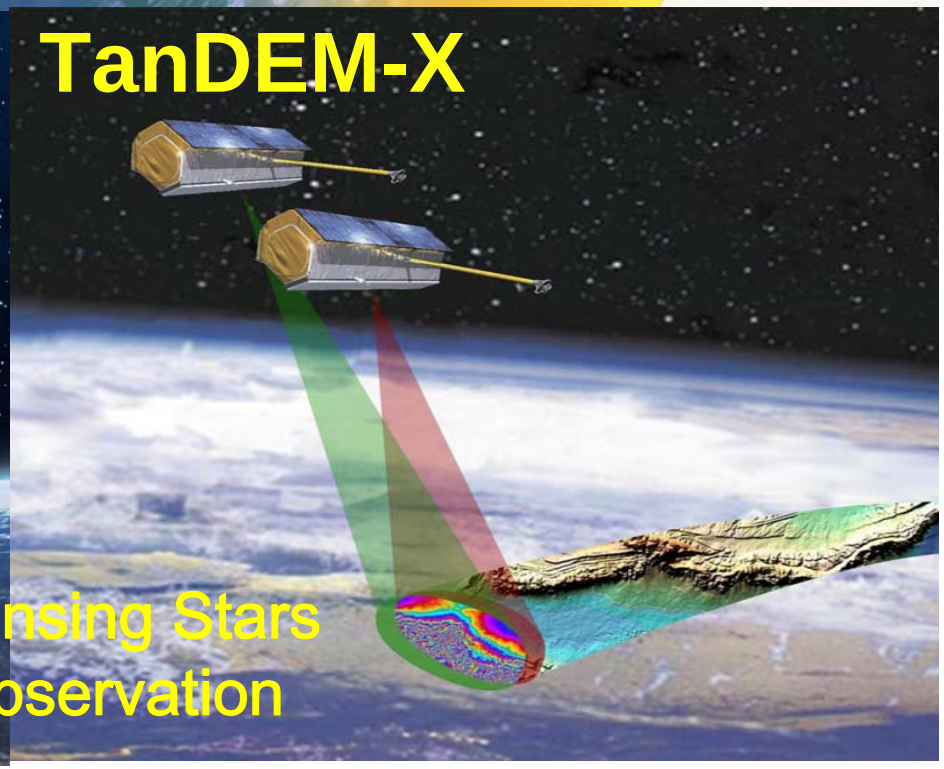
TerraSAR-X & TanDEM-X



two Innovative Remote Sensing Stars for Space-borne Earth Observation

- **Wolfgang Keydel & Alberto Moreira**
  Microwaves and Radar Institute,
  German Aerospace Research Center (DLR),
  D-82230 Oberpfaffenhofen, Germany
  Tel.: +49-8152-980 523; 49-8153-28 2305; e-mails:
- **wolfgang@keydel.com; alberto.moreira@dlr.de**

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

TerraSAR-X
A National Science Mission with Commercial Potential

Public Private Partnership

DLR
- Project Management
- G/S Development & Ops
- Science Coordination

EADS Astrium
- Platform Development
- Instrument Development
- Launch on Dnepr (2006)

Infoterra
- Service Infrastructure
- Information Products
- Commercial Exploitation

Main Mission Goals:
- Provision of TerraSAR-X data for scientific applications → public interest
- Commercial exploitation of TerraSAR-X data → by industry

TerraSAR-X
Application Areas

Agriculture

Precision Farming Suite
Crop Ripeness
Crop Inventory
Yield Prediction Cereals

Forestry

Strategic Forest Inventory
Reconnaissance Inventory
Inventory Update

Cartography

Topo Map Local
Topo Map Regional / Macro
Regional Planning Map
Environmental Planning Map
Infrastructure Planning Map

Risk

Flood Damage Assessment
Fire Damage Assessment
Storm Damage Assessment

Utilities

Telecom Planning
Utility Planning

Security

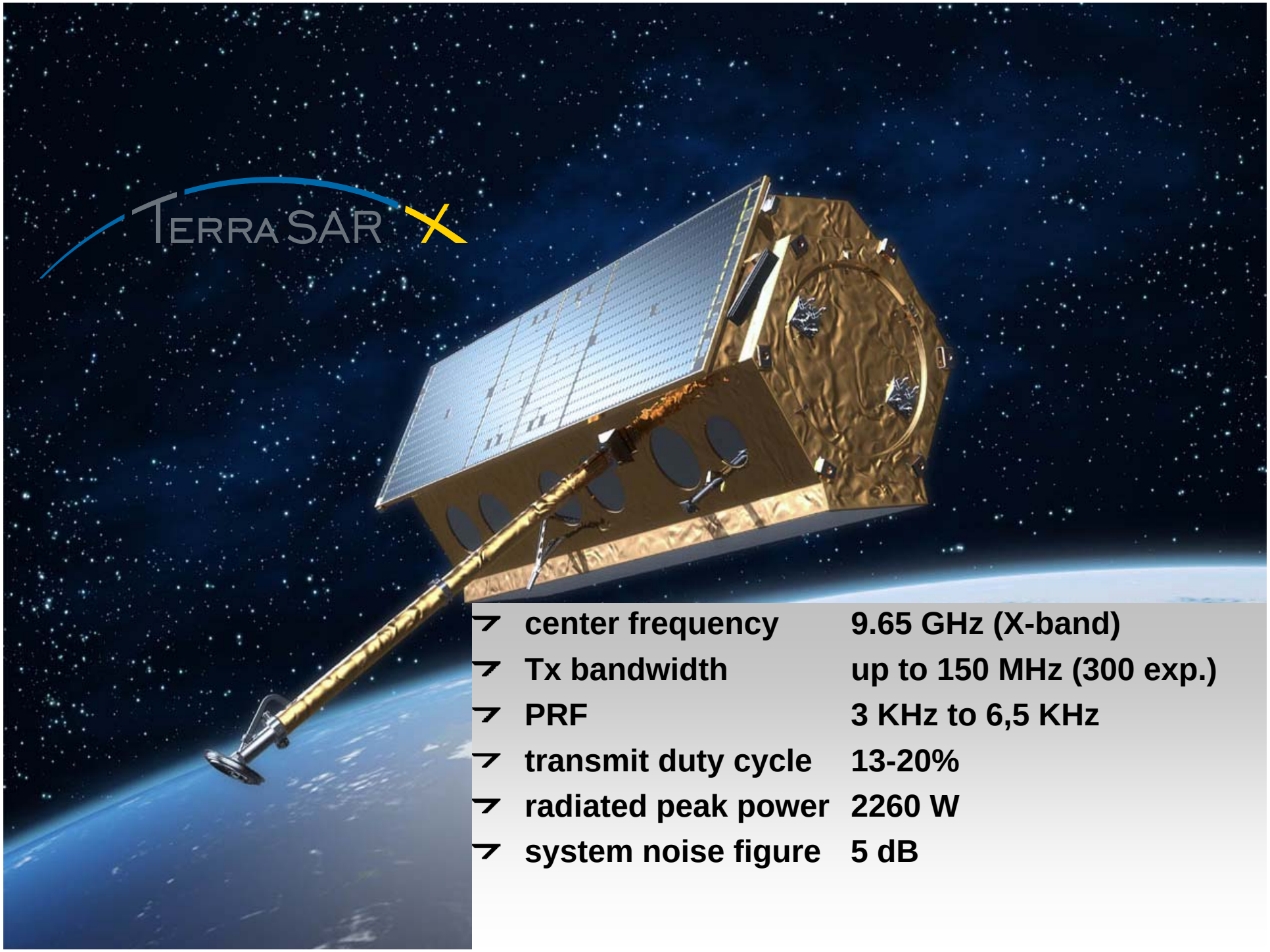
Reconnaissance Imagery
(VHR-SAR)

Geology

Geology Structure Map
Geology Image Map
Geological Elevation Map
Oil Seep Detection

Marine

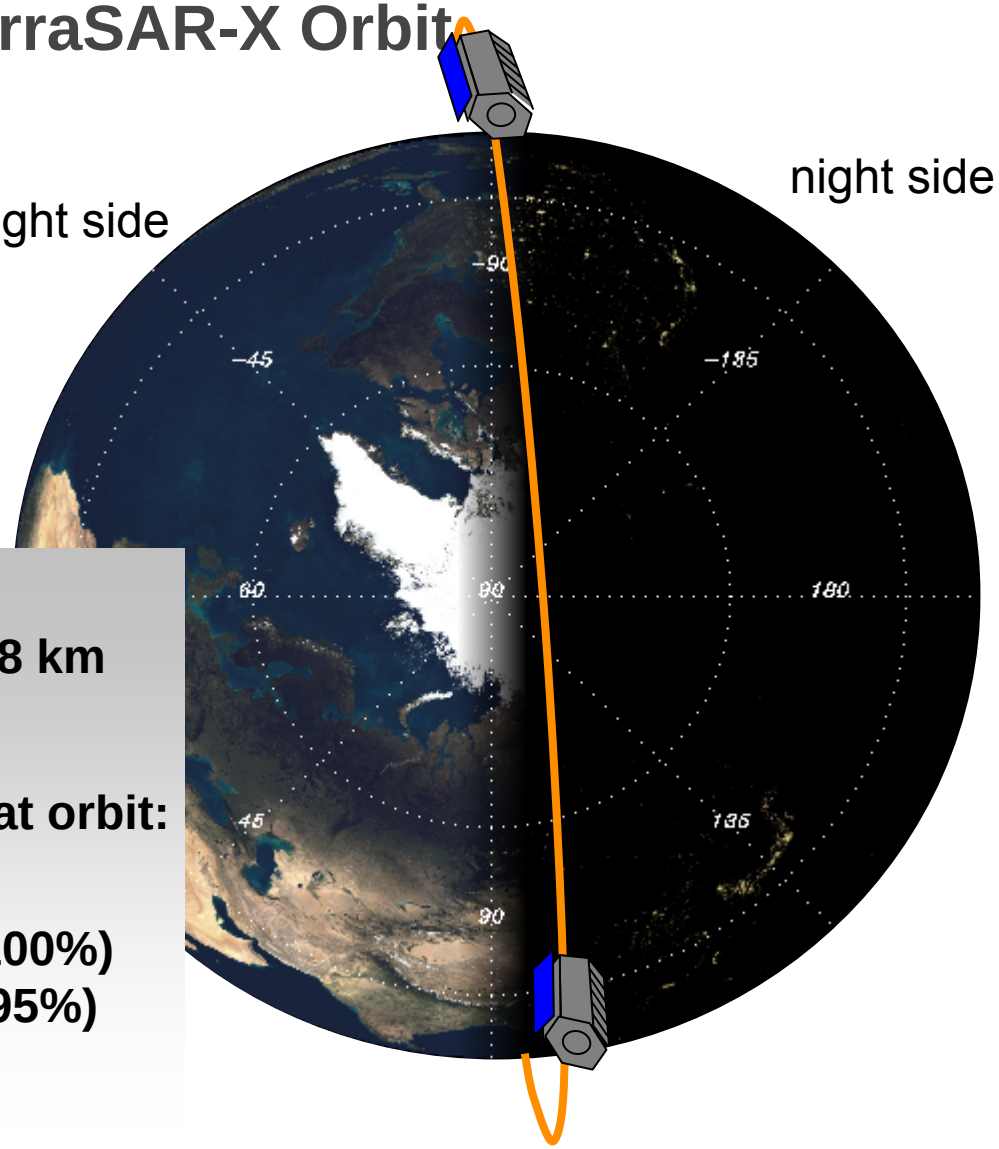
Ship Detection Service
Oil Spill Monitoring
Sea Ice Monitoring



center frequency	9.65 GHz (X-band)
Tx bandwidth	up to 150 MHz (300 exp.)
PRF	3 KHz to 6,5 KHz
transmit duty cycle	13-20%
radiated peak power	2260 W
system noise figure	5 dB

- antenna dimension in azimuth 4.784 m
- antenna dimension in elevation 0.704 m
- azimuth beamwidth 0.33°
- elevation beamwidth 2.3°
- scan angle azimuth ± 0.75°
- scan angle elevation ± 19.2°

TerraSAR-X Orbit



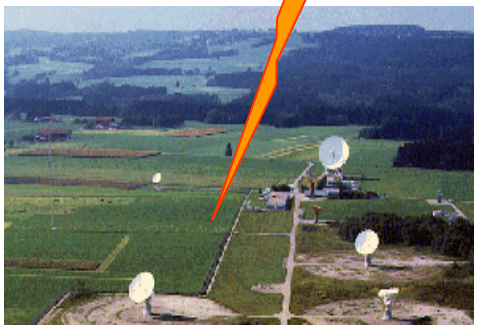
- dusk/down orbit
- altitude at equator 514.8 km
- inclination 97.44°
- sun-synchronous repeat orbit: repeat period 11 days
- revisit time: 4.5 days (100%)
  2.5 days (95%)
- orbits per day 15 2/11

TerraSAR-X Mission Profile

X-Band Downlink
300 Mbit/sec

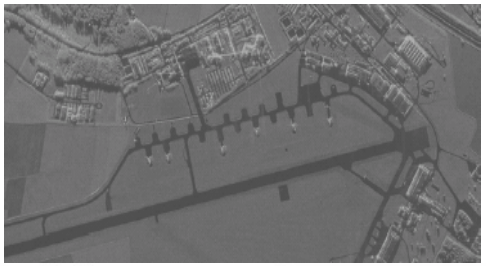
S-Band
TM & TC

Raw Data
Acquisition

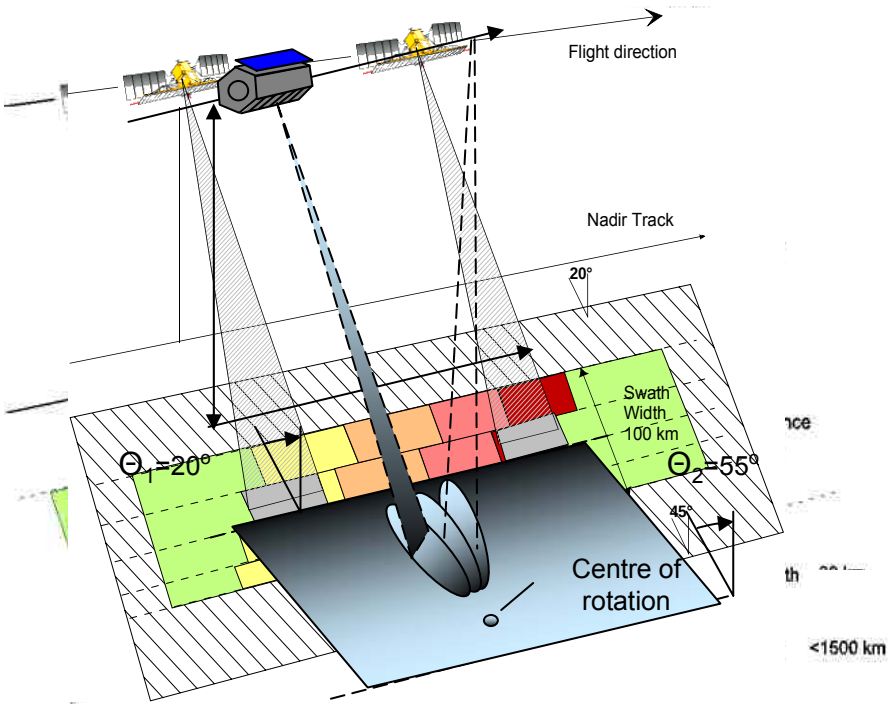


DLR GS Neustrelitz

DLR GS Weilheim



Mission
Operations
DLR
Oberpfaffenhofen



TerraSAR-X Imaging Modes

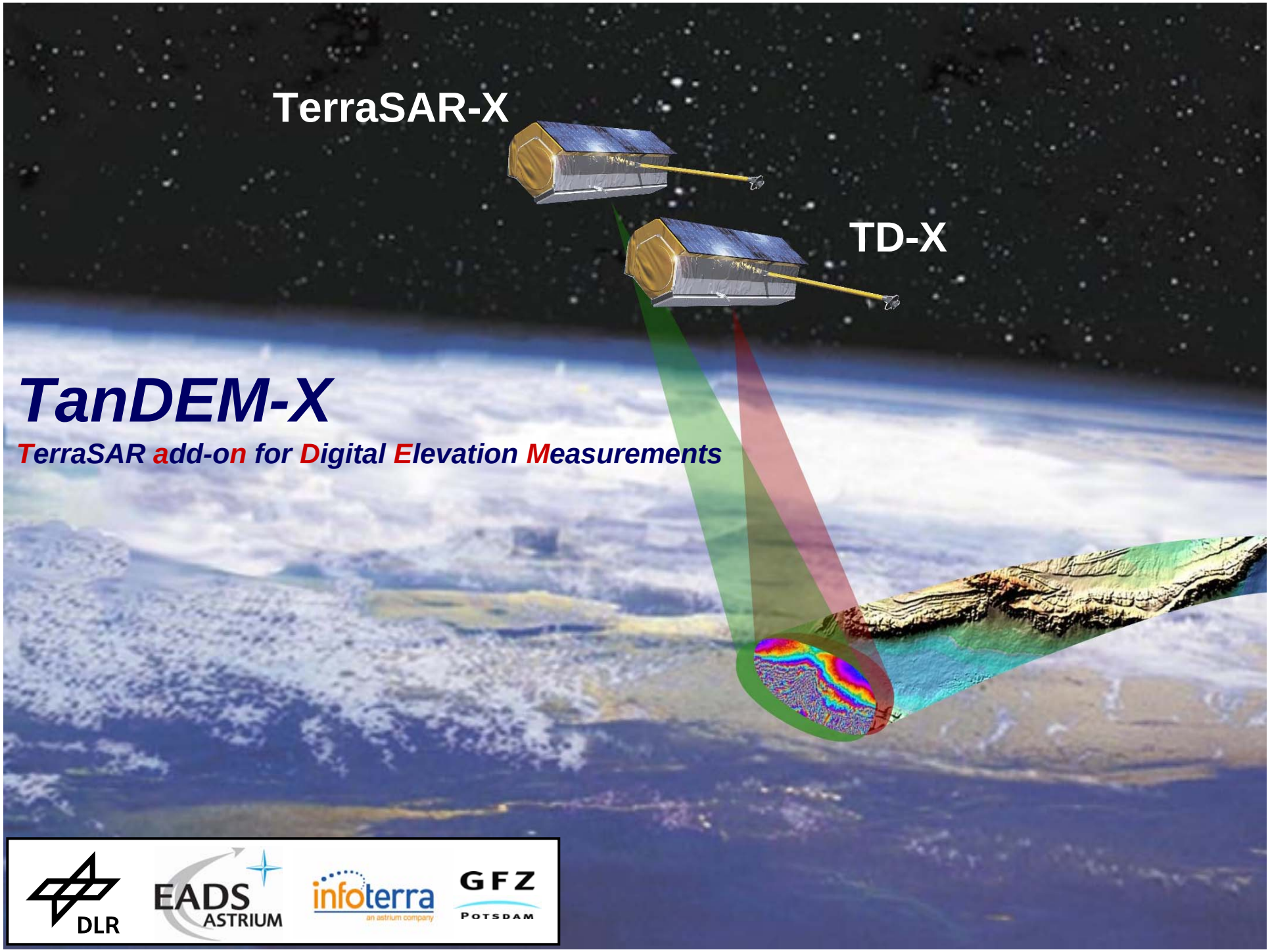
Stripmap Mode

ScanSAR Mode

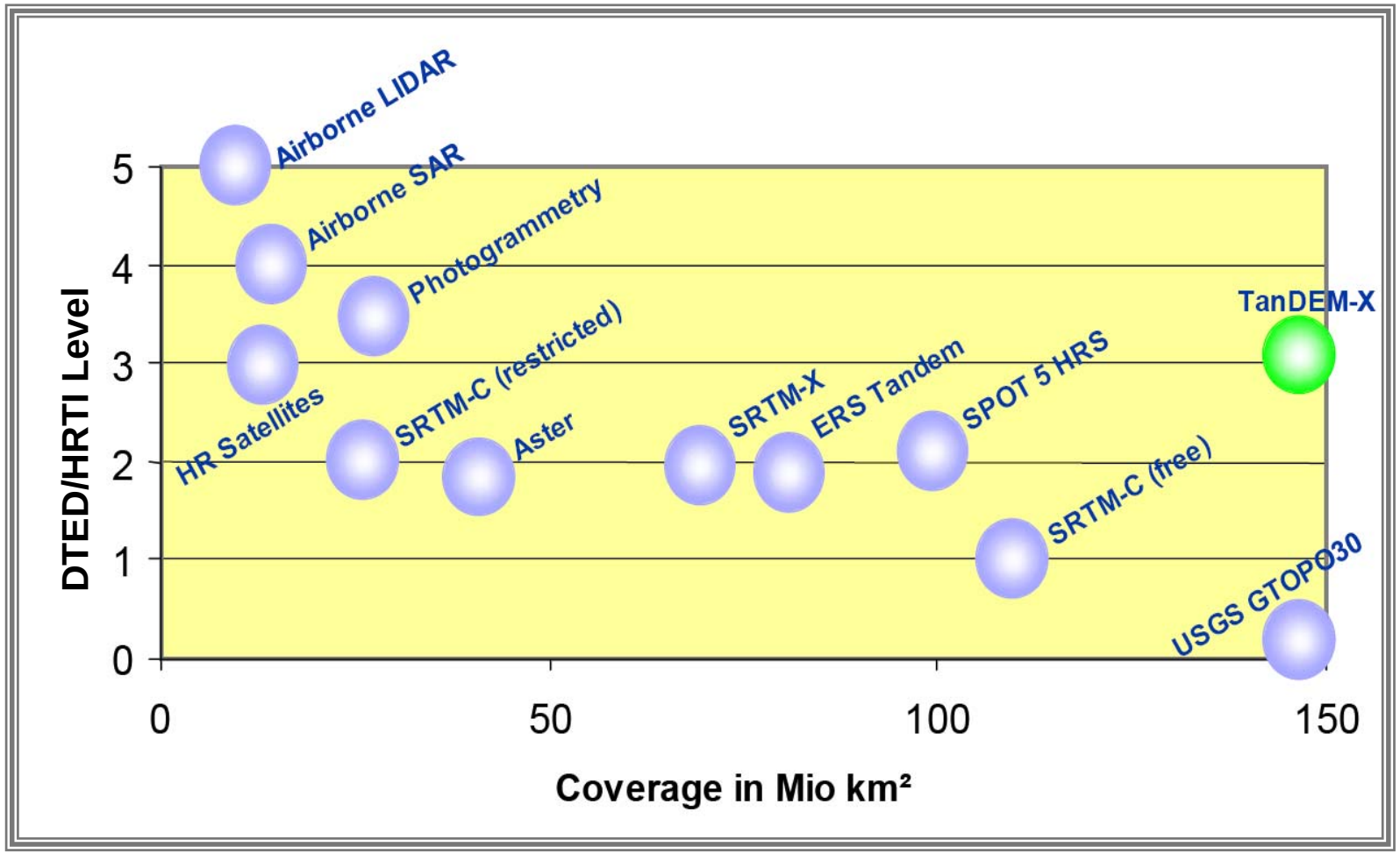
Spotlight Mode (Sliding)

HighRes Spotlight Mode (Sliding)

	Stripmap	ScanSAR	Spotlight	HighRes Spotlight
full perf. inc, angle range	20° - 45°	20° - 45°	20° - 55°	20° - 55°
scene size along track	acqu. length	acqu. length	10 km	5 km
scene size ground range	30 km	100 km	10 km	10 km
single look az. resolution	3 m	16 m	2 m	1 m
single look range resolution	3 m (ground)	16 m (ground) @ 5 looks	1.2 m (slant)	1.2 m (slant)

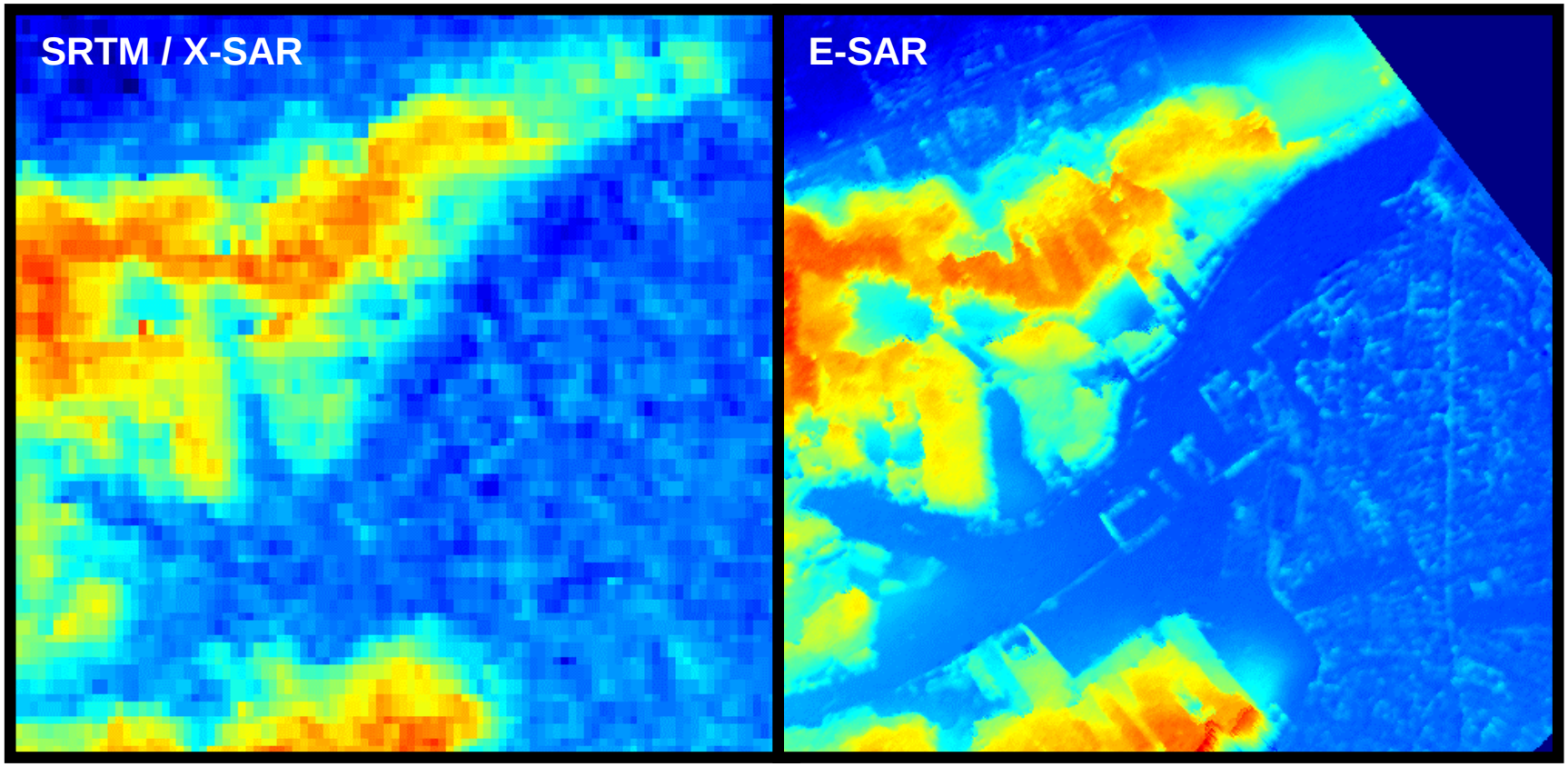

TerraSAR-X
TD-X
TanDEM-X
TerraSAR add-on for Digital Elevation Measurements
DLR
EADS ASTRIUM
infoterra
an astrium company
GFZ
POTSDAM

Primary Mission Goal:
Generation of a global HRTI-3 DEM

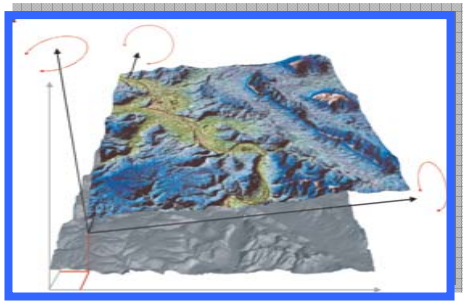


Comparison of DTED/HRTI-Levels: Example

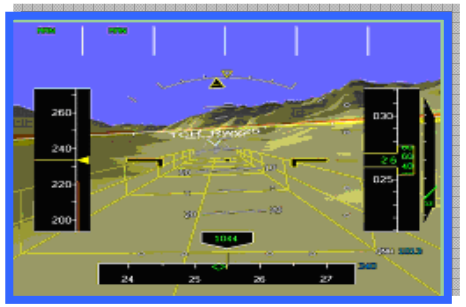
DTED-2 **HRTI-3**



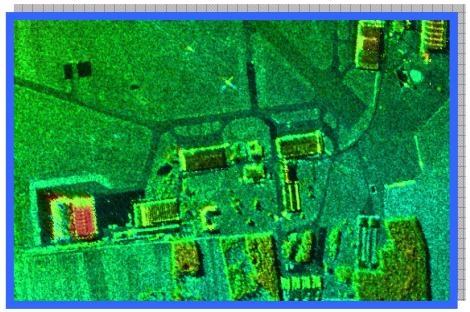
Applications of Cross-Track Interferometry



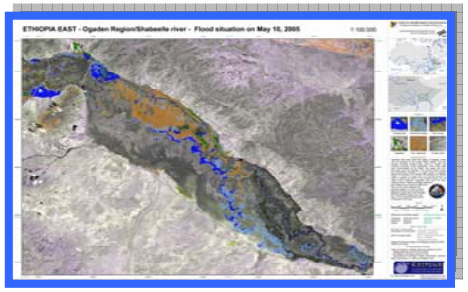
Topography



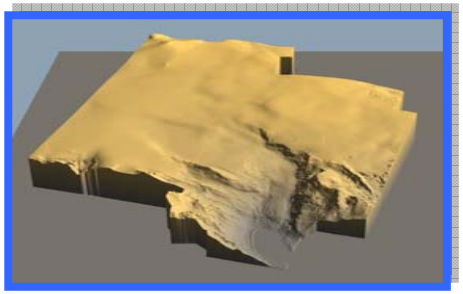
Navigation



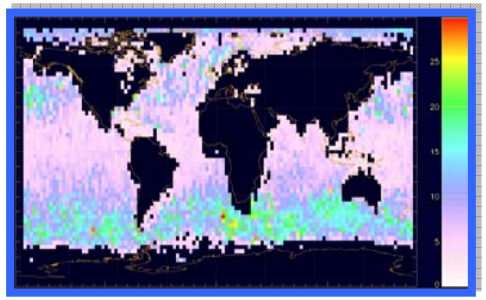
Urban Areas



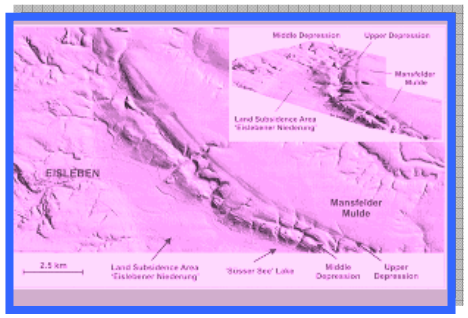
Crisis Management



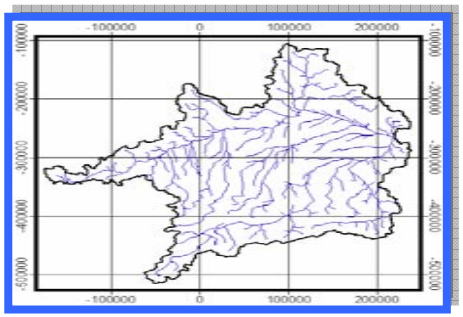
Glaciology



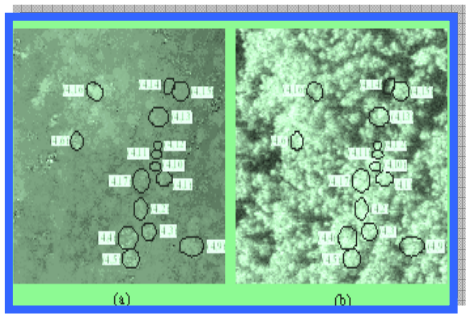
Oceanography



Geology



Hydrology



Land Use

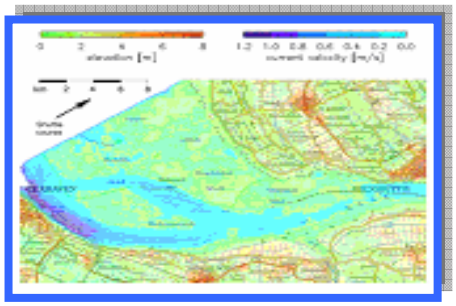
TanDEM–X HRTI-3 Spezification

- **relative vertical accuracy 2 m**
  (90% linear point-to-point error over 1° x 1° cell),
- **absolute vertical accuracy 10 m**
  (90% linear error),
- **absolute horizontal accuracy 10 m**
  (90% circular error), post spacing 12 m x 12 m

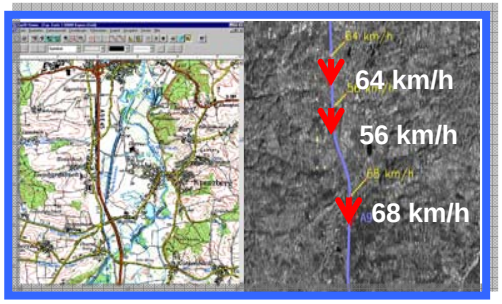
TanDEM-X provides a configurable
SAR Interferometry Platform for
Demonstrating new SAR Techniques & Applications

Applications ATI & New Techniques

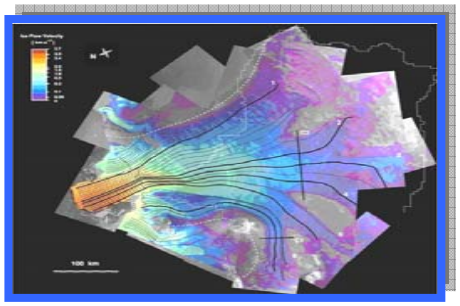
Along-Track Interferometry



Ocean Currents

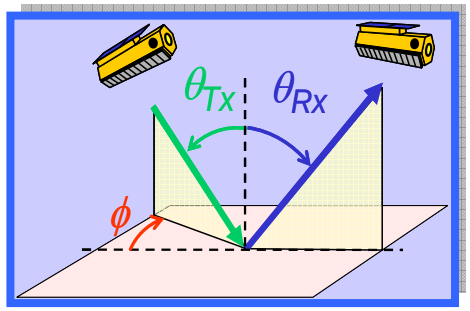


Traffic Monitoring

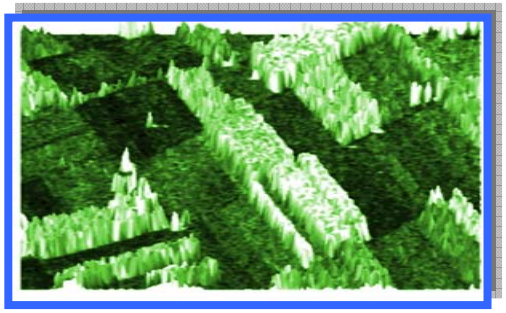


Glacier Mass Balance

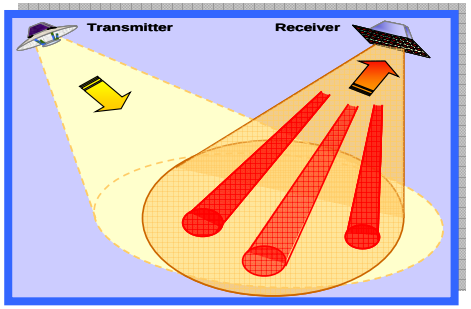
New SAR Techniques



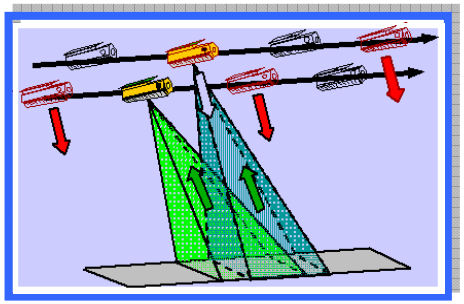
Bi-Static SAR



Polarimetric InSAR

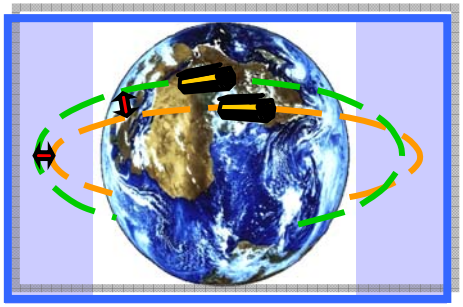


Digital Beamforming



InSAR Processing

Super Resolution



Formation Flying

TerraSAR - X versus Tandem - X

→ **SAR System Parameters of both Systems fully compatible**

allowing both

- **Independent TanDEM-X Operation in a Monostatic Mode**
- **Synchronised Operation in a Bistatic Mode**

Main Differences

- **More sophisticated Propulsion System of TanDEM-X allows for Constellation Control**
- **Additional S-band Receiver enables for Reception of Status & GPS Position Information broadcast by TerraSAR-X**
- **X-band Inter-Satellite Link for Phase Referencing between both Radars (resp. Modifications on TerraSAR-X already implemented).**

Calibration Concept for Multiple Mode High Resolution SARs like TerraSAR-X

- **M. Schwerdt, D. Hounam and T. Molkenthin**

- IRS 2003, Dresden Germany
- 1st October 2003

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

Introduction

- TerraSAR-X Features/Operation Modes
- Philosophy of Radar Calibration
- PN-Gating Method
- Concept of Antenna Pattern Model
- DLR Calibration Facilities
- Calibration / Validation Overview

Features/Operation Modes of TerraSAR-X

- single/dual polarisation
- wide range of swath positions (20° - 55°)
- **3 basic operation modes**
  - **Strip Map** (26 look angles)
  - **ScanSAR** (WS à 4 SS)
  - **Spotlight** (123 look angles)
- left/right looking SAR
- **experimental modes**
  - wide band width
  - along track interferometry

large number of:

- operation modes
- **antenna beams**

26 elevation **beams**

123 elevation **beams** à **100** azimuth **patterns**

↓

active antenna array

calibration → major challenge → **costs affordable**

Philosophy

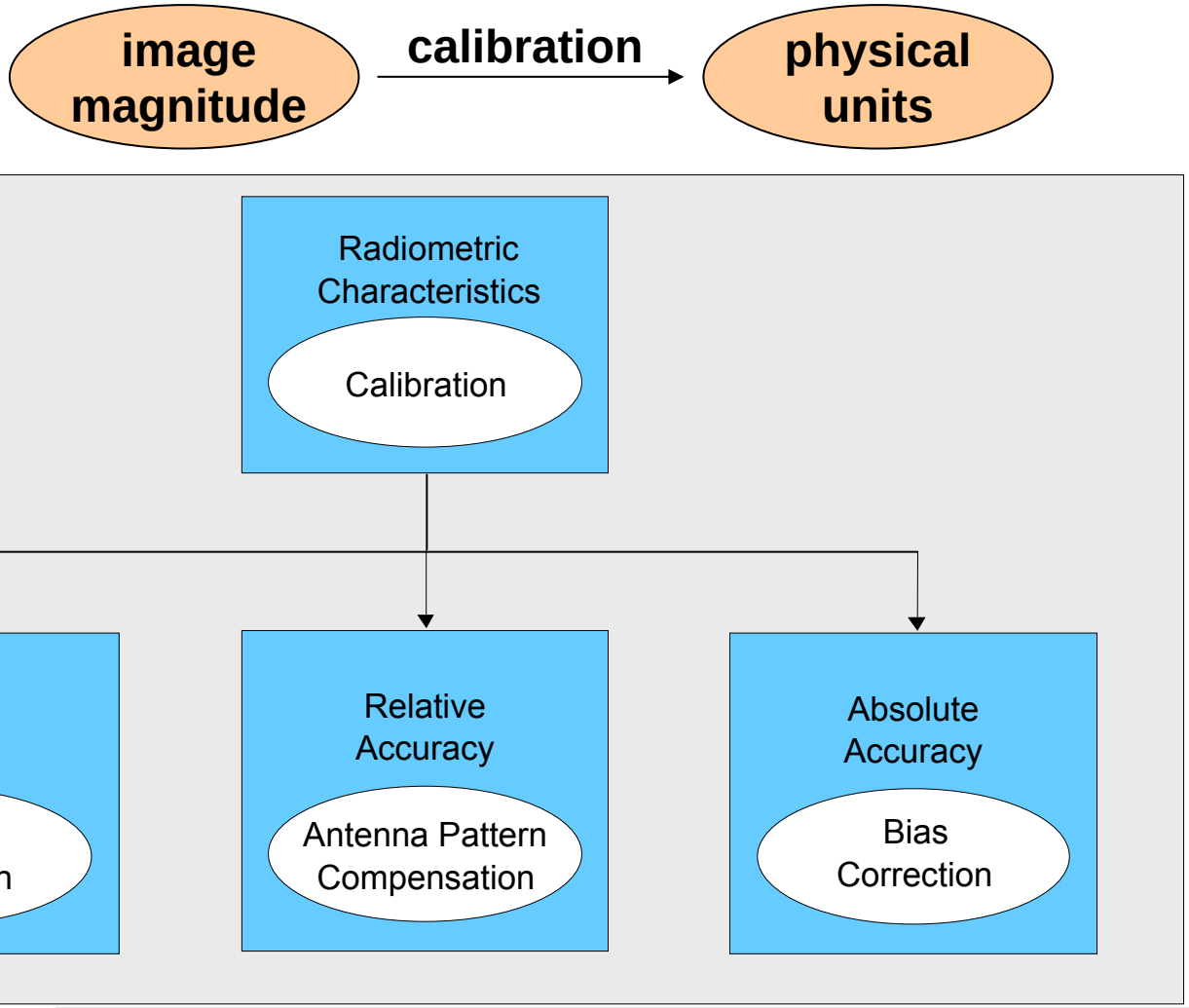


image magnitude
calibration
physical units
Radiometric Characteristics
Calibration
Stability
Internal Calibration
Relative Accuracy
Antenna Pattern Compensation
Absolute Accuracy
Bias Correction

New Calibration Concept

Internal Calibration	PN-Gating Method	→	In-Orbit Analysing of Individual TRMs
Antenna Pattern	Precise Model	→	Estimation of Actual Antenna Pattern

Measurements as much as possible	Sufficient Number of Ground Targets	→	Reliable Reference

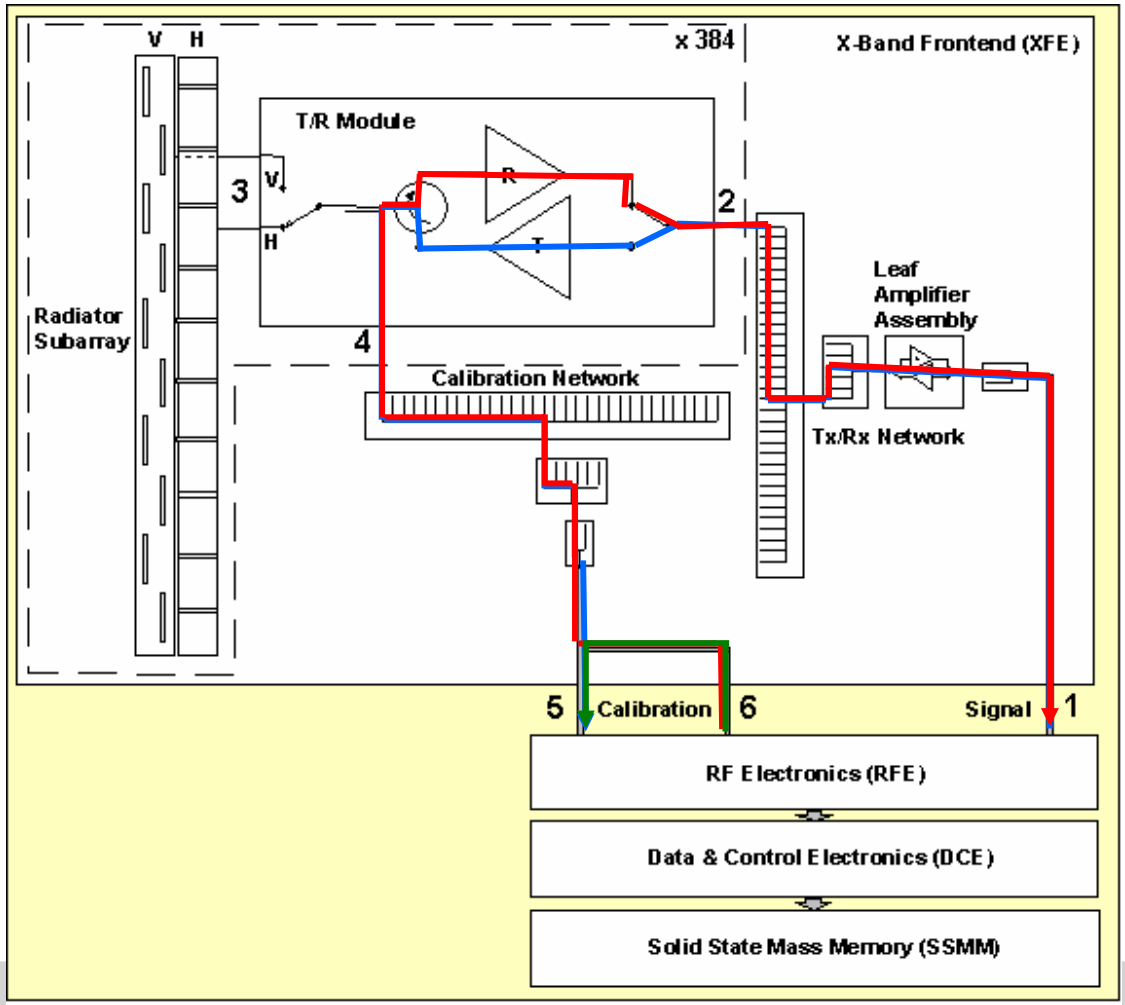
(Index: PN = Pseudo Noise)

Internal Calibration

- **3 Calibration Pulses:**
  - 1 Transmit Path 1-2-4-5
  - 2 Receive Path 6-4-2-1
  - 3 Only RFE/DCE 6-5

↓

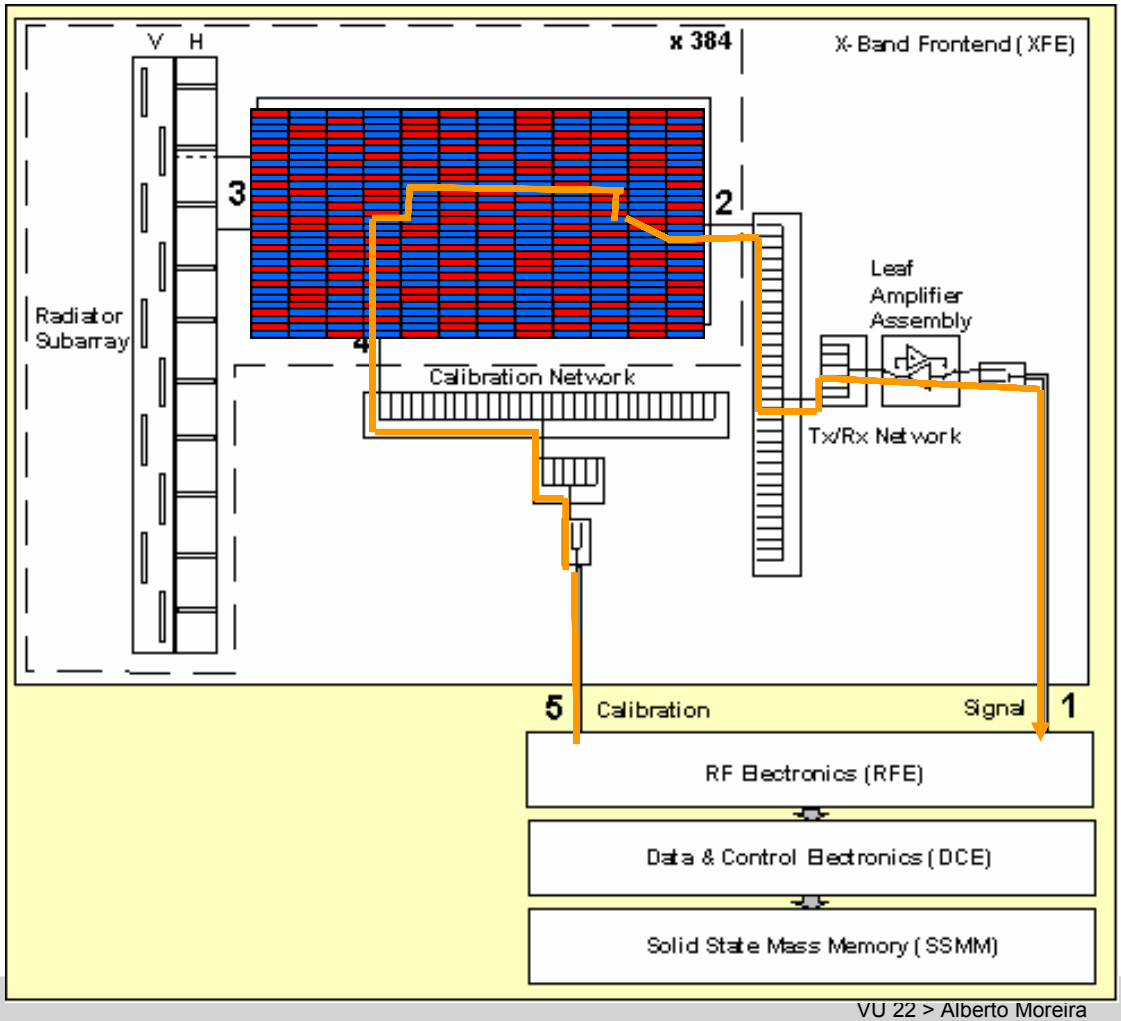
controlling
the instrument
as a whole



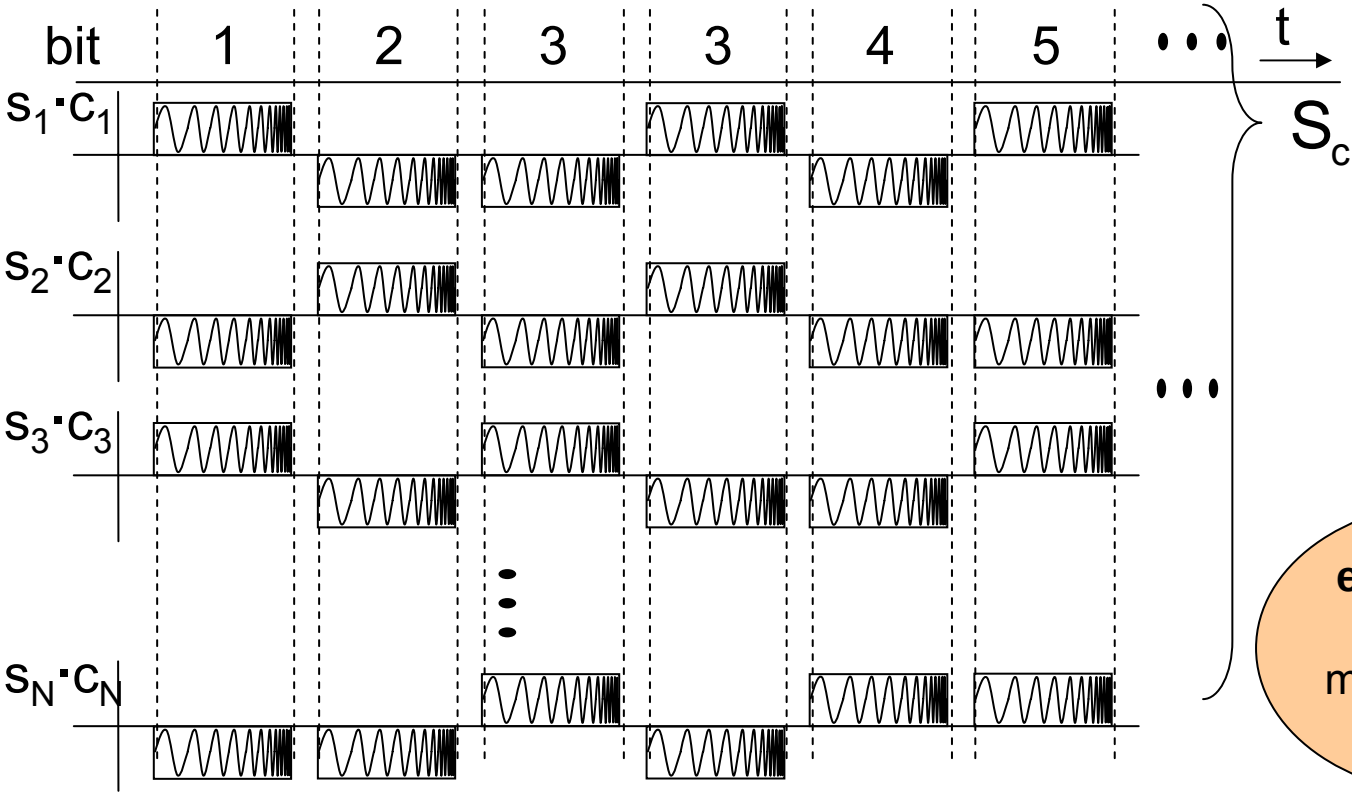
individual modules?

PN-Gating: technique of characterizing individual T/R modules while all modules are operating, i.e. a characterization under most realistic conditions.

- **Phase of each T/R module** individually **shifted** about $\pm\pi/2$ (phase shift keying) **between Cal-pulses** according to a **PN code sequence**.
- **Each T/R module** has a **different PN code** or **code shift.**



Superposition of all T/R Signals



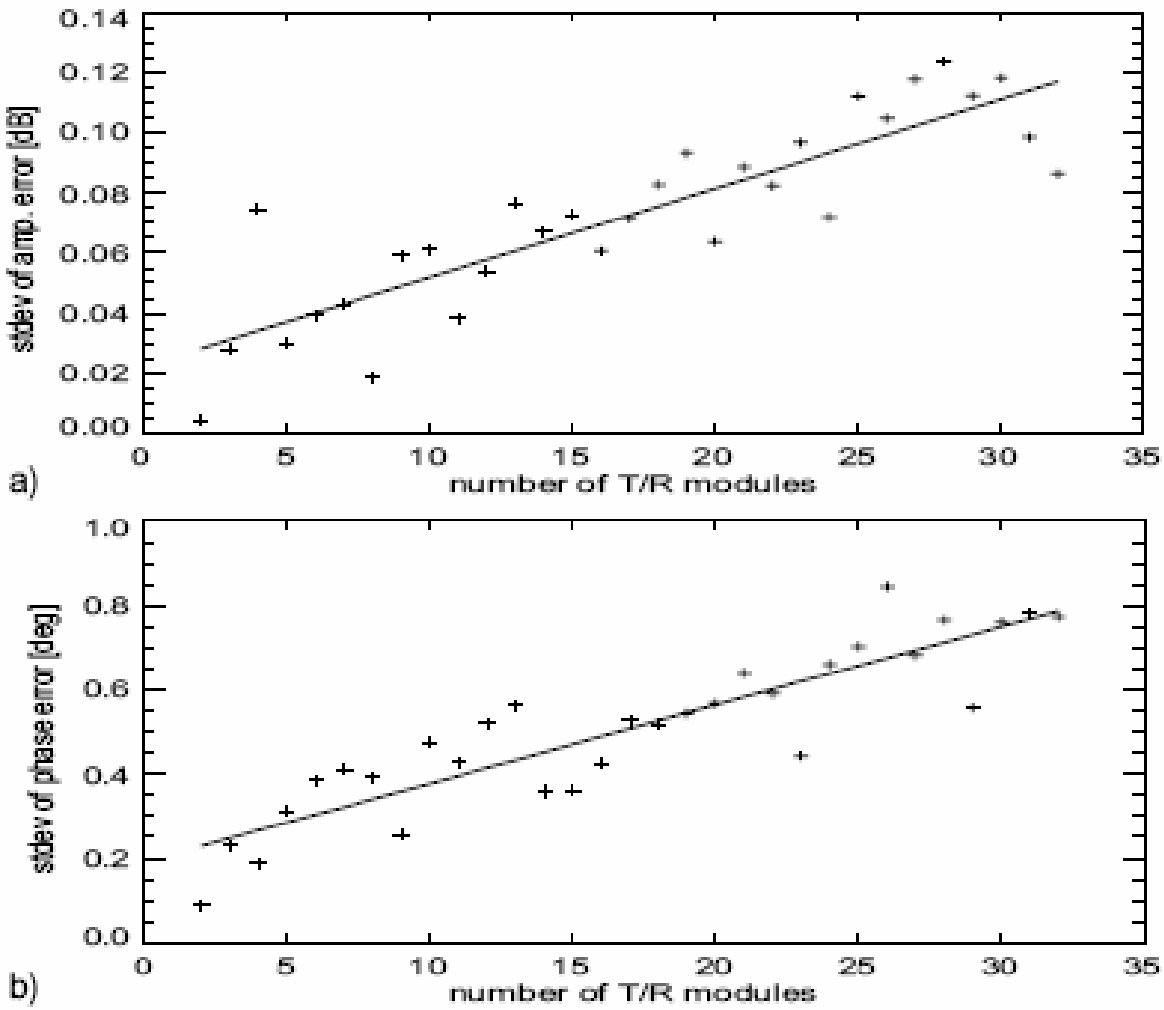
$$S_c(t) = \sum_{i=1}^{N_{T/R}} s_i(t) \cdot c_i(t)$$

correlation with the inherent Module code c_i

extraction of **individual** module **signal** s_i

Standard Deviations versus Number of T/R Modules

S/N =20db, 30 Modules, Codelength=1023



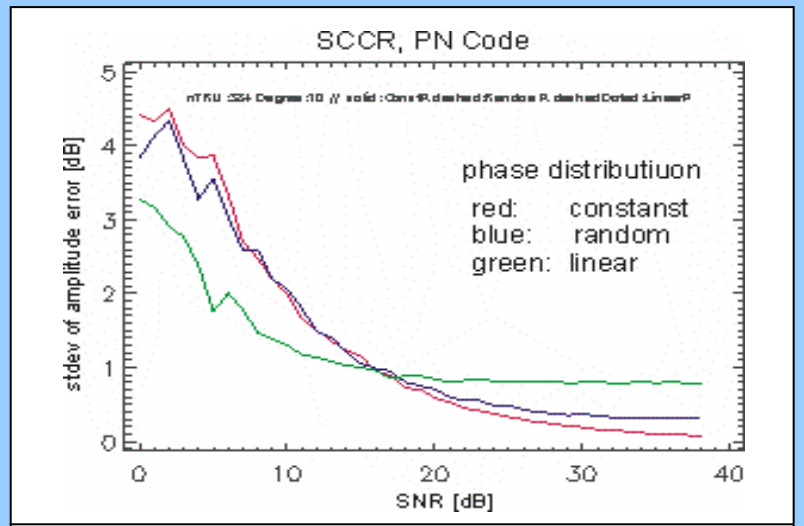
For larger Number of T/R Modules code length would need to be increased correspondingly to achieve the same errors. But using of an ideally orthogonal code (Walsh sequence f.e.) the cross correlation of two distinct sequences is 0. Thus the code length can be reduced considerably down to 512 for 384 T/R modules.

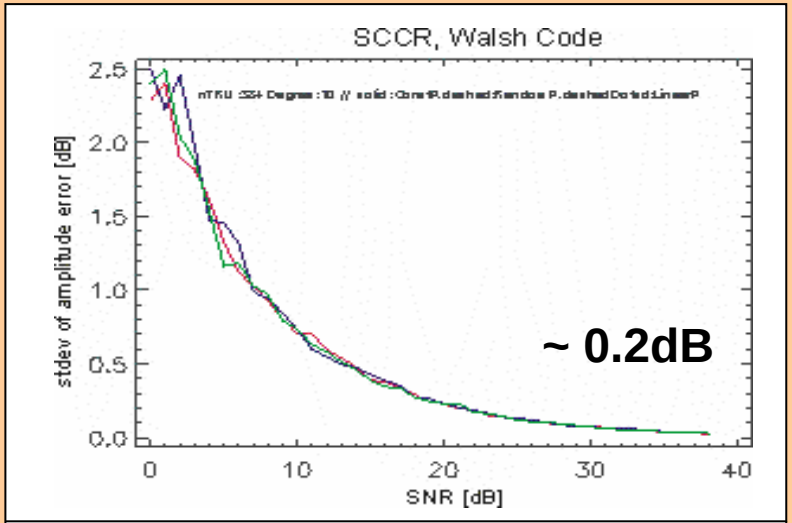
Amplitude & Phase Error as function of SNR (TerraSAR, 384 Modules)

Pseudo Noise Code

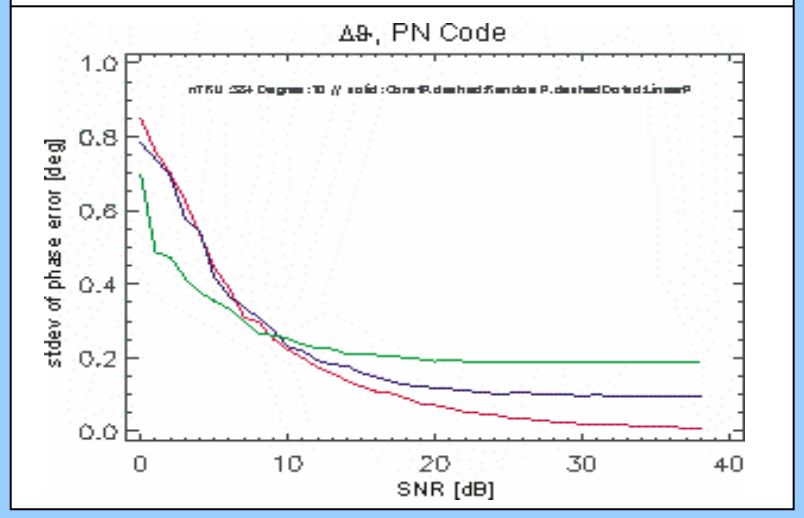
Walsh Code

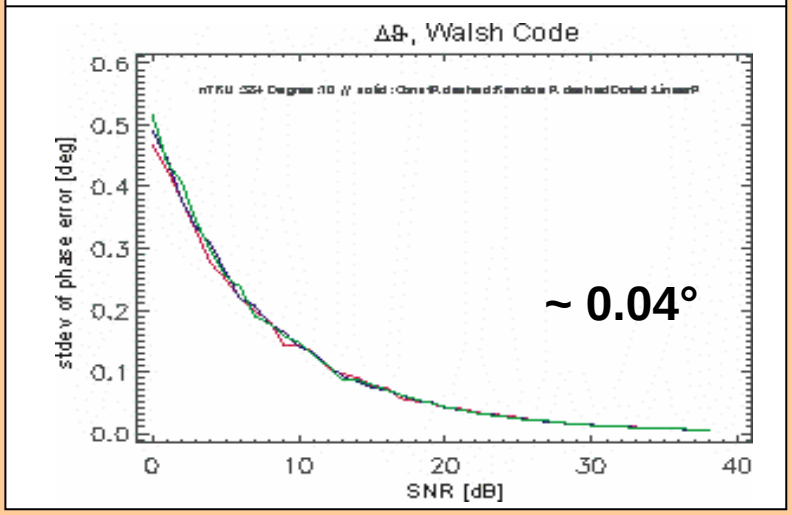
Amplitude/dB



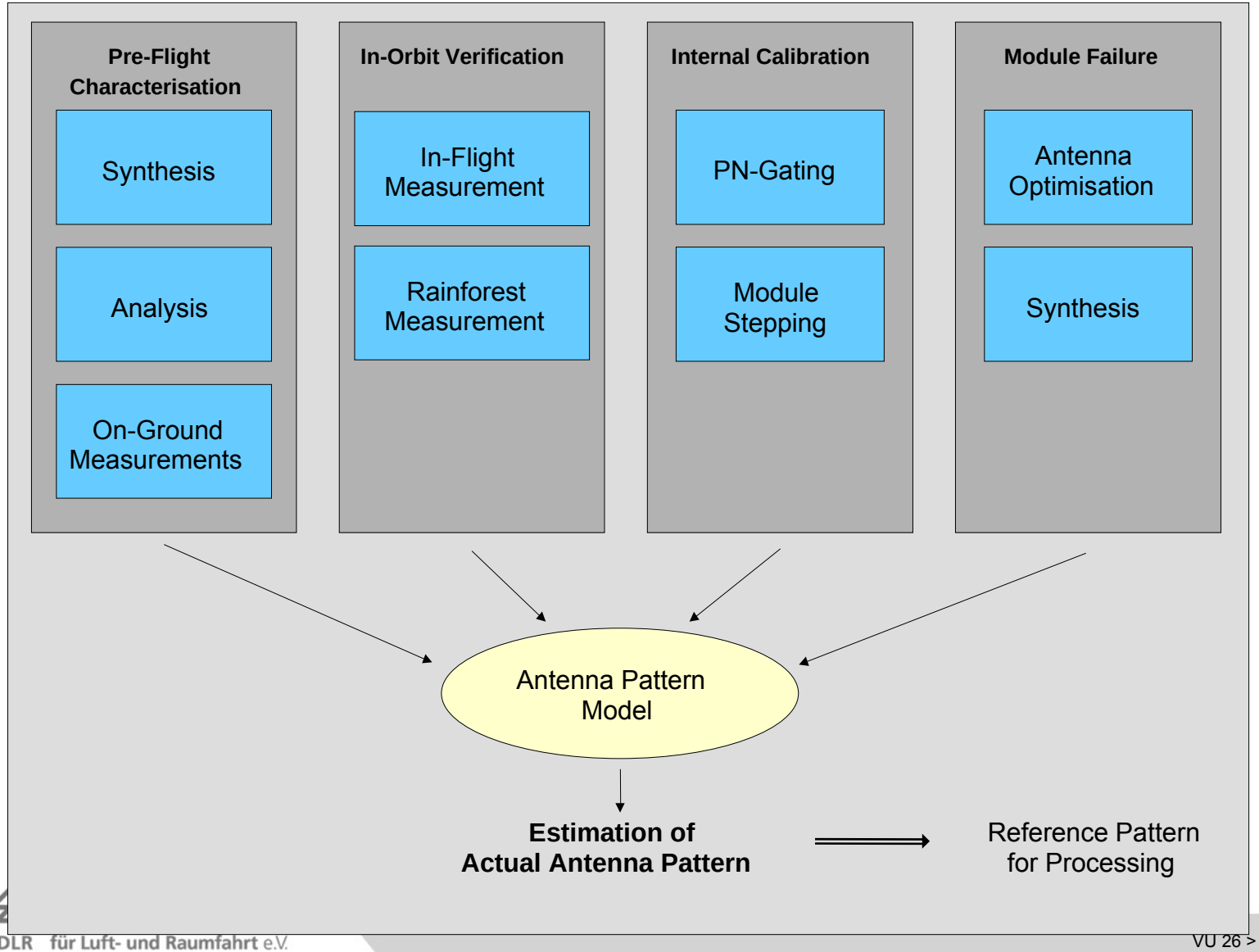


Phase/degree





Antenna Pattern Model



Antenna Pattern Model

Goal: Derive all reference pattern required for SAR data processing; i.e. provide an accurate estimation of the actual antenna pattern with a minimum number of costly in-flight antenna pattern measurements.

- **Pre-flight Characterization:** calculating & analyzing antenna patterns of the different operation modes as well as on-ground antenna pattern measurements like those of a single radiation element or individual rows or panels.

- **In-Orbit Verification:** in-flight antenna patterns measured in use of ground receivers & by rainforest measurements (expensive!).

- **Internal Calibration:** PN-gating method, an antenna pattern can be calculated with the actual excitation coefficients of the individual modules.

- **Module Failure Analysis**: in case of contingencies, for example failed T/R modules, an optimization of the excitation coefficients of the remaining modules is intended in order to obtain the best beam of each operation mode.

Antenna Pattern Model

Verification accuracy determines the minimum number of inflight measurements

When developing the model

core attention

has to be focused on two questions:

- **What relevant beams have to be measured in order to verify sufficiently the antenna pattern model?**
- **How can the best estimation of the actual pattern be extracted from all inputs and information described above?**

Essential TerraSAR-X calibration facilities

- **Standard ground targets for bias correction**

- **Ground receivers for in-flight measurements**

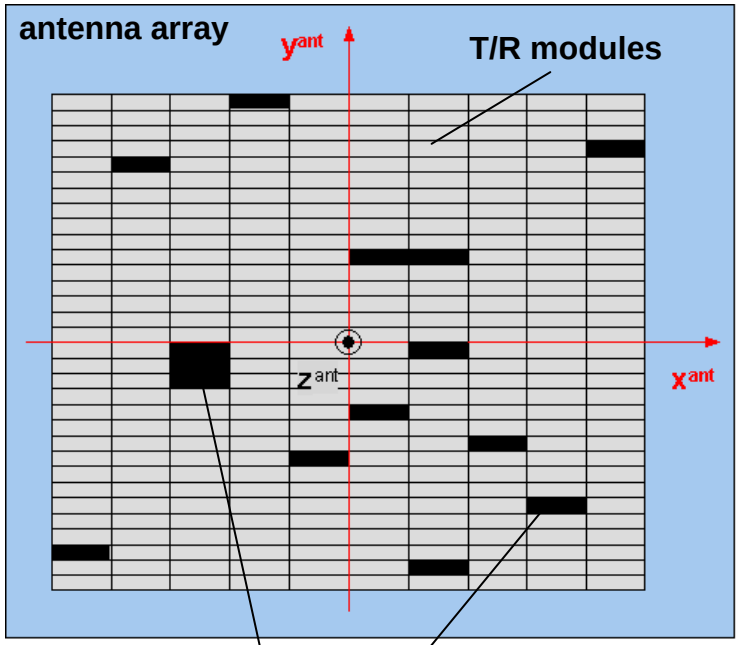
- **Different analysis & evaluation tools, like**
  - the presented antenna pattern model providing an estimation of the actual antenna pattern
  - SAR Product Control Software (SARCON) for target analysis of different calibration targets

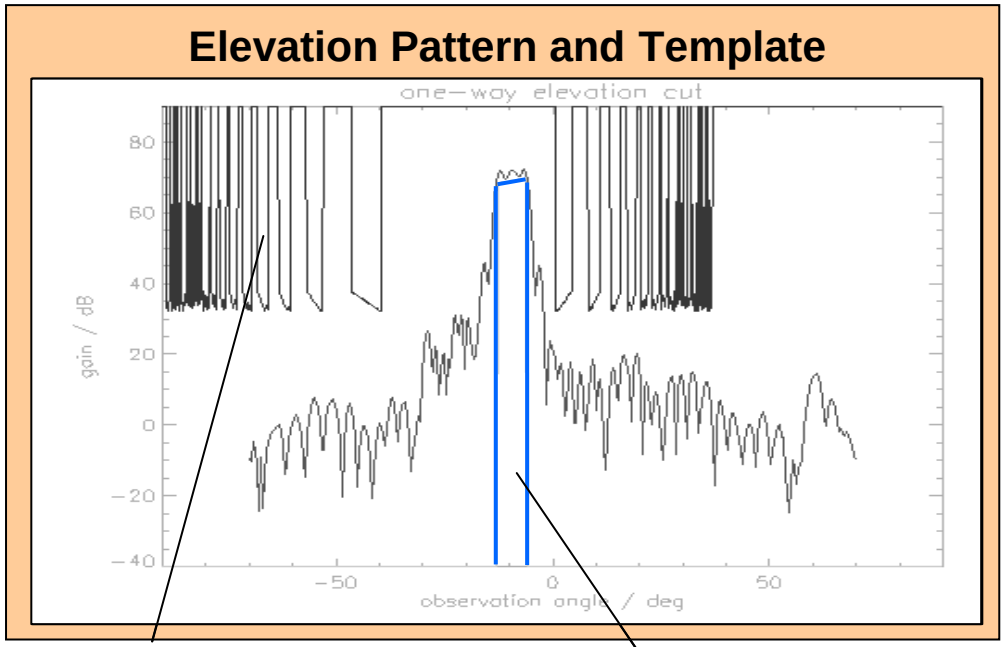
- **Appropriated SAR processor, as there are two types of calibration data that have to be processed:**
  – SAR images covering deployed calibration targets,
  – Special calibration products like these of the presented

- **PN-gating method.**

In addition to the high demands, keeping the cost affordable is a major challenge for calibrating the TerraSAR-X instrument.

Challenge of Antenna Pattern Optimisation



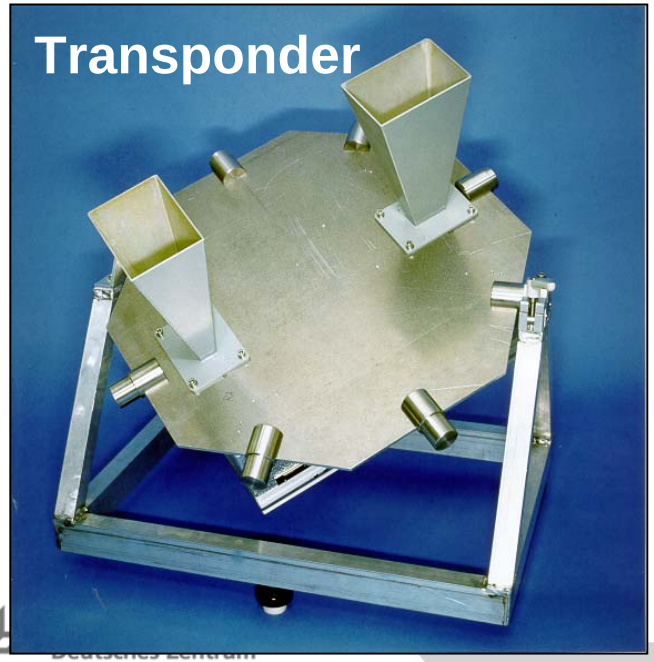


side lobe region **main lobe region**

drifted or failed T/R modules → optimization of remaining modules → **best beam steering**

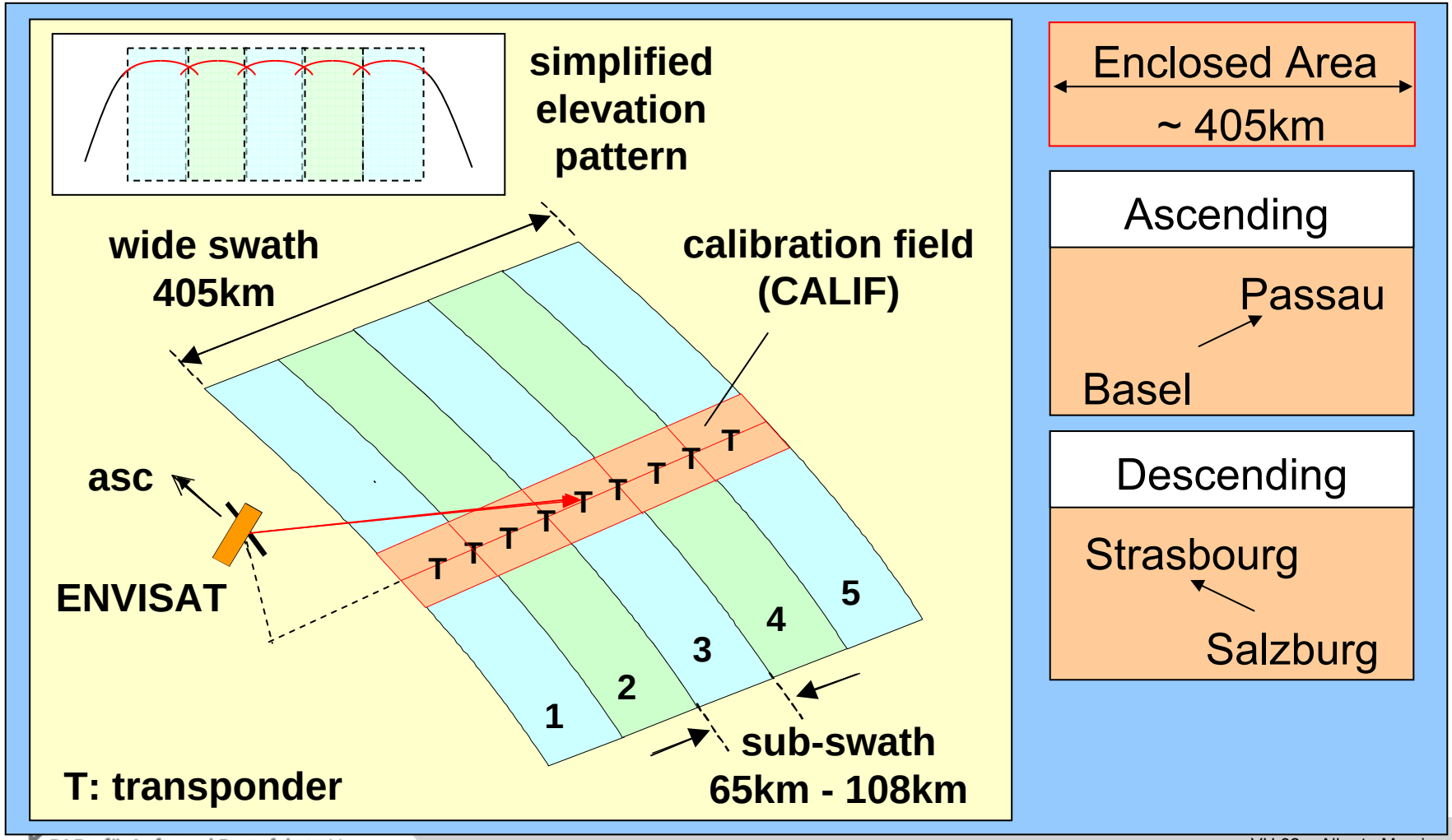
Bias Correction

- On-Ground Calibration Targets with known RCS
- External Calibration

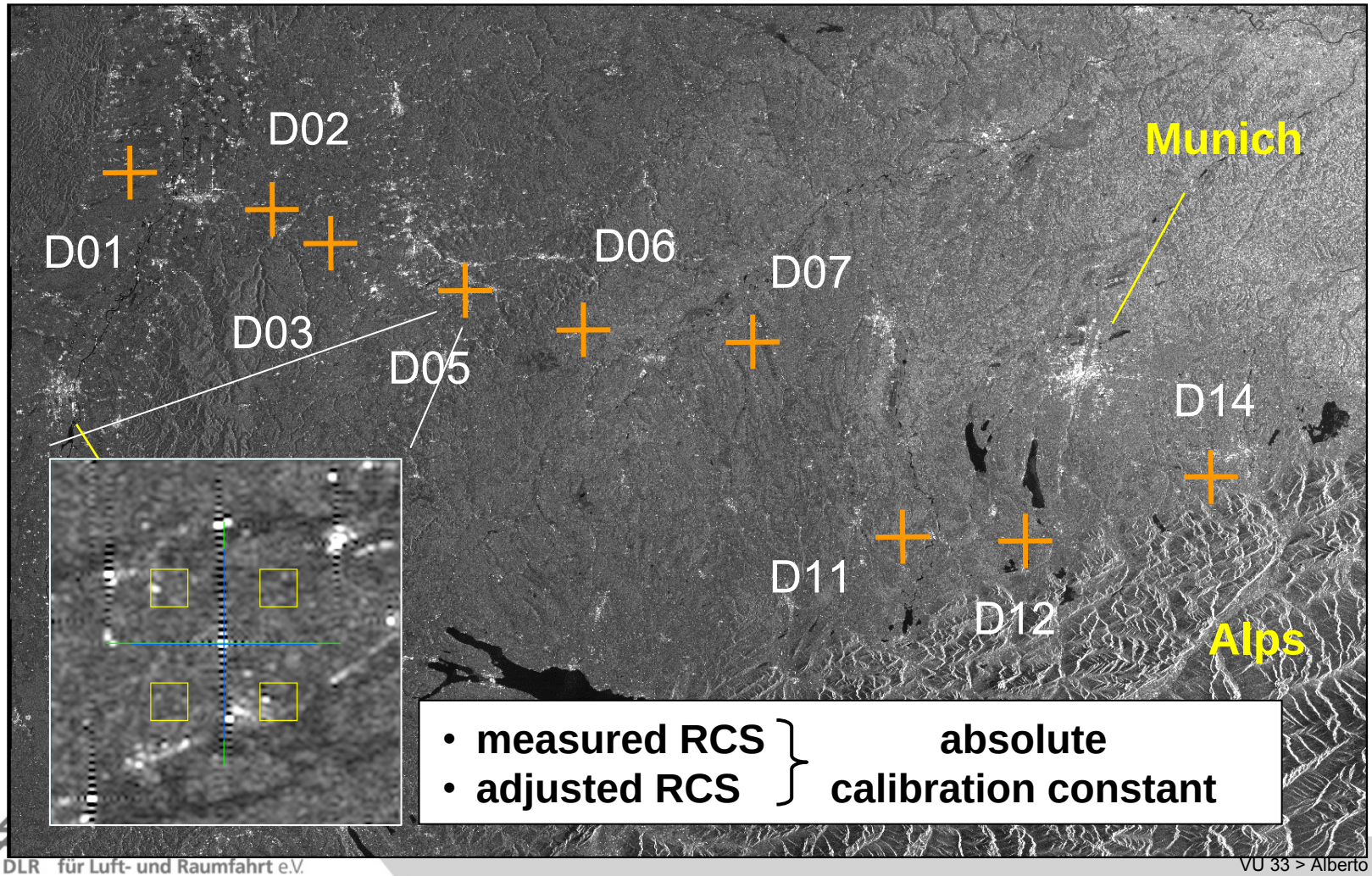


- SRTM 2000
- ENVISAT/ASAR 2002

Calibration Field for Scan SAR, ENVISAT/ASAR



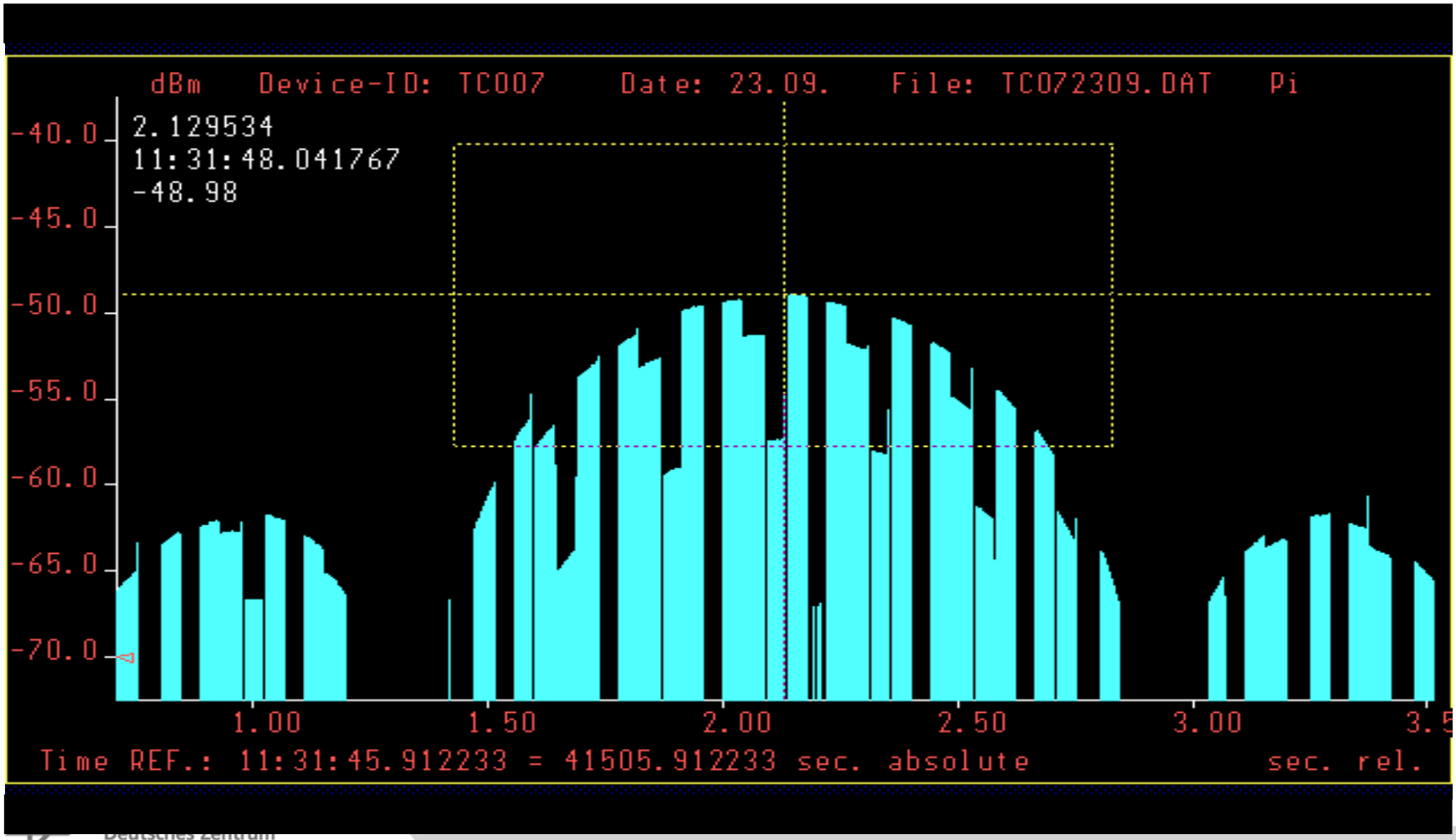
ScanSAR Image of ASAR/ENVISAT, 12-10-02



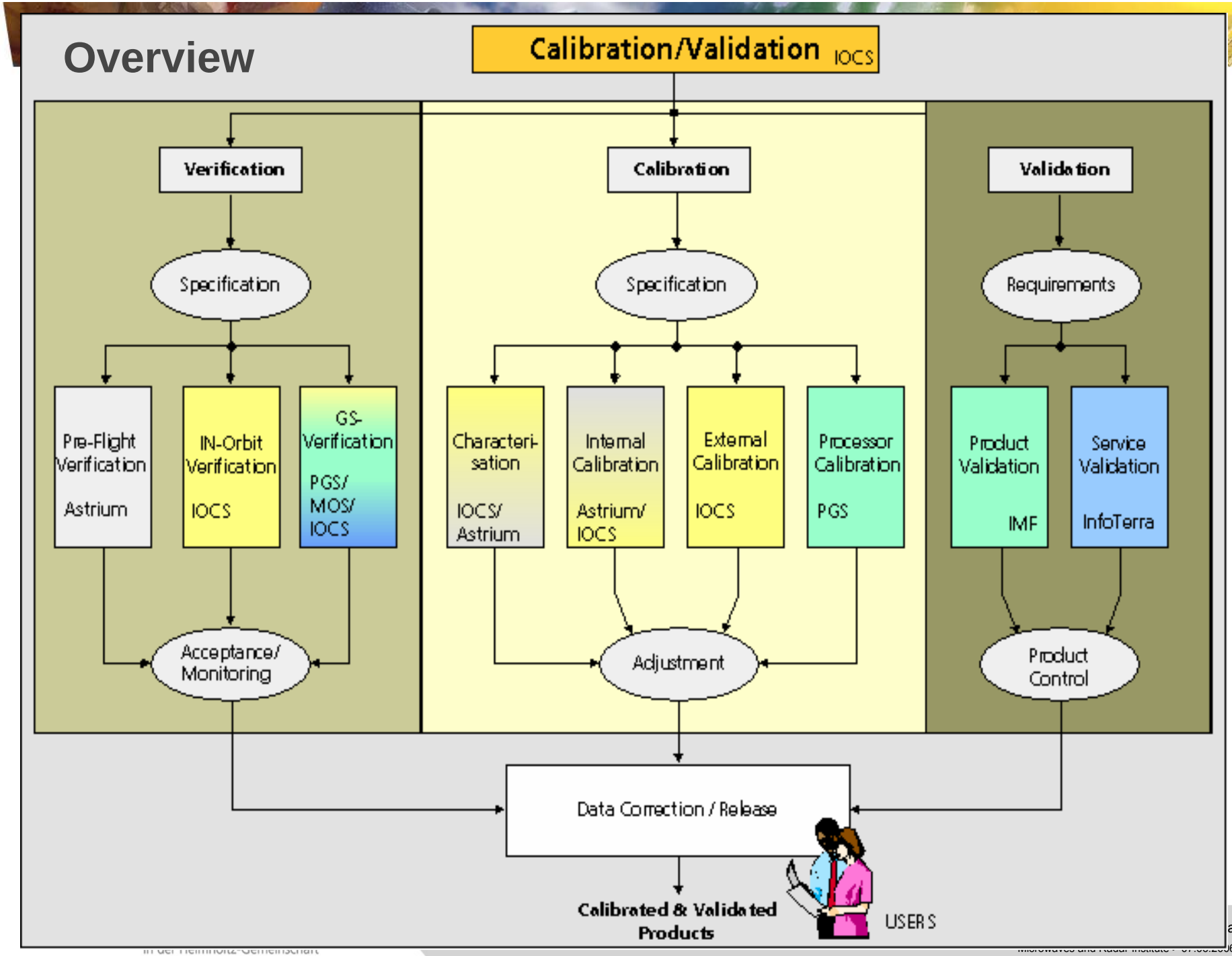
- **measured RCS**
- **adjusted RCS**

} **absolute calibration constant**

Measured Azimuth Antenna Patterns of ASAR/ENVISAT



Overview


Calibration/Validation IOCS
Verification
Calibration
Validation
Specification
Specification
Requirements
Pre-Flight Verification Astrium
IN-Orbit Verification IOCS
GS-Verification PGS/ MOS/ IOCS
Characteri-sation IOCS/ Astrium
Internal Calibration Astrium/ IOCS
External Calibration IOCS
Processor Calibration PGS
Product Validation IMF
Service Validation InfoTerra
Acceptance/ Monitoring
Adjustment
Product Control
Data Correction / Release
Calibrated & Validated Products
USERS