Interferometric TanDEM-X Data Processing – First Operational Experiences

CEOS SAR Calibration and Validation Workshop
Fairbanks, Alaska, November 07 – 09, 2011
Outline

- Integrated TanDEM-X processor (ITP) overview
- Bistatic processing challenges: oscillator and data take start time synchronization
- InSAR processing highlights
- High throughput and quality control
- ITP production and quality data base
The Integrated 
TanDEM-X 
Processor (ITP)

From Instrument Raw 
Data to 
Raw DEMs
Bistatic TanDEM-X Acquisitions

- bistatic acquisition geometry
- combined satellite dependent transmit and receive delays
- oscillator phase and data take start time synchronisation

TSX Satellite

TDX Satellite

TSX Satellite

TDX Satellite

or

Pico Teide, Tenerife

Mt. St. Helens, USA
Independent Ultra Stable Oscillators in Bistatic Mode

Problem:

- Carrier frequency and phase of SAR transmitter is not equal to the demodulation frequency of the bistatic SAR receiver and the sampling raster is not adequate.

- If not compensated, unacceptable image distortions ($\approx 3.7 \text{ m/s}$) and interferometric phase errors ($\approx 2\pi \cdot 120 \text{ rad/s}$) occur.
Way Out: Synchronization Pulse Exchange
Oscillator and Data Take Start Time Synchronization

- On-ground processing of synchronization pulses, determination of the compensation function including data take start time shift correction

- Challenges:
  - Sync pulse peak locations and phases are affected by unwanted relativistic offsets (cm-level) caused by the motion of the receiving satellite with respect to the transmitter during the sync pulse travel time $\Delta \tau$
  - Measured phase of the sync pulses contains unknown multiples of $2\pi$ $\Rightarrow$ Compensation phase is ambiguous by $\pi$
  - Application of the compensation function during SAR processing
Bistatic Synchronization Accuracy Contribution to Relative Height Accuracy

Test Site: Salar de Uyuni, Bolivia

- if correction with fixed frequency offset only => relative height errors in range of +/- 10 m for phase-to-height conversion factor 39 m / 360°
- check of azimuth height profile on flat salt lake area => maximum variation of 30 cm along 40 km

thus: perfect synchronization, no indication of residual phase errors
Test Site Salar de Uyuni: Difference of 2 bistatic raw DEMs

- Raw DEMs are free of time varying height errors potentially caused by oscillator offsets and drifts or other system errors.
ITP Interferometric Processing Sequence

Coregistered Single-Look Slant-range Complex (CoSSC) products are intermediate products for dual baseline phase unwrapping & experimental user products

- signal based high-res. coregistration
  - no reference DEM required
- essential “byproduct”:
  - radargrammetric shifts used for
    - absolute phase offset
determination
    - = absolute height “pre-” calibration
- fully automated phase unwrapping
  - quality control
- dual baseline phase unwrapping in 2nd year using both coverages to unwrap the problematic (large baseline) data
Absolute Radargrammetric Heights

Coregistration range shift

The point $P$ is seen – in ground range – in $A$ for the master and in $B$ for the slave.

$\Delta = \Delta(h)$

Coregistration $\Rightarrow$ radargrammetric shift if
- all instrument delays are well calibrated
- orbits / baselines are known
- independant from reference data (specifically in polar regions)
- achievement of consistent estimates for all scenes of data take

$\Delta_{gr}$

parallactic angles $\Rightarrow$ time delays in SAR = phases in InSAR

$\theta_1$, $\theta_2$

$A$, $B$, $P'$

$\Delta = \Delta(h)$
Absolute Phase Offset, DEM Processing & Calibration

Long data takes split in *independently processed* scenes: DEM continuity is required to apply only data take based small residual DEM calibration parameters (tilts, trends, …) in MCP.

ITP pre-calibrates each individual scene without *any* tie-pointing!

Only integer offset corrections applied, fractional phases untouched.

*Optimal* unwrapped phase avoids discontinuities.
Absolute Phase Offset, DEM Processing & Calibration

Long data takes split in **independently processed** scenes: DEM continuity is required to apply only data take based small residual DEM calibration parameters (tilts, trends, …) in MCP.

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**Phase offset between radargrammetry and SRTM**
- relative shift measurement variation < 2mm (incl. errors in SRTM)
- integer phase offsets easily match right HoA band
- even match pi ambiguity band in about 90% of scenes

scenarios = 50x30 km @ 3m res.
Radargrammetry for Phase Unwrapping Quality Control

A filtering step is implemented for the “histogram shrinking” step to robustly detect only one distinct phase offset $\leftrightarrow$ outliers are incoherent and / or unwrapping errors.

Color coded difference (in cycles) between radargrammetric and unwrapped phase for each patch.

Ex: two clear phase unwrapping regions are detected after an Anisotropic Diffusion (Perona & Malik) filter.
Feed Back Loops for Bistatic Calibration

Complex feed back loops were implemented in the TanDEM-X ground segment for the challenging bistatic calibration of the overall system.

ITP performed the analysis for

- radargrammetric phase calibration: calibration/determination of all bistatic delays, e.g. RX gain, sync horn
- sync errors in interferometric phase
- sync link signal quality (gain optimization) and oszillator stability monitoring
- acquisition quality assessment (beam illumination, common coverage)
- interferometric quality parameters (coherence, phase unwrapping error detection) for optimization of acquisition strategy
ITP Throughput and Quality Control

- designed for 600 Raw DEM scenes per day (about 150 % in terms of daily expected TanDEM-X acquisitions)
- able to generate 1300 Raw DEM scenes per day
- no operator interaction, automated system inherent quality control:
  - coherence
  - phase unwrapping ratio (residual density, branch cuts), phase unwrapping statistics
  - ...
- philosophy: annotate suitable quality measures, flag deviations, but do not yet make final quality decisions
- however: interactive quality control done at DEM mosaicking and calibration which may initiate reprocessings at ITP

ITP Production and Quality Data Base gathers comprehensive ITP info (annotation and parameter files, quicklooks, maps, parameter plots, log files,...) and stores a large set of parameters to support data base queries
Processing System ITP Hardware Environment

- 16 processing nodes with 8x8 Core Opteron CPU
- 4 processing nodes with 8x12 Core Opteron CPU
- each processing node: 128 GByte RAM
- thus: 2560 GByte RAM and 1408 CPUs in total

processing cache with 60 TByte

10 Gbit Ethernet

10 Gbit InfiniBand connection

Fibre Channel
see generation time stamps for single scene Raw DEM generation frequency

blue=water (Globecover)
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*blue* = water (Globecover)
*black* = problematic region
## TDM-1 - RDEMGRA QA - tdm0_w147d73n65d26_20557_20110228T031643_005_ITP

Processing Run Id: 231937, Acquisition Item Id: 1012222, Application: usedForGlobalDEM
TAP Take Id: TAP_0101.211_0_NA_USA_tanDEM_at_040R_002318
Baseline Product: TDM1_OFZ__BLI_CALB_20110227T234945_20110228T120645_20110819T201245.xml

### Master Satellite | Slave Satellite
---|---
DT-Time | 2011-02-28T03:18:08.910785  
2011-02-28T03:18:08.910785  
2011-02-28T03:18:21.094723  
2011-02-28T03:18:21.094723
SatID | TDX-1  
TSX-1
Orbit | 20557 A  
20557 A
Imaging Mode | SM (bistaticActive)  
SM (bistaticPassive)
Polarisation | S (HH)  
S (HH)
Scene Index 6 | Scene Times | 2011-02-28T03:18:43.727838  
2011-02-28T03:18:51.727774  
2011-02-28T03:18:43.727838  
2011-02-28T03:18:51.727774
Incidence Angle | 36.988...39.962  
37.022...39.990

### Status | Quality related Parameters | Logging Messages | Consistency
---|---|---|---
Average Coherence | 0.755398 | Normalized | 1.759742 | ALARM
Effective Baseline | 146.31 m | Alongtrack | 70.62 m | EXCEPTION
Height of Ambiguity | 43.00 m | Track Distance | 304.55 m | QA_WARNING

*Generated on 2011-10-28 at 12:33:54*

*Show parameter table*
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Huge Selection of Parameter Plots
Data Processed between Aug 23 and Oct 26
TanDEM-X Raw DEMs Close to Fairbanks

Mosaic of 11 TanDEM-X Data Takes Acquired over Alaska
Conclusions

- Integrated TanDEM-X processor ITP is up and running since one year and thus most reliably fulfilling its TanDEM-X duty. Operational data processing of global DEM data started after completion of bistatic calibration phase August 23, 2011.

- In-orbit sync pulse exchange and on-ground processing are reliable and accurate as expected.

- RawDEMs are free of time varying height errors potentially caused by oscillator offsets and drifts.

- Excellent performance of the bistatic synchronization.

- InSAR processing and raw DEM generation are robust, reliable, and accurate. The performance exceeds the expectations.

- We successfully pushed the limits of exploiting the outstanding absolute and relative bistatic geometric accuracy to support calibration, quality control and to become independent of any reference data in InSAR processing.

- ITP’s radargrammetry and phase offsets became a workhorse for the bistatic system and baseline calibration process.
Thank You For Your Attention