TERRASAR-X: APPLICATIONS FOR SPACEBORNE HIGH RESOLUTION SAR DATA

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Abstract. This paper gives an overview of capabilities of TerraSAR-X and provides some first application results. The TerraSAR-X mission is based on a public-private-partnership agreement between the German Aerospace Centre DLR and EADS Astrium GmbH. It is the continuation of the scientifically and technologically successful radar missions X-SAR (1994) and SRTM (2000) and is designed for scientific and commercial applications. TerraSAR-X was launched on Friday the 15th of June 2007 from the Russian Cosmodrome in Baikonur (Kazakhstan). It continues to provide high quality imagery for numerous applications and for the establishment of an extended worldwide commercial EO-market. SpotLight, StripMap and ScanSAR are available acquisition modes and polarization diversity can be selected. Example results for mapping, digital elevation models, monitoring of tropical forest, CO2 storage, emergency response, and change detection are provided. Methods are discussed and an outlook for further work is given.

Keywords: SAR remote sensing, TerraSAR-X, mapping, change detection, CO2 storage, DEM

1. Introduction

TerraSAR-X, the German X-band high resolution satellite has been collecting imagery since its launch on June 15. 2007. Data prove of outstanding quality for numerous applications. The space mission TerraSAR-X is the first German space project implemented under a Public Private Partnership (PPP), Buckreuss et al. (2003). Cooperation partners are the Federal Republic of Germany represented by the German Aerospace Center (DLR) and Europe's leading satellite company EADS Astrium. Under this construct DLR is in charge of the scientific use of the TerraSAR-X data in the framework of the continuation of the scientifically and technologically successful radar missions X-SAR (1994) and SRTM (2000). The commercial marketing is undertaken exclusively by Infoterra GmbH, a wholly-owned EADS Astrium subsidiary specializing in the collection, processing, and distribution of air and spaceborne imagery and value-added products.

The TerraSAR-X SAR instrument is an active phased array X-Band system with a centre frequency of 9.65GHz. Data can be acquired in SpotLight, StripMap and ScanSAR modes with single-, dual- or full polarization. The nominal range bandwidth is 150 MHz, for High resolution SpotLight acquisitions (HS) 300 MHz bandwidth are available. The spacecraft was successfully launched into a sun-synchronous duskdawn orbit with a nominal orbit height at the equator of 514 km. It is flying at a velocity of 7,6km/s; this results in about 15 revolutions around the Earth per day and in a revisit time of 11 days. An overview of TerraSAR-X imaging modes is given in Table 1.

Table 1. Overview of TerraSAR-X Imaging Modes.

	SpotLight Mode (SL)		StripMap Mode		ScanSAR Mode
Polarization	single: HH or VV	dual: HH/VV	single: HH or VV	dual: HH/VV, HH/HV or VV/VH	single: HH or VV
Scene dimensions	10km x 10km (SL) 10km x 5km (HS)	10 km x 10km (SL) 10km x 5km (HS)	50km x 30km	50km x 15km	150km x 100km
Full performance range	20° - 55°	20° - 55°	20° - 45°	20° - 45°	20° - 45°
Azimuth resolution	1.7m (SL) 1.1m (HS)	3.4m (SL) 2.2m (HS)	3.3m	6.6m	18.5m
Ground range resolution (@ incidence angle)	1.48 – 3.49m (@55°…20°) HS with 300MHz 0.74 – 1.77m (@55°…20°)	1.70 – 3.49m (@55°…20°)	1.70 – 3.49m (@45°…20°)	1.70 – 3.49m (@45°…20°)	1.70 – 3.49m (@45°…20°)

2. TerraSAR-X Applications

TerraSAR-X application fields are based on a combination of new features of SAR instrument that are for the first time available on space sensors. The very high resolution, the multi-polarization and multiincidence angle capability of TerraSAR-X open very interesting perspectives of applications, as shown in Faller and Weber (2007).

SAR data is applicable to a large number of applications.

- Maritime applications include ship and oil spill detection, coastal monitoring, sea ice monitoring, and the extraction of wind and wave information.
- Land applications include topographic and thematic mapping, agriculture and forestry applications, DEM extraction, and subsidence measurements.

The number of available analysis methods includes:

- Visual analysis (for mapping and image intelligence)
- Segmentation and Classification (supervised or unsupervised, pixel based or object based)
- Interferometric techniques (InSAR, DInSAR, PSInSAR) can be used to extract digital elevation information, monitor changes between acquisitions or measure subsidence or uplift of the observed surface.
- Radargrammetry (which proves to be a more robust method to extract DEM information)

The High resolution SpotLight mode provides imagery with enough detail to be of use for the image intelligence community. Besides the high resolution for single acquisition analysis, TerraSAR-X is particularly suited for monitoring and change detection approaches.

Of the many possible applications, the remainder of this section will provide some examples of select land results.

2.1 Topographic and Thematic Mapping

Figure 1 shows a TerraSAR-X radargrammetry based DEM of a test site in Papua New Guinea. Ascending and descending image pairs were used to generate two DEM's, which were subsequently merged. Radargrammetry proves to be the more robust approach for TerraSAR-X DEM production as vegetation causes temporal decorrelation in an interferometric approach. The achievable DEM quality is currently under review and depends on the modulation of the terrain. First results are promising and indicate a significant improvement over the currently available SRTM C-band DEM's.

Figure 2 shows an example topographic base map (produced using visual interpretation) based on an international mapping standard. While optical data is the standard for this type of application, TerraSAR-X data can be acquired reliably even in areas with frequent cloud cover.

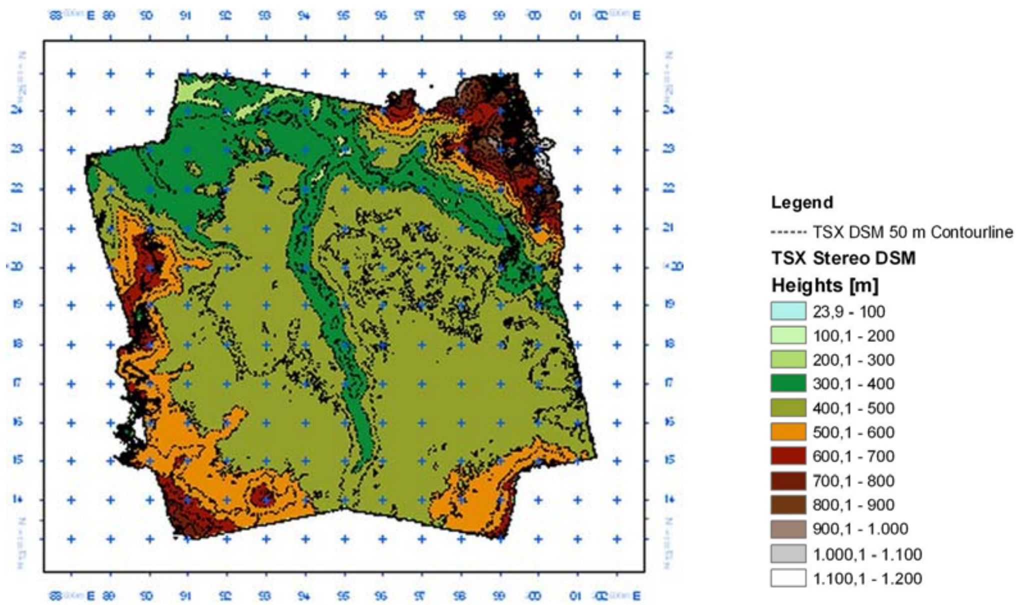

Figure 1. TerraSAR-X radargrammetric DEM (Papua New Guinea)

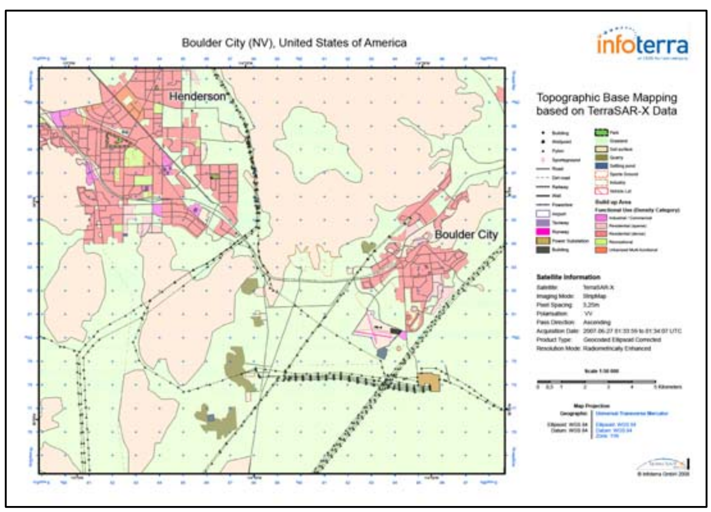

Figure 2. Topographic base map example based on TerraSAR-X

2.2 Contribution of TerraSAR-X for tropical forest monitoring

Deforestation presently accounts for roughly 20 percent of anthropogenic greenhouse gas emissions. Remote sensing systems will play a critical role in the development of Reduced Emissions from Deforestation and Degradation mechanisms that seek to compensate tropical forest nations for avoiding and reducing deforestation.

Very little knowledge is available on the suitability of X-band radar for forest mapping. Studies in various tropical sites demonstrated that multi-temporal TerraSAR–X acquisitions in StripMap and ScanSAR are useful:

a) to detect changes in forest cover, clear-cuts as well as selective logging
b) to map broad land use/ land cover and forest types (see Figure 3)
c) to map tropical forest types (peat swamp, tall interior and low pole forest) and to characterize forest degradation and status of re-growth (demonstration based on TerraSAR–X StripMap for peat swamp forest in Kalimantan).

Figure 3i illustrates the ScanSAR data base (3 acquisition dates) used for classification of broad land cover and forest types. The light green areas in the top left half of the image mark tropical peat-swamp forest of the Sebangau Ecosystem in Central Kalimantan, which is renowned for its high conservation importance and natural resource functions. The Sebangau is suffering from drainage caused by the construction of hundreds of canals by illegal loggers (many of these can also be distinguished in the image), who use them to float felled timber out of the forest. These canals are rapidly draining the peat of moisture, which threatens to cause peat and forest collapse and large-scale forest fires (various fire scars can be identified in the image). The area of deforestation can be identified in darker green colour in the bottom right half of the image (conversion to rice field) and purple (open land resulting from forest clearing or fire).

Figure 3ii shows the result of an object-based classification approach according to GSE Forest Monitoring service level agreement nomenclature. Interactive post-processing was used to improve differentiation between dense bush land and forest as well as between fire scars/ burnt forest and other open land. Quantitative validation of results is currently underway. By visual interpretation a more detailed legend can be applied even for ScanSAR (18m resolution) which allows mapping scales up to 1 : 50 000.

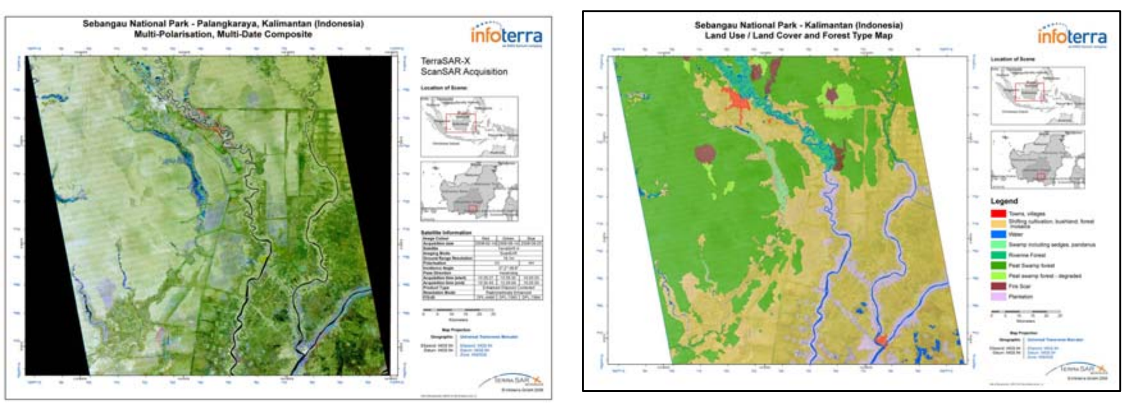

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Figure 3. Sebangau Ecosystem in Central Kalimantan
(i) Multi-temporal/ multi-polarized ScanSAR color composite
(ii) Land Use/ Land Cover &Forest type map derived from multi-temporal TerraSAR-X

ScanSAR data

2.3 CO_2 Storage and Enhanced Oil Recovery Monitoring

The capability of TerraSAR-X has been tested for the derivation of surface movements related to injection and production activities. Differential Interferometry has shown a sensitivity to surface movements of cm/year. TerraSAR-X with its high resolution in combination with its 11 day repeat orbit provides an opportunity to observe small scale as well as highly dynamic events.

The In Salah CO_2 storage site in Algeria operated by Sonatrach, BP and Statoil is an industrial-scale CO_2 capture and storage project within the In Salah Gas Joint Venture. CO_2 from several fields within the development is removed from the production stream and injected into the aquifer several km away from one of the gas reservoirs (the Carboniferous sandstone at Krechba). Injection commenced in 2004 and to date over 2.5 million tonnes of CO_2 have been stored in the saline aquifer as shown in Ringrose et al. (2008).

For analysis a total of 13 TerraSAR-X StripMap datasets have been available from March to September, 2008. This data have been processed using the technique of Differential Inteferometric SAR (DInSAR). In order to separate the low surface movement signal from existing atmospheric distortions, an integration of subsequent interferograms of low temporal baseline has been made.

The first result of this integration is visualized in Figure 4. This result shows that TerraSAR-X is very well suited for the derivation of low amplitude surface movements in conjunction with CO_2 storage and production activities: Nearby injection wells KB-501 and KB-502 an uplift of approx. 6 mm is visible. A displacement rate of approx. 3 mm/year can be calculated by analyzing the temporal evolution of surface displacements nearby KB-501. In addition, the impact of production can be identified as low subsidence in the vicinity of production wells.

Further data acquisitions and analyses are currently ongoing in order to manifest the results obtained, so far.

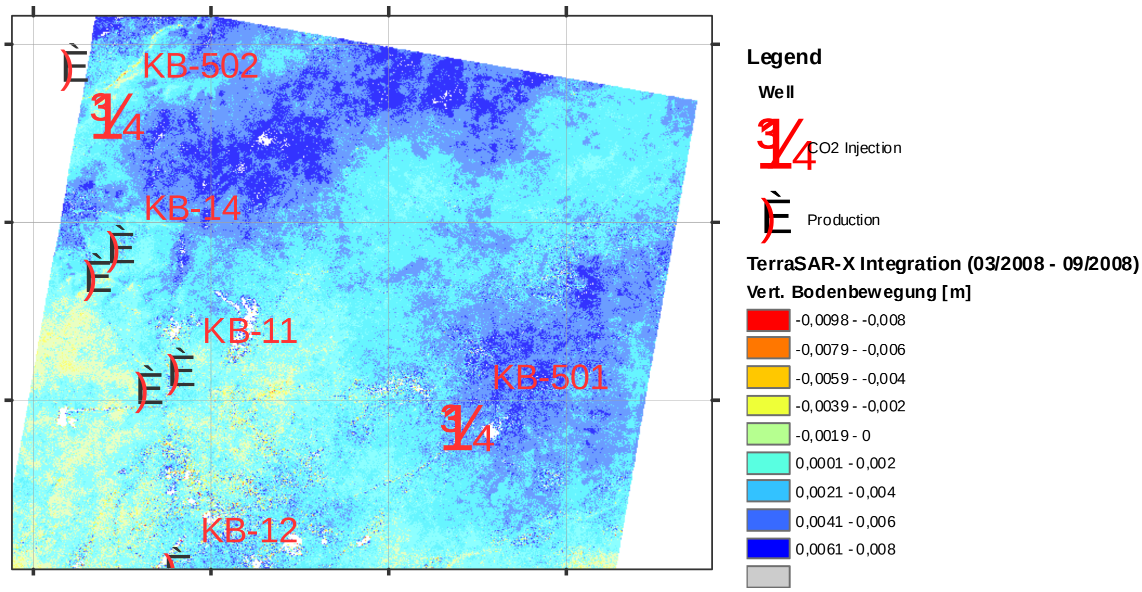


Figure 4. TerraSAR-X Surface Displacement Map at In Salah Gasfield (Algeria) and CO2 Injection/Storage site

Table 2. Flood event mapping using TerraSAR-X

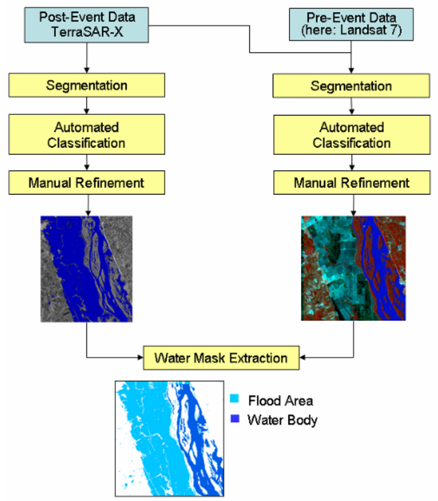
Flood event	Link for further information
England, July 2007	http://www.infoterra.de/image-gallery/images.html
Mexico, November 2007	http://www.zki.caf.dlr.de/applications/2007/mexico/142_en.html
Australia, January 2008	http://www.infoterra.de/image-gallery/images.html
Bolivia, February 2008	http://www.infoterra.de/image-gallery/images.html
Namibia, March 2008	http://www.zki.caf.dlr.de/applications/2008/namibia/149_en.html
Myanmar, May 2008	http://www.zki.caf.dlr.de/applications/2008/myanmar/150_en.html
Mississippi, June-July 2008	http://www.infoterra.de/image-gallery/images.html
Romania, July 2008	http://portal.rosa.ro/inundatii/2008_07/inundatii_2008_Iulie.htm
Nepal/India, September 2008	http://www.zki.caf.dlr.de/applications/2008/nepal/156_en.html
Haiti, September 2008	http://www.zki.caf.dlr.de/applications/2008/haiti/158_en.html

2.4 Emergency Response – Flood Mapping

Since its launch in June 2007, TerraSAR-X data has been applied in support of Flood Mapping and Flood Monitoring on several occasions. Data analysis was undertaken by Infoterra, the German Center for Satellite Based Crisis Information (ZKI), and/or local organizations. Table 2 gives a summary of the flood events in question and provides links for further information. The number of events offers a considerable sample set covering a range of environmental conditions in different parts of the world. Data were used to develop a semi-automated work flow for TerraSAR-X based flood mapping and monitoringas shown in Figure 5. This multi-mission concept has several advantages:

- flood masks with the highest possible accuracy can be produced even when no TerraSAR-X pre-event data are available;
- the revisit time (i.e. the time between subsequent acquisitions of the affected area) can be reduced if data from multiple sources are applied. This is an important factor when processes such as rising or declining water levels are to be monitored.

for near-coincident acquisitions, new algorithms could be developed that utilize information from several sources to provide more accurate results.



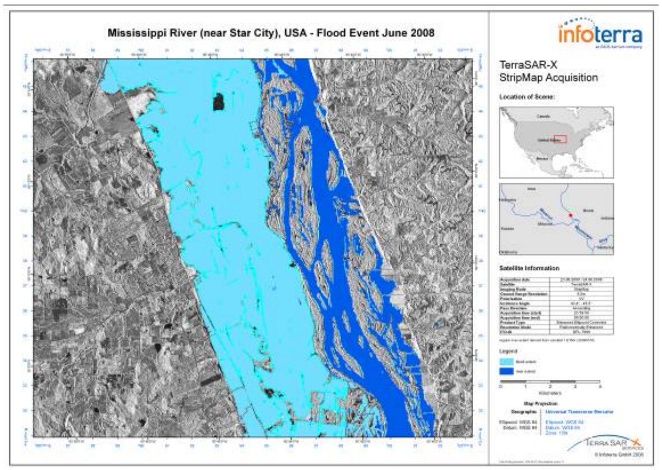


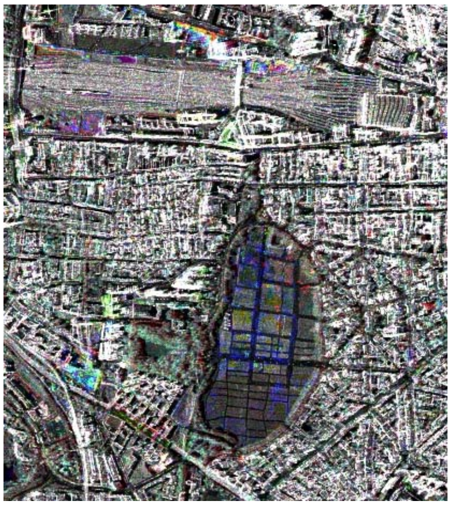
Figure 5. Work flow and resulting flood extent map based on TerraSAR-X (post event) and Landsat ETM (pre event). Dark blue areas are water bodies; light blue depicts flooded areas.

2.4 Change Detection

Change detection has a wide range of applications. Satellite remote sensed data and GIS for land cover, land use and its changes are key information for urban planning, forestry, agriculture, and security for example.

Two main approaches for change detection can be distinguished and applied with TerraSAR-X data; the incoherent and coherent change detection. The selection of the most adequate TerraSAR-X imaging modes, polarisation and incidence angle depends on the considered area and of the amplitude of the changes that should be detected.

- Incoherent change detection identifies changes in the amplitude image of a scene (amplitude ratio estimation, combination of the amplitudes image of a time series of a same test-site colouring differently each date in order to highlight changes). Figures 6 I and ii show that a high level of changes can be detected using TerraSAR-X SpotLight and StripMap modes.
- Coherent change detection identifies changes in the complex signal (both on amplitude and phase) using coherence analysis. As the SAR image amplitude and phase are sensitive to changes in the spatial distribution of scatterers within a resolution cell.



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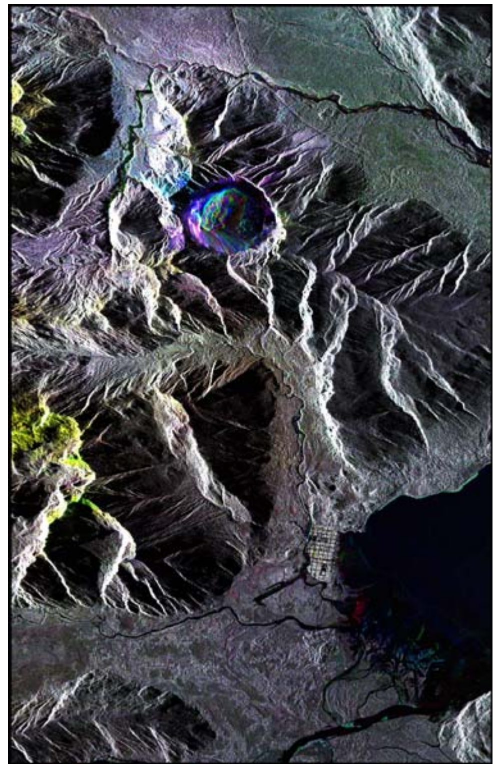

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Figure 6. Amplitude change detection results
(i) RGB combination of TerraSAR-X images (HS 300 Mhz-EEC SE) over Munich City centre - Red (2008-05-02), Green (2008-06-26), Blue (2008-08-09) - Constructions installed for the summer season are highlighted in blue
(ii) RGB combination of TerraSAR-X images (SM-SSC) over the Chaiten volcano (Chile) - Red (2008-05-23), Green (2008-06-03), Blue (2008-06-14) – The changes due to the volcano eruption and the lava flows appear in color

3. Discussion

TerraSAR-X shows to be an excellent source of information for a large number of applications. The examples shown in this paper only provide few samples out of the wide of the range of possibilities.

The high resolution of the sensor combined with precise orbit information makes radargrammetry an interesting approach for DEM extraction. DEM's better than the currently available SRTM DEM can be produced.

Topographic mapping in cloud covered areas proves feasible, as data can reliably be collected. Tests were conducted using visual analysis and interpreter based map production.

While longer wavelengths may be more suited for general forestry applications, tests have shown that TerraSAR-X can be used for detecting changes in forest cover and to map tropical forest. In particular, X-band time series complement L-band data terms of timely data supply in case of rapid mapping (e.g. forest fire) but also where more detailed mapping on forest types and degradation is required.

The application of differential interferometry shows the sensitivity of the system to small movements (subsidence or uplift) of the area monitored. High resolution combined with a 11 day repeat orbit make the system particularly suited to monitor small areas affected as well as highly dynamic events. First results of data stack analyses show a considerably higher number of persistent scatterers compared to lower resolution SARs, particularly in urban areas.

A flood map was selected for a disaster response example. The workflow for providing the map is also discussed. TerraSAR-X emergency response is not limited to flood mapping. It also includes oil spill monitoring, and damage assessments following hurricanes and earthquakes.

Change detection has a large variety of applications ranging from urban monitoring, emergency response applications to mapping and defense and security. TerraSAR-X offers a short repeat orbit and a high positional accuracy well suited for this application.

Numerous more applications are possible with TerraSAR-X and are currently being explored. Infoterra is working on the commercialization of both TerraSAR-X data as well as value added services. Product development in industry is augmented by a dedicated science program for TerraSAR-X coordinated by DLR. The TerraSAR mission concept includes TanDEM-X, an approach to generate a global high quality DEM, and TerraSAR-X2, which will continue high resolution x-band data coverage beyond the life time of TerraSAR-X.

4. Acknowledgements

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