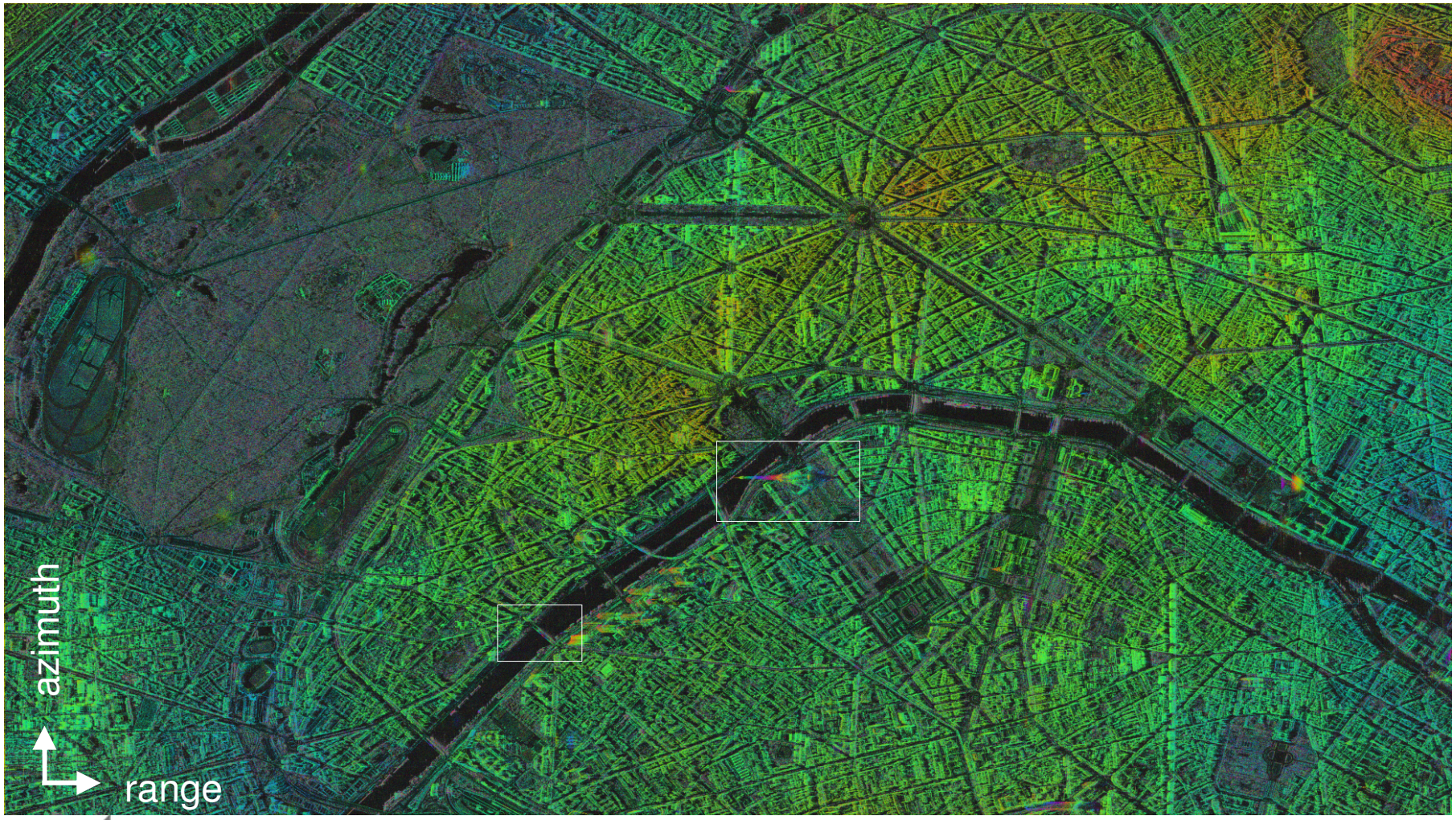
SRTM
DEM


TERRASAR X


TERRASAR X

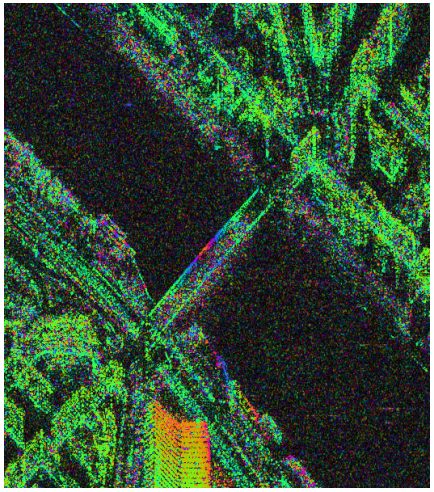
TerraSAR-X Interferogram of Paris

(HS 300 MHz 16.1.-27.1.2008)

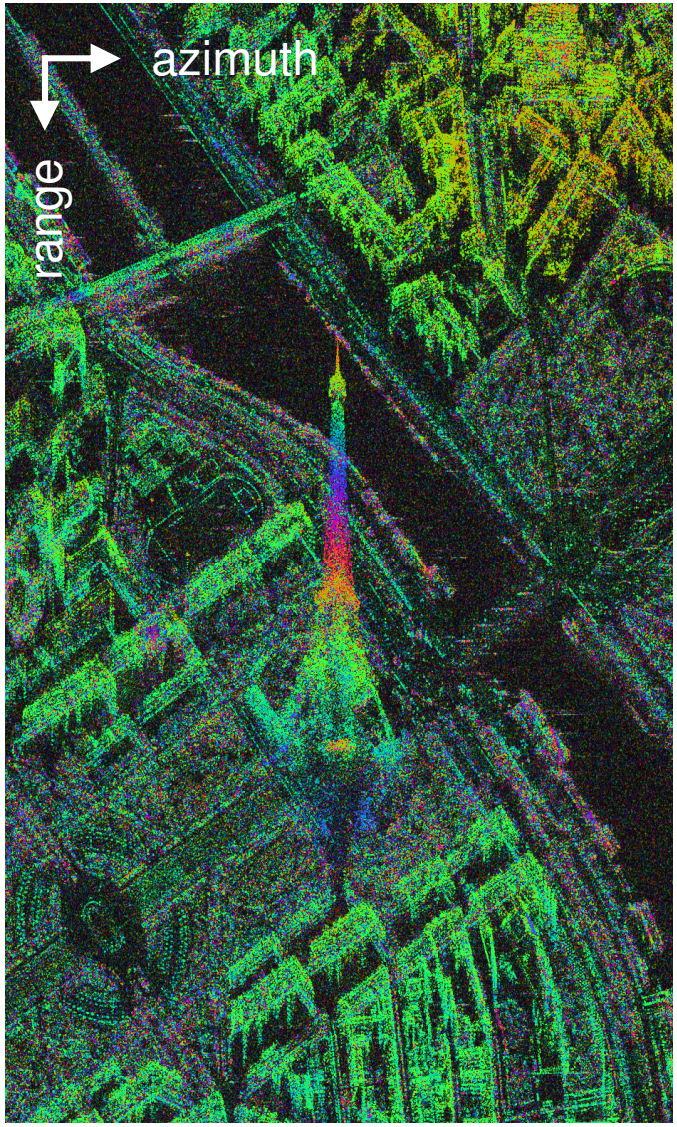


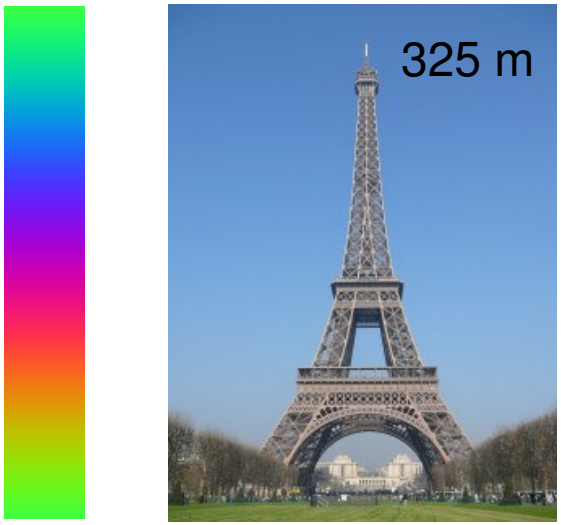
Tour Eiffel and Pont Mirabeau

Topographic height and millimeter LOS displacements (~7 mm) measurable

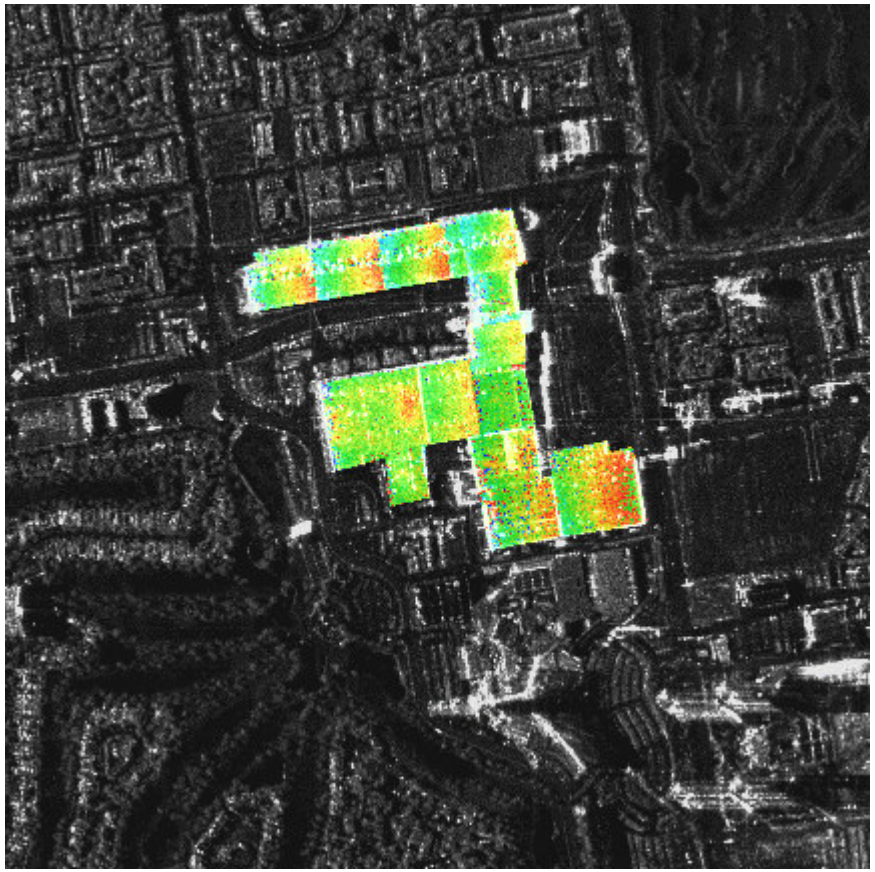


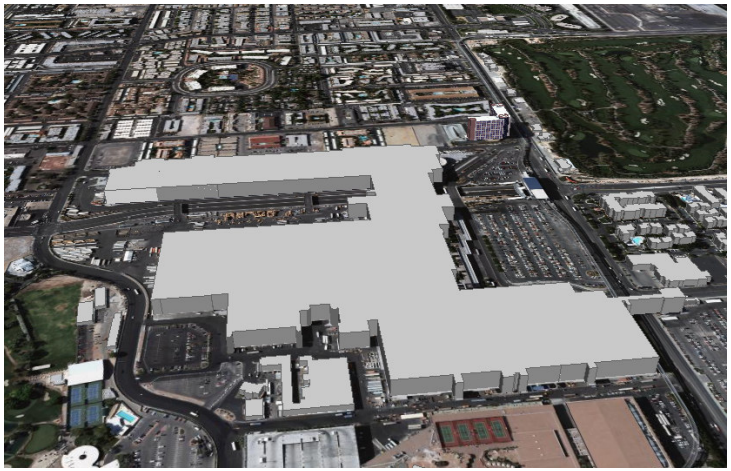
12 mm LOS displacement (270°)





TerraSAR-X Interferometry

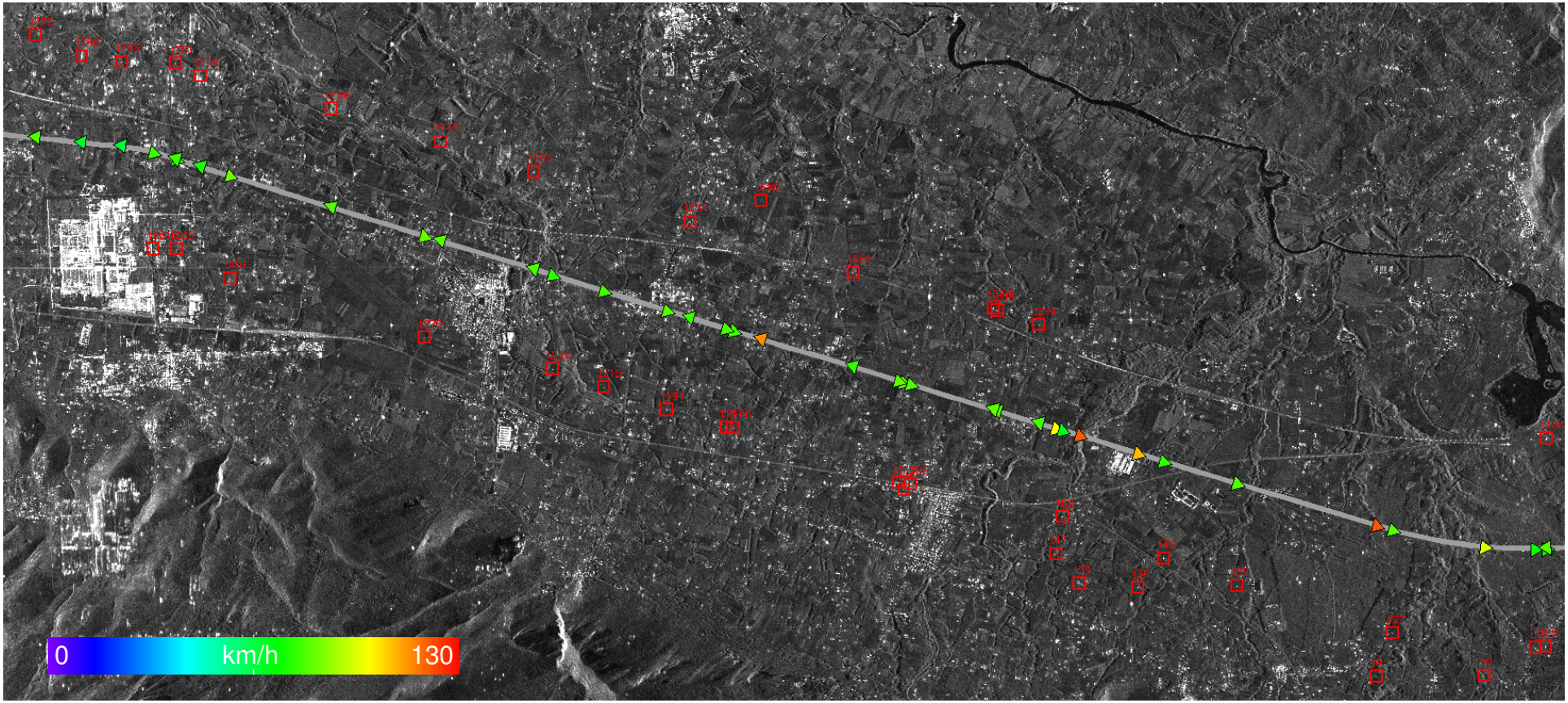




Las Vegas Convention Center

TerraSAR-X Along Track Interferometry

Automatically Detected Vehicles



Ground range approx. 14 km →

Total number of detections: 38

Detected vehicles driving away from Radar (West): 23

Detected vehicles driving towards Radar (East): 15

Dual Receive Antenna Mode

Principle

- For transmit the full antenna is used
- For receive the antenna is ‚electrically' divided into two sections in azimuth direction ➔ two independent receive channels are available

New Experimental Modes

- **Along-Track Interferometry (ATI)**

  (Moving Target Indication, Widespread Traffic Control, Ocean Current Measurement)

- **Quad polarization**

  (Sea/Ice, Snow Cover, Urban Environment)

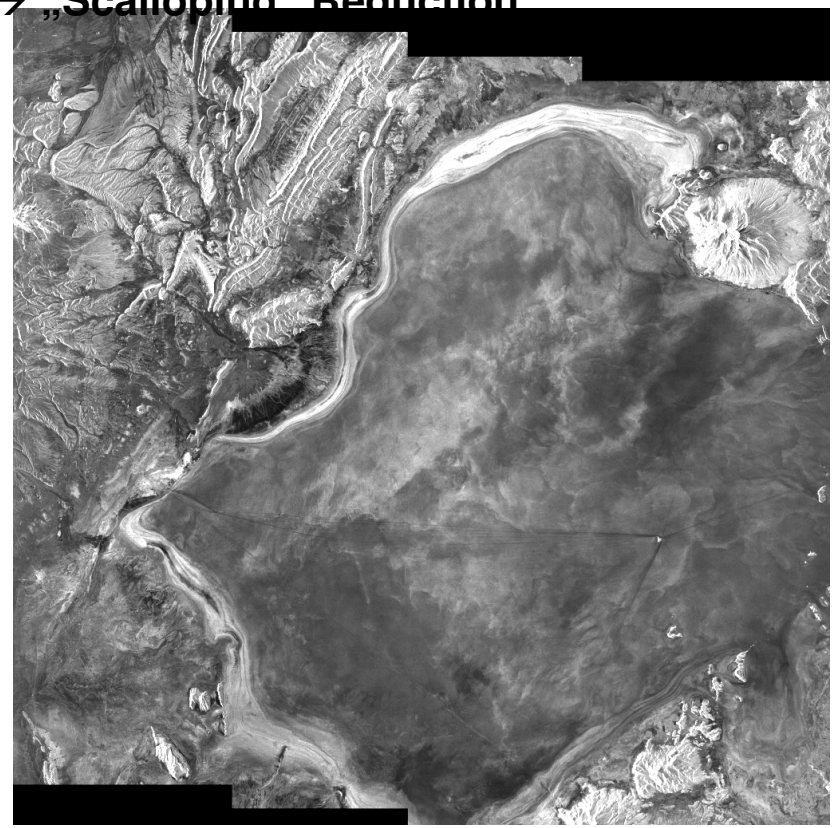
- **Enhanced azimuth resolution for stripmap mode**

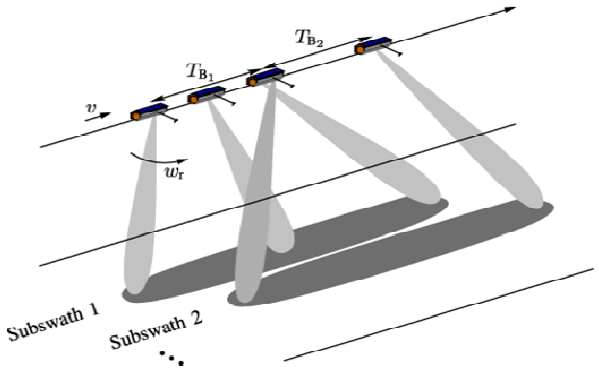
TOPSAR Acquisition Mode

TOPSAR is a modified ScanSAR mode:

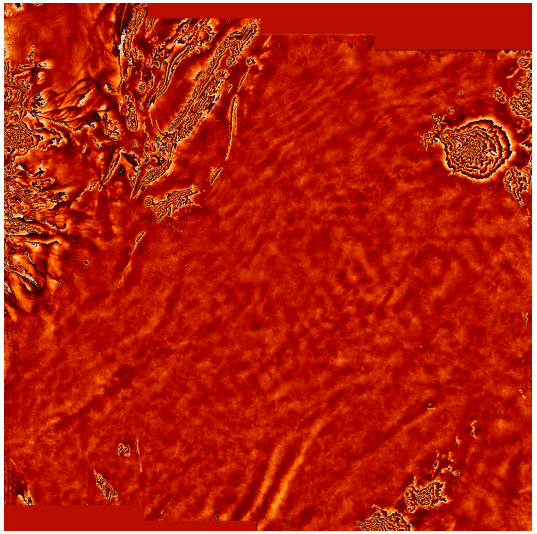
→ Ambiguity Reduction

→ „Scalloping“ Reduction

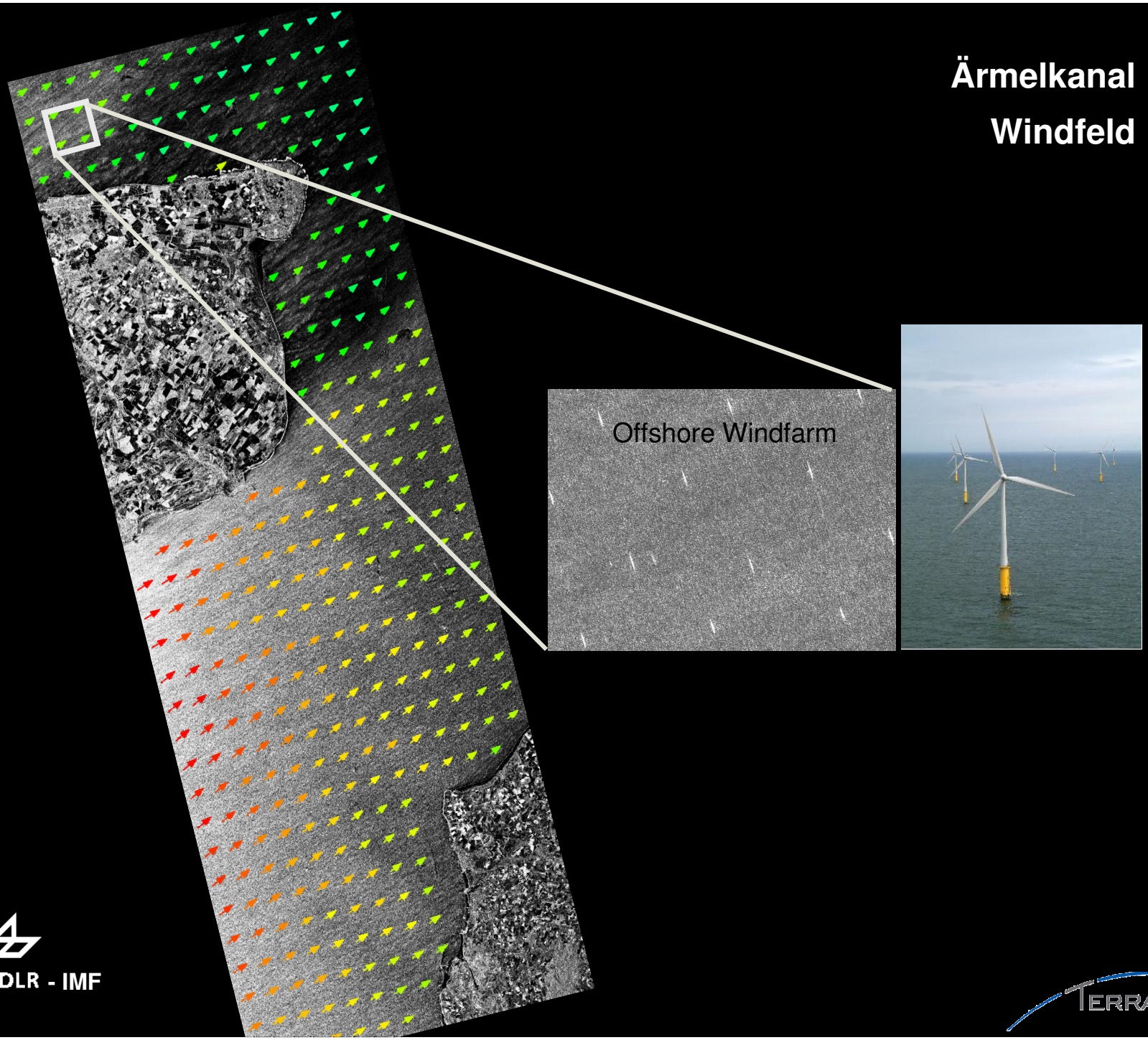




TOPSAR Interferogram



Ärmelkanal
Windfeld



DLR - IMF

TerraSAR X

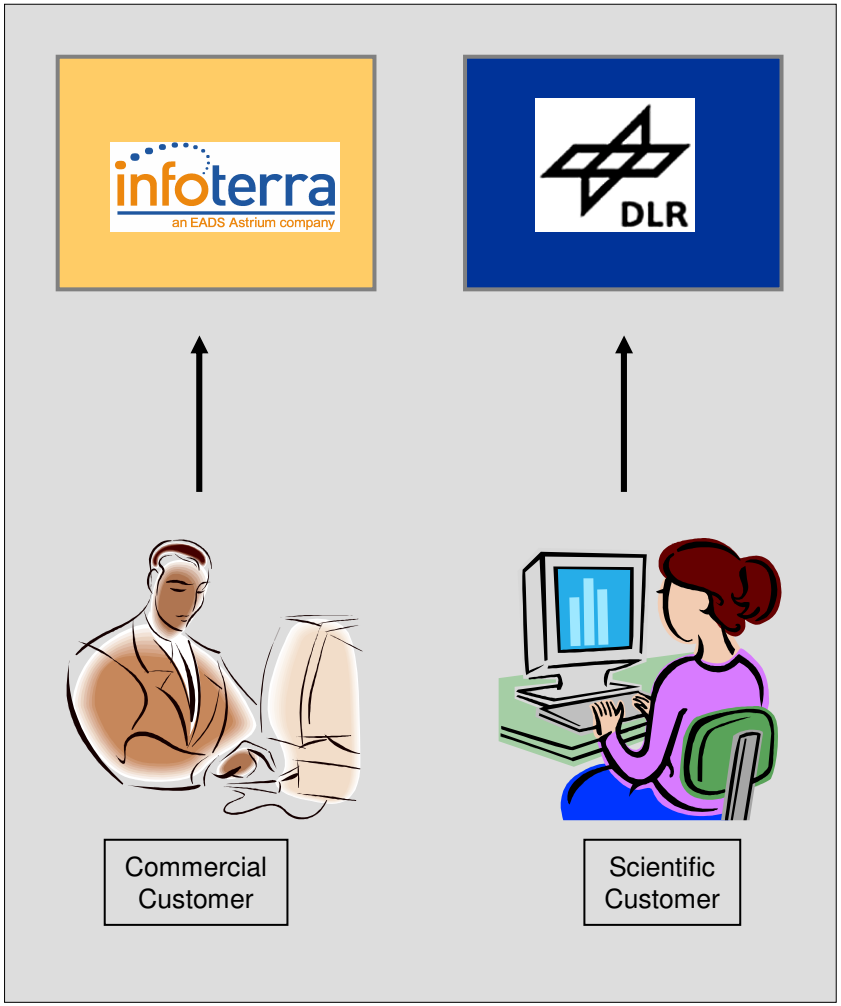
Data Availability

Scientific Data:

- DLR is in charge of coordinating the scientific use of the TerraSAR-X data
- Data will be generally provided via a Announcement of Opportunity (AO)
- Data will be provided for COFUR-cost (cost of fulfilling the user request)
- License agreement is required
- **http://www.dlr.de/tsx/main/science_en.htm**

Commercial data:

- Commercial Customers will receive data via Infoterra GmbH
- Market price will be determined by Infoterra GmbH
- **http://www.terrasar.de**



Scientfic Use of TerraSAR-X

- Order interface EOWEB open to the public since January 7th, 2008
- 197 proposals were accepted in the context of the pre-launch AOs
  - 350 science teams (~ 3000 scientists) from 43 countries
- Since October 2007 permanent submission of proposals admitted
  - 22 proposals submitted
  - 14 proposals accepted thereof
- For each accepted proposal an individual order account is established
  - Preconditions for activation:
    Use license, list of users and affirmation of funding
  - 94 accounts activated for ordering
  - 20 PIs have ordered acquisitions and products up to now

Conclusions

- Spacecraft and ground segment are fully operational
- Image products (Spotlight, Stripmap, ScanSAR) are calibrated and released
- Product quality within initial specification or better!
- SAR instrument proved to be very stable
- Demonstration of Repeat Pass Interferometry, Along Track Interferometry, persistent scatterer evaluation, TOPSAR, total zero Doppler steering
- The use of TerraSAR-X data was demonstrated for geo-scientific applications, oceanography and disaster monitoring during commissioning phase

Way Forward

- Activation of Dual Receive Antenna (DRA) mode
- Implementation of TOPSAR mode
- Preparation of TanDEM-X mission

TerraSAR-X Costs

- **Satellite:** **Development and Launch:** **130 Mio Euro (201 Mio US-$)**

  DLR Contribution: 102 Mio Euro (158 Mio US-$)

  EADS Contribution: 28 Mio Euro (43 Mio US-$)

- **Ground Segment:** **Development and Operations:** **55 Mio Euro (85 Mio US-$)**

  DLR Contribution: 44 Mio Euro (68 Mio US-$)

  Infoterra Contribution: 11 Mio Euro (17 Mio US-$)

- **Total:** **Satellite + Ground Segment: + 5 years operations** **ca. 185 Mio Euro (ca. 286 Mio US-$)**

Satellite Data Security Law (SatDSiG)

- Law in force since December 1st, 2007
- Currently DLR and Infoterra are acting in the context of a transitional contract with the *Federal Ministry of Economics (BMWi) & Federal Office of Economics and Export Control (BAFA)*
- Application filed for operation of a high grade earth observation system (DLR only)
- Application filed for distribution of data of a high grade earth observation system (DLR & Infoterra)
- Licencing requirements:
  - Savety of operation, i.e. protection against unothorized access to satellite and data
  - Sensitivity check (customer ID, timeliness, area of interest, spacial resolution, etc.)

Commissioning Phase (1)

- **Orbit and attitude verification via laser ranging**
- **Radar instrument characterization/verification**
  - instrument temperature characterization
  - check of instrument configurations
  - antenna pointing calibration, etc.
- **Overall SAR system performance characterization**
  - analysis of raw data and point targets
- **Calibration of the radar data**
  - geometric calibration
  - antenna pointing calibration
  - antenna model verification
  - relative radiometric calibration
  - absolute radiometric calibration
  - internal instrument calibration

Commissioning Phase (2)

- **Check-out of receiving station and processing system**
- **SAR product verification and release of the basic products**
  - Verification of format, annotation and content
  - Updated basic product specification
    Improvements w.r.t. initial version as for example
    - *absolute* radiometric accuracy: 1.1 dB → 0.6 dB
    - *relative* radiometric accuracy 0.68 dB → 0.31 dB
    - spotlight mode (azimuth) resolution 2.2 m → 1.7 m
    - pixel localization accuracy 2.0 m → 0.3 m in range
      2.0 m → 0.53 m in azimuth
    - side lobe ratio improved by ca. 4 dB*

      *(at the cost of a reduction of the slant range resolution of 9 % from 1.1 m to 1.2 m)

Commissioning Phase (3)

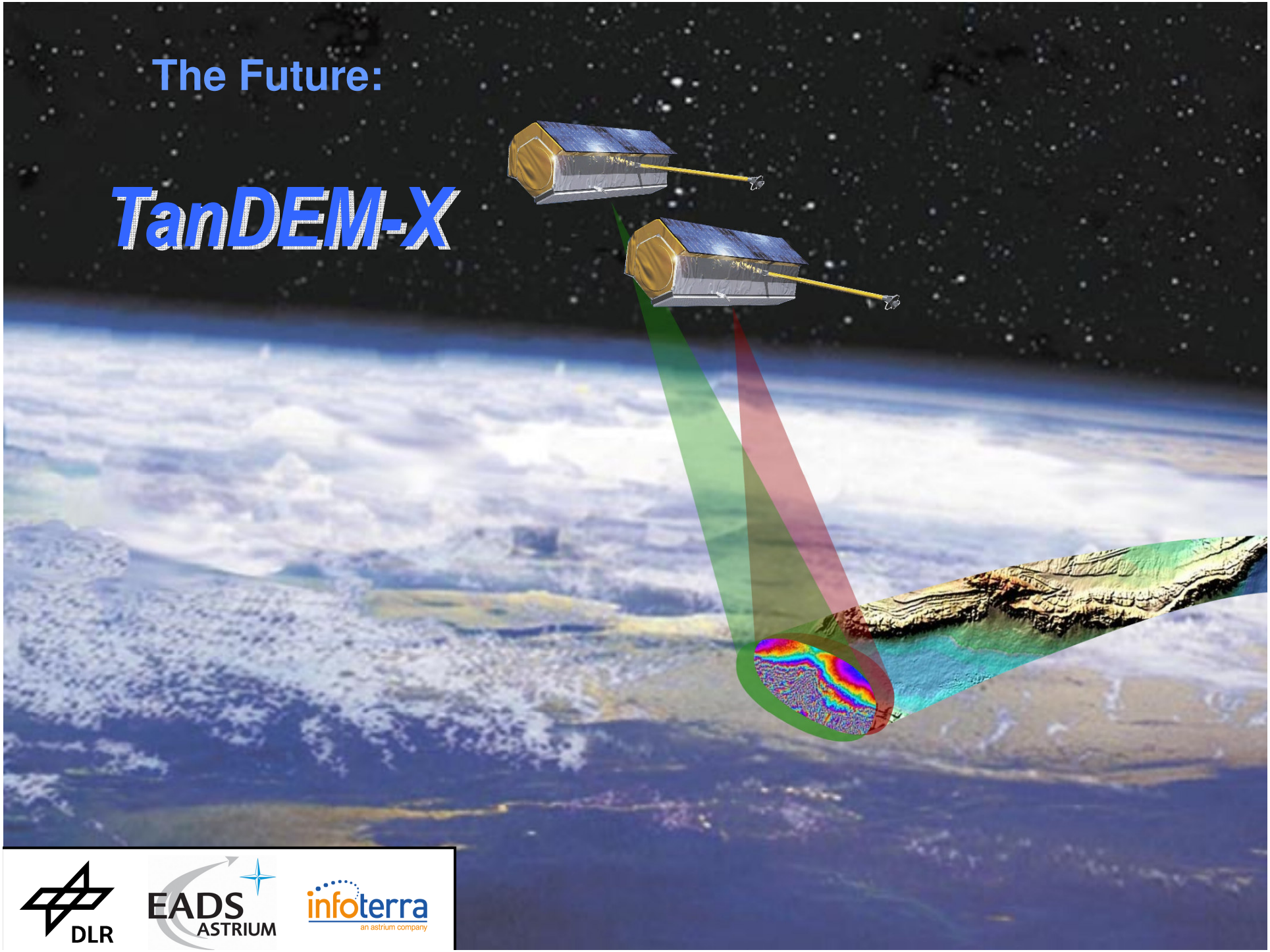
- **Check out of Direct Access Stations operated by Infoterra GmbH**
- **Load tests including the commercial service segment**
  - Simulation of a realistic load for ordering, processing and delivery work flow
- **Interferometric processing**
  - Verification of complex data product format
  - Consistency checks for Doppler, timing, velocity “B” parameter, etc.
  - Assessment of relative geolocation accuracy
  - Assessment of relative orbit accuracy
  - Verification of phase preserving processing

Instrument Key Parameters

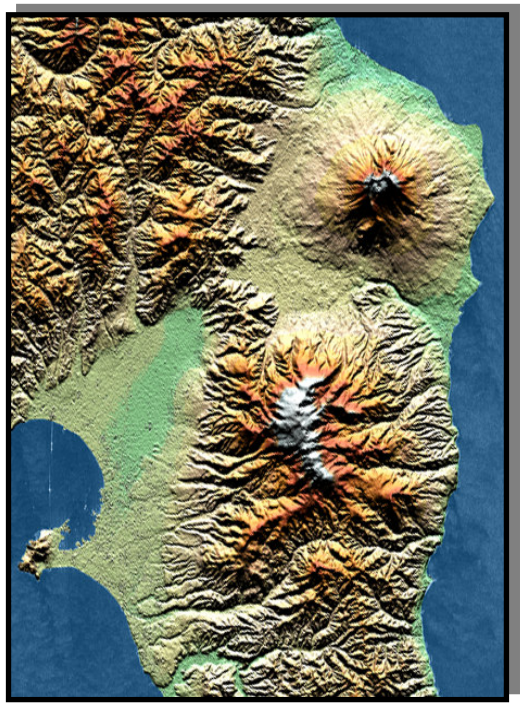
Center Frequency:	9.65 GHz (X-Band)	
Transmit Bandwidth:	5 ... 150 MHz nominal; 300 MHz experimental	
TR Module RF Output Power:	37.7 dBm	
Nominal Radar Duty Cycle:	18 % nominal; 20 % max.	
Radiated peak power output:	2.261 kW	
System Noise Figure:	5 dB	
Quantization of Signal:	8 bit I / 8 bit Q	
SAR Data Compression:	online BAQ	
Pulse Repetition Freq. Range:	3 ... 6.5 kHz	
Polarization:	HH / VV / HV / VH	
Antenna Dimension	Azimuth: 4.784 m	Elevation: 0.704 m
Beamwidth (uniform excitation)	Azimuth: 0.33°	Elevation: 2.3°
Scan Angle	Azimuth: ± 0.75°	Elevation: ± 19.2°

TerraSAR-X Calibration Results

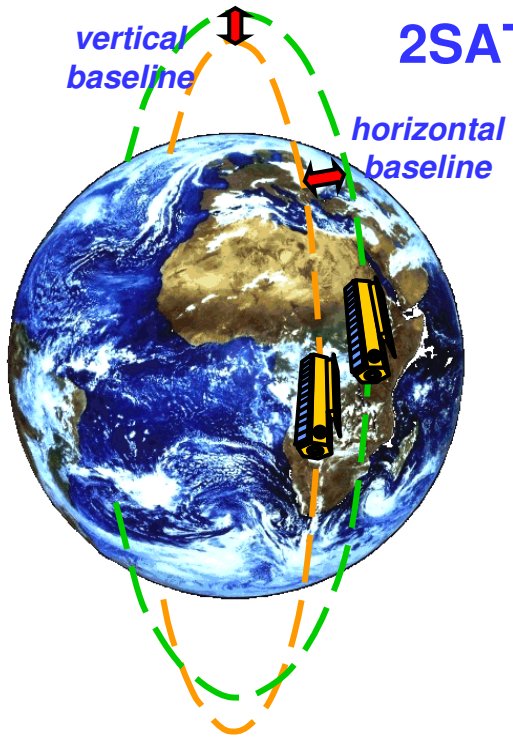
		Goal	Achieved	Status
Internal Calibration:	Temp Freeze / Temp Comp Mode - Amplitude - Phase	0.05 dB / 0.25 dB 0.7° / 1°	< 0.05 dB / ±0.2 dB < 0.7° / ±1°	✓
T/R Module Characterisation:	Individual TRM Accuracy: - Amplitude - Phase	0.3 dB 2.5°	< 0.2 dB < 2°	✓
Antenna Pointing Knowledge:	Elevation	0.015°	< 0.006°	✓
	Azimuth	0.002°	< 0.002°	✓
Geometric Calibration:	Pixel Localisation Accuracy - Range - Azimuth	2 m 2 m	0.30 m 0.53 m	✓
Antenna Model Verification:	Elevation Pattern Accuracy (two-way)	±0.2 dB	< ±0.2 dB	✓
	Azimuth Pattern Accuracy (one-way)	±0.1 dB	< ±0.1 dB	✓
	Beam-to-Beam Offset - two-way over rain forest - one-way over ground receiver	±0.2 dB ±0.1 dB	< ±0.2 dB < ±0.1 dB	✓
Radiometric Calibration:	Radiometric Stability	0.87 dB	0.2 dB	✓
	Relative Radiometric Accuracy	0.68 dB	0.31 dB	✓
	Absolute Radiometric Accuracy	**1.1 dB**	**0.6 dB**	✓


The Future:
TanDEM-X
DLR
EADS
ASTRIUM
infoterra
an astrium company

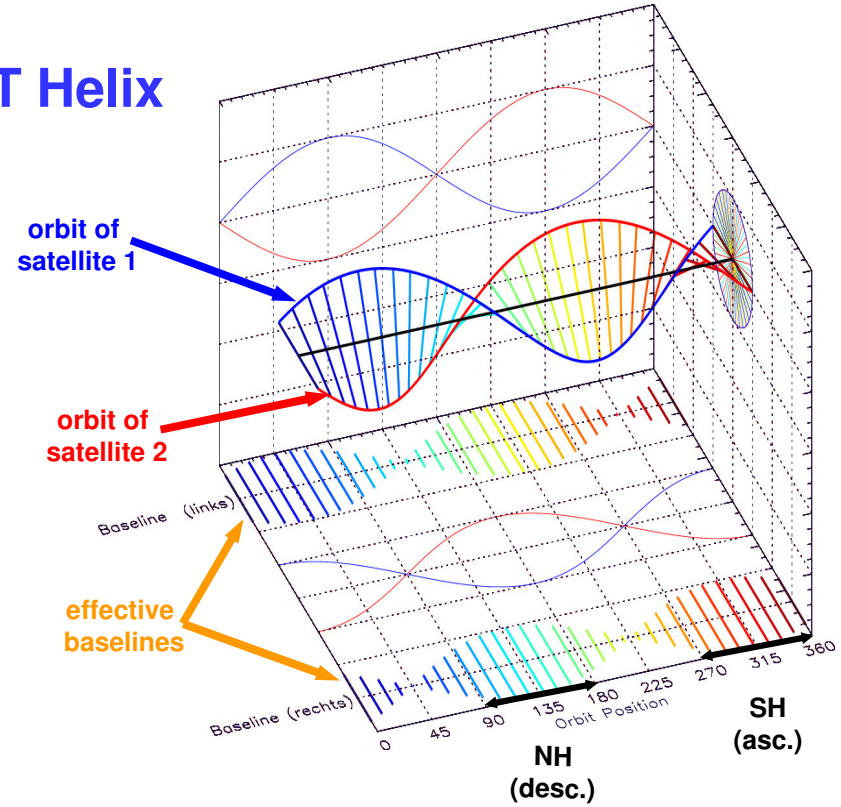
Interferometry with TanDEM-X

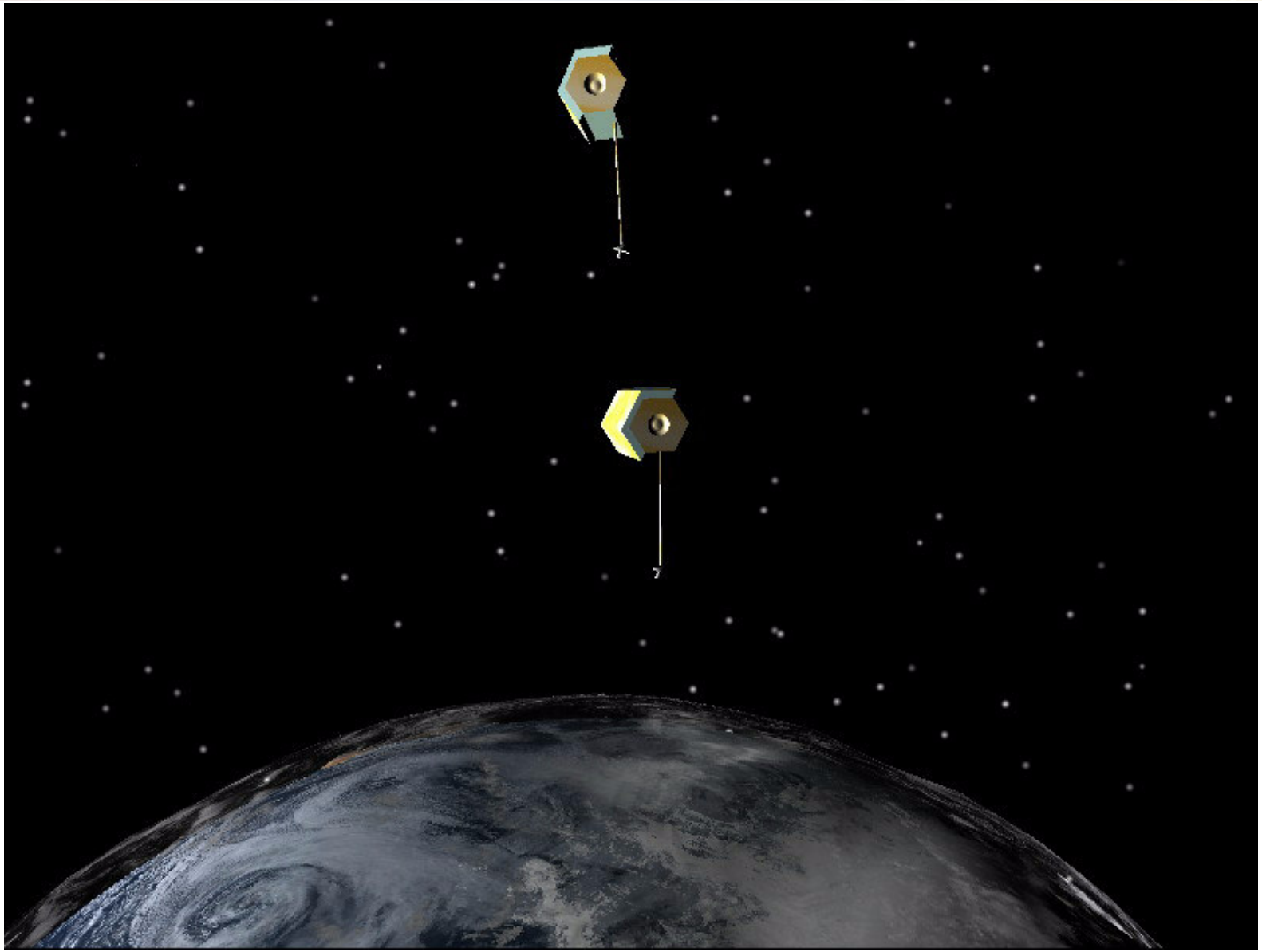


Digital Elevation Model (DEM) from SRTM Mission



2SAT Helix



Single-Pass Cross-Track Interferometry with TerraSAR-X Tandem:

- no temporal surface decorrelation
- almost no atmospheric distortions
- large selectable interferometric baselines