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Potential of spaceborne SAR for monitoring the tropical environments

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Abstract: Since the launch of the *ERS-1* and *-2* satellites on July 17, 1991 and April 21, 1995, respectively, and *RADARSAT* on November 4, 1995, microwave imagery has proven to be a powerful tool for ARD (afforestation, reforestation, deforestation) monitoring from space. The cloud penetrating capability of the spaceborne SAR (synthetic aperture radar) facilitated the monitoring of large perpetually cloud-covered tropical regions. The continuity of such data is assured by *ENVISAT* (launched on March 1, 2002) and *RADARSAT-2*. With the launch of very high resolution SAR systems such as the *TerraSAR-X* (launched on June 15, 2007) and the Constellation of Small Satellites for Mediterranean Basin Observation, *COSMO SkyMed* (launched on June 7, 2007), new opportunities for improved mapping and monitoring of tropical environments are available. The TerraSAR-X, the first operational commercial system offers up to 1 m spatial resolution with unprecedented weather-independent image quality and details. This paper illustrates the technical features of TerraSAR-X and presents first results from TerraSAR-X image analysis of tropical environments.

Resumen: Desde el lanzamiento de los satélites *ERS-1 y ERS-2* el 17 de julio de 1991 y el 21 de abril de 1995, respectivamente, y del RADARSAT el 4 de noviembre de 1995, se ha probado que las imágenes de microondas constituyen una herramienta poderosa para el monitoreo desde el espacio de los procesos de forestación, reforestación y deforestación. La capacidad de penetración de las nubes que posee el SAR (Radar de Apertura Sintética, siglas en inglés) desde el espacio ha facilitado el monitoreo de grandes regiones tropicales que están perpetuamente cubiertas de nubes. La continuidad de este tipo de datos fue asegurada a través del *ENVISAT* (lanzado el 1º de marzo de 2002) y del *RADARSAT-2*. Con el lanzamiento de sistemas SAR de muy alta resolución tales como el *TerraSAR-X* (lanzado el 15 de junio de 2007) y la *COSMO SkyMed (Constellation of Small Satellites for Mediterranean Basin Observation*, Constelación de Satélites Pequeños para la Observación de la Cuenca del Mediterráneo), puesta en órbita el 7 de junio de 2007, tenemos a nuestra disposición nuevas oportunidades para la cartografía y el monitoreo mejorado de los ambientes tropicales. El TerraSAR-X, el primer sistema comercial en operación, ofrece una resolución espacial de hasta 1 m, con una calidad y un nivel de detalle de imágenes independientes del estado del tiempo que no tienen precedentes. Este artículo ilustra las características técnicas de TerraSAR-X y presenta los primeros resultados del análisis de imágenes TerraSAR-X de ambientes tropicales.

Resumo: Desde o lançamento dos satélites ERS-1 e 2 em 17 de Julho de 1991 e 21 de Abril de 1995, respectivamente, e do RADARSAT em 4 de Novembro, 1995, as imagens de microondas provaram ser uma ferramenta poderosa para a monitorização a partir do espaço da ARD (florestação, reflorestação e desflorestação). A capacidade de penetração das nuvens pelo SAR (radar de abertura sintética) aerotransportado facilitou a monitorização de extensas regiões tropicais permanentemente nubladas. A continuidade de tais dados é assegurada pelo ENVISAT (lançado em 1 de Março, 2002 e RADARSAT-2. Com o lançamento de sistemas SAR de alta resolução como o TerraSAR-X (lançado em 15 de Junho, 2007) e da Constelação de Pequenos Satélites para a Observação da Bacia do Mediterrâneo e do COSMO SkyMed (lançado em 7 de

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Junho de 2007), encontram-se abertas novas oportunidades para melhorar o mapeamento e a monitorização dos ambientes tropicais. O TerraSAR-X, o primeiro sistema comercial operacional, oferece uma resolução espacial até 1 m com uma qualidade de imagem e de detalhes independentes das condições meteorológicas. Este artigo ilustra as características técnicas do TeeraSAR-X e apresenta os primeiros resultados das análises de imagem de ambientes tropicais.

Key words: Backscattering, interferometry, monitoring, rain forests, TerraSAR-X, tropical environment.

Introduction

Tropical rain forests are highly endangered ecosystems. Fast growing economies and population growth has resulted in increased rain forest conversion all over the world. Large scale deforestation in the tropics frequently leads to decreasing humidity and rainfall, which in turn impacts biodiversity, decreases agricultural and forest yields and increases the probability of large conflagrations. In many areas, where the exploitation and conversion of tropical rain forests proceed uncontrollably and with increasing rate, the unrecoverable degradation of the tropical ecosystems are to be expected.

Satellite systems play an increasingly important role in monitoring and controlling forest exploitation and land use practices worldwide. In the past, mainly optical satellite images (e.g. Landsat, IRS, SPOT) and aerial photographs were used based on the experience gathered from visual or computer-aided interpretation approaches. However, images taken in the visual spectral range show some disadvantages for operational monitoring of rain forests in tropical regions. Mean cloud coverage of about 90% in the tropical areas does not allow complete and repetitive coverage of the predetermined areas within a certain time frame. Besides possible deviations stemming from political conditions in many countries determining country level projections on forest conversion from a small number of cloud-free scenes is another major reason for the extreme discrepancy among authors on forest conversion rates (e.g. Holmgren & Persson 2002). Synthetic aperture radar (SAR) data offer a potential solution to this perpetual problem in the tropics. It is important to note that there are significant differences between a backscattered microwave signal and optical imagery in the way the SAR data is analysed. At first sight the new generation of SAR images appear like black and white photographs. But in contrast to optical information where objects appear in different colours and shapes, the backscatter of a SAR signal is mainly influenced by two components: the geometry and the dielectric properties of the target. The latter is mostly related to the moisture content of the target surface. Under tropical environmental conditions, this is another reason why SAR data might play an important role for forest monitoring and degradation assessment due to micro-climatic changes after forest conversion. In addition, the SAR images are degraded by a multiplicative noise known as speckle. However, since speckle is a result of the interaction of the SAR signal with the target surface it contains certain information about the target. Therefore, the SAR data interpretation, mainly related to geometry, noise, speckle and the complex interaction of radar signal with the heterogeneous surfaces, especially the vegetation cover, requires more scientific analysis to better exploit the information contents of the SAR data. The most striking features of ground range SAR image interpretation in contrast to optical interpretation are:

Table 1. Examples for large airborne SAR campaigns in the tropics (after Kessler, 1986).

Country/Project	Year	Area covered (km²)	Acquisition System
East Panama, N.W. Columbia (RAMP)	1967 & 1969	40,000	Westinghouse
Brasil(RADAM)	1970 / 76	8,500,000	Aero Services/Goodyear
Nicaragua	1971	80,000	Westinghouse
Peru	1974/75	600,000	Aero Services Motorola
Columbia (PRORADAM)	1973/76	320,000	Aero Services/Motorola
Nigeria (NIRAD)	1976 / 77	950,000	Motorola
Venezuela	1975 / 76	900,000	Aero Services

1. images contain shadows with no information due to the side-looking effect of the SAR antenna. Although ascending and descending orbits can be used (e.g. to acquire images in mountainous areas), there might be areas without any information. However, the terrain is better visible due to such shadow effects and the shadows may enhance certain features like single trees or forest edges. They might even allow estimation of height of an object, as the viewing angle of the object and its distance to the antenna is always known.
2. the shape of objects depends on SAR imaging geometry and also on the imaging mode.
3. speckle phenomenon leads to a grainy appearance, while some features appear as bright spots (corner reflection) which are not very conspicuous in optical data.
4. features underneath an object may be visible, for instance under a bridge due to multiple scattering.
5. multiple polarisation facilitates better recognition of features.
6. the radar signature of an object (backscattering at a certain wavelength and polarisation) depends on the aspect angle which might be assigned to a number of different objects, since their orientation towards the radar is not known, and
7. using SAR interferometry, it is possible to derive large-area surface terrain models such as those from the Shuttle Radar Topography Mission (SRTM) or the use of L-Band JERS data over rainforests (Werner *et al.* 2000).

Beside all these challenges and advantages, the cloud penetration capability of SAR sensors has fascinated scientists working in tropical environments since the beginning of this technology. Even in 1960s, the extensive airborne SAR campaigns were undertaken in many tropical regions (Table 1).

A good summary of the status of SAR applications in developing countries can be found in Sayn-Wittgenstein (1991). However, the real breakthrough of this technology was noticed after the successful launch of the *ERS*-1 and -2 satellites (July 17, 1991 and April 21, 1995 respectively) and RADARSAT (November 4, 1995). Since then microwave imagery has proven as a powerful tool for ARD (afforestation, reforestation, deforestation) monitoring from space. Kuntz (1997) and Kuntz & Siegert (1994, 1996, 1999a & 1999b) used for the first time the cloud penetrating capability of spaceborne SAR for monthly monitoring of large tropical regions in Indonesia and its ability to detect and monitor surface movements and anomalies over large areas has led to significant progress in SAR applications world-wide.

The continuity of SAR data is assured by *ENVISAT* (launched March 1, 2002), *RADARSAT-2* and *ALOS* (Advanced Land Observation Satellite). The latter was successfully launched on January 24, 2006 from the Tanegashima Space Center, Japan. The ALOS is equipped (besides other sensors) with a Phased Array type L-band SAR (PALSAR) for day and night and all weather land observations.

New very high resolution SAR systems

The new very high resolution systems, offering up to 1 m spatial resolution like TerraSAR-X, facilitate a variety of applications with weather independent, unprecedented image quality and information content. TerraSAR-X is the first German satellite implemented as a Public-Private

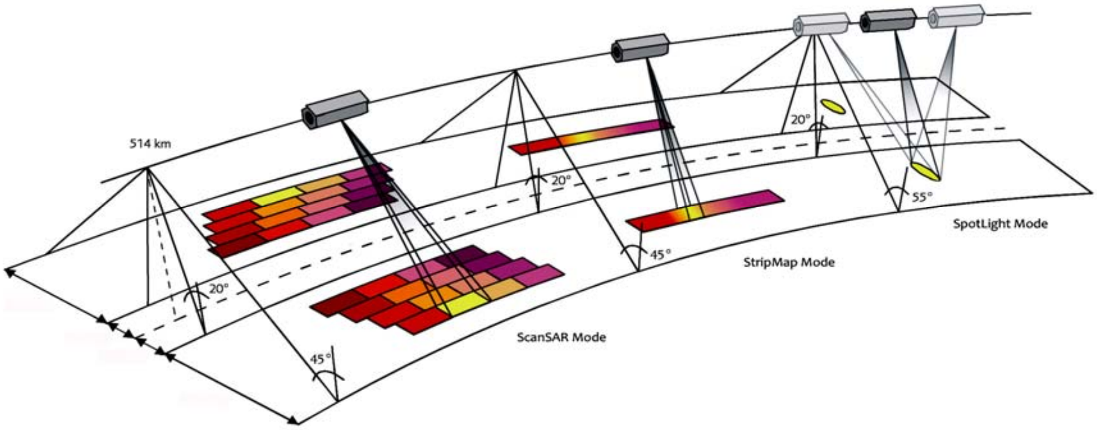


Fig. 1. The acquisition modes of TerraSAR-X (copyright by EADS-Astrium).

Table 2. Overview on some recently launched SAR systems.

Characteristics		TerraSAR-X	RADARSAT-2 *	COSMO-SkyMed **
Launch		06/2007	12/2007	06/2007
Resolution	SpotLight	~ 1 m (150 Mhz) (5x10 km)	~ 2.5 m (20 km swath)	~ 1 m (10 km swath)
	StripMap	~ 3 m (30 km swath)	~ 7.5 m (50 km swath)	< 5 m (40 km swath)
	ScanSAR	~ 16 m (100 km swath)	~ 50 m (300 km swath) ~ 100 m (500 km swath)	< 30 m (100 km swath)
Frequency		X-Band	C-Band	X-Band
Incidence Angle (NESZ)		15-60°	20-60°	20-60°
Polarisation		Quad pol	Quad pol	Quad pol

*http://www.radarsat2.info/product/RS-2_Product_Details_2007-Aug-1.pdf (not all modes included); **http://www.e-geos.it/products.html (not all modes included).

Partnership (PPP) between DLR (German Aerospace Centre) and Astrium, Europe's leading satellite company. Astrium contributes to the costs of system development, construction, and the launch of the spacecraft while DLR ensures the scientific use of the data. The Infoterra GmbH, a subsidiary of Astrium, is responsible for the commercial marketing of the data.

Placed in a polar orbit at 514 km, the TerraSAR-X is the first commercial satellite continuously providing global SAR data in X-Band (9.65 GHz). TerraSAR-X operates in three different modes - the ScanSAR, Stripmap and Spotlight mode with varying geometric resolution from 1 to 18 m. The TerraSAR-X also provides single or dual polarised data. Quad polarisation and along-track interferometry are possible on an experimental basis. Fig. 1 illustrates the acquisition modes of TerraSAR-X.

COSMO-SkyMed (Constellation of Small Satellites for Mediterranean Basin Observation) is a four spacecraft constellation, funded by the ASI (Agenzia Spaziale Italiana), and the Italian Ministry of Defense. Each of the four satellites is equipped with an SAR instrument and is capable of operating in all visibility conditions at high resolution and in real time (Table 2). The first satellite was launched on June 8, 2007.

First results from TerraSAR-X image analysis over tropical environments

Since January, 2008, TerraSAR-X is the first VHR SAR sensor which offers images operationally in its different modes on a commercial basis via Infoterra GmbH and for scientific purposes via DLR. Although many scientific issues still need to be investigated (e.g. best use of multi-polarisation imagery, image enhancement techniques, improved automated classification of image features, interferometric analysis etc.) by simply looking into the images the potential for applications in the tropics becomes obvious. Thus,

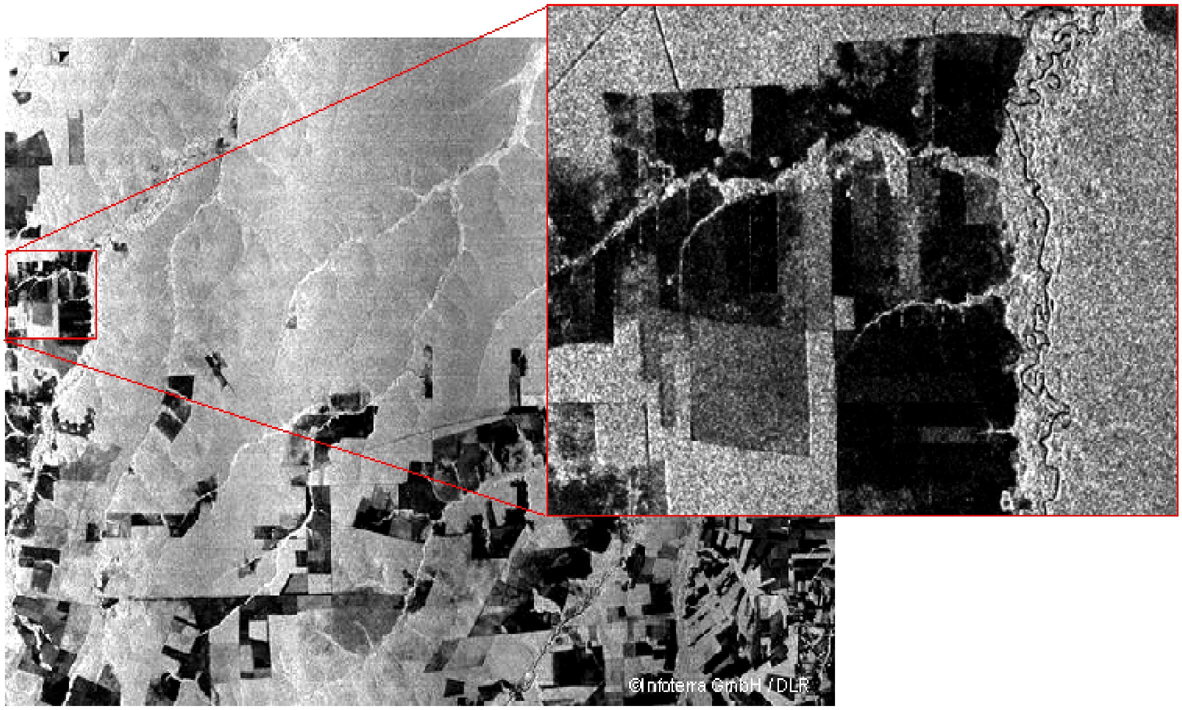
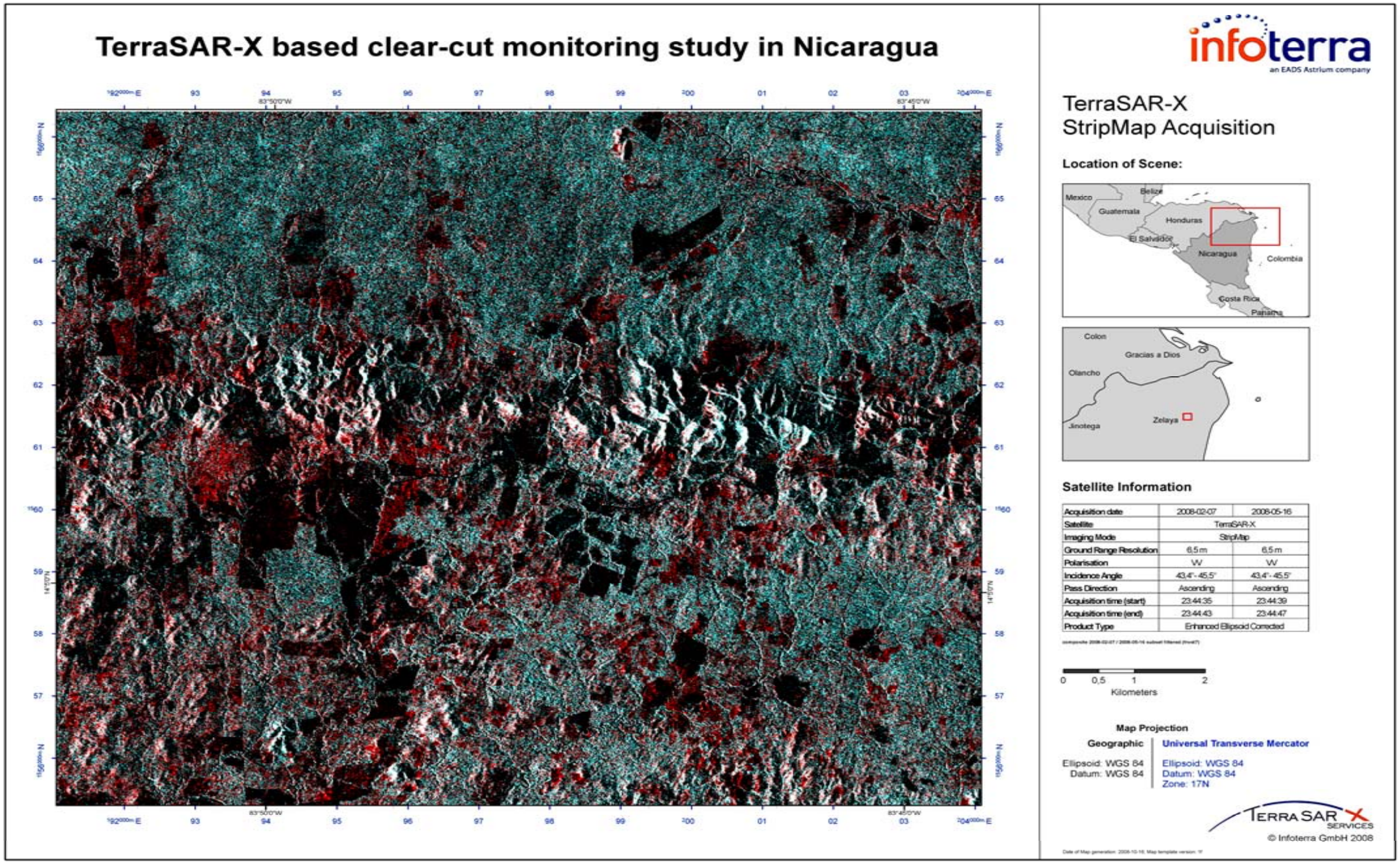


Fig. 2. Mato Grosso, Brasil: Rain forest - TerraSAR-X ScanSAR acquisition (18 m resolution, reduced), Jul. 08, 2007; polarisation: HH. The image shows conversion of rain forest (homogenous areas in the North into agriculture and plantations). At the right in the expanded view shifting cultivation pattern along the meandering river can be detected (©Infoterra GmbH).

a few examples are given below from different tropical forest conditions to illustrate the potential of the new VHR SAR systems.

In Fig. 2 TerraSAR-X ScanSAR image is shown from Brazil illustrating the encroachment in pristine forests for agriculture and plantations. Undisturbed areas show a rather homogenous surface (in light grey values by diffuse scattering), while plantations and pastures appear in dark tones due to reduced backscatter after trees are removed. The various tones in these rectangular features result from re-growth of vegetation allowing rough estimates of the age of these clear-cuts (see zoom-in image at the right). Shifting cultivation patterns appear in the lower right part of the image. They are distinct from the much larger clear-cuts for plantations and industrial agriculture. Morphological features such as the rivers and drainage systems can be observed as well. As the TerraSAR-X ScanSAR mode allows economically sound acquisition campaigns for large areas this feature is suitable for large area coverage such as national forest inventories or regular surveys of endangered areas.

Fig. 3 shows results of recent studies on forest clear cut monitoring demonstrated in Nicaragua. The upper image shows one of the rare optical images from this tropical area (i.e. a SPOT-2 image acquired 2008-09-23). The well-known problem of cloud coverage in optical imagery is evident. Under such circumstances the advantages of TerraSAR-X StripMap imagery can be used to identify clear-cut activities from time series. In the multi-temporal colour composite from two data takes acquired in February and May, 2008 potential change areas are indicated in the light red areas which are based on surface backscatter changes between bare soils and dense forests. Fig. 4 depicts clear-cuts (in light green) in the temporal TerraSAR-X data set, which were distinctly classified using object-oriented classification approaches. The potential clear-cut changes were finally estimated by calculating differences between classification results from different acquisition dates.



Acquisition date	2008-02-07	2008-05-16
Satellite	TerraSAR-X	
Imaging Mode	StripMap	
Ground Range Resolution	6,5 m	6,5 m
Polarisation	VV	VV
Incidence Angle	43,4°- 45,5°	43,4°- 45,5°
Pass Direction	Ascending	Ascending
Acquisition time (start)	23:44:35	23:44:39
Acquisition time (end)	23:44:43	23:44:47
Product Type	Enhanced Ellipsoid Corrected	

Fig. 3. Forest clear-cut monitoring using multi-temporal TerraSAR-X StripMap data in Nicaragua. On top one of the rare optical images (i.e. a SPOT-2 image acquired 2008-09-23) from this tropical area is given facing the well-known problems of cloud coverage. The image below is a RGB composite from two TerraSAR-X Scenes. Light red areas indicate clear-cut changes. Imaging Mode: StripMap; Pass Direction: Ascending; Incidence Angles: 43,4° - 45,5°; Acquisition Dates: 2008-02-07 and 2008-05-16. Colour-coding: Red = 2008-02-07, Green = 2008-05-16, Blue =2008-05-16.

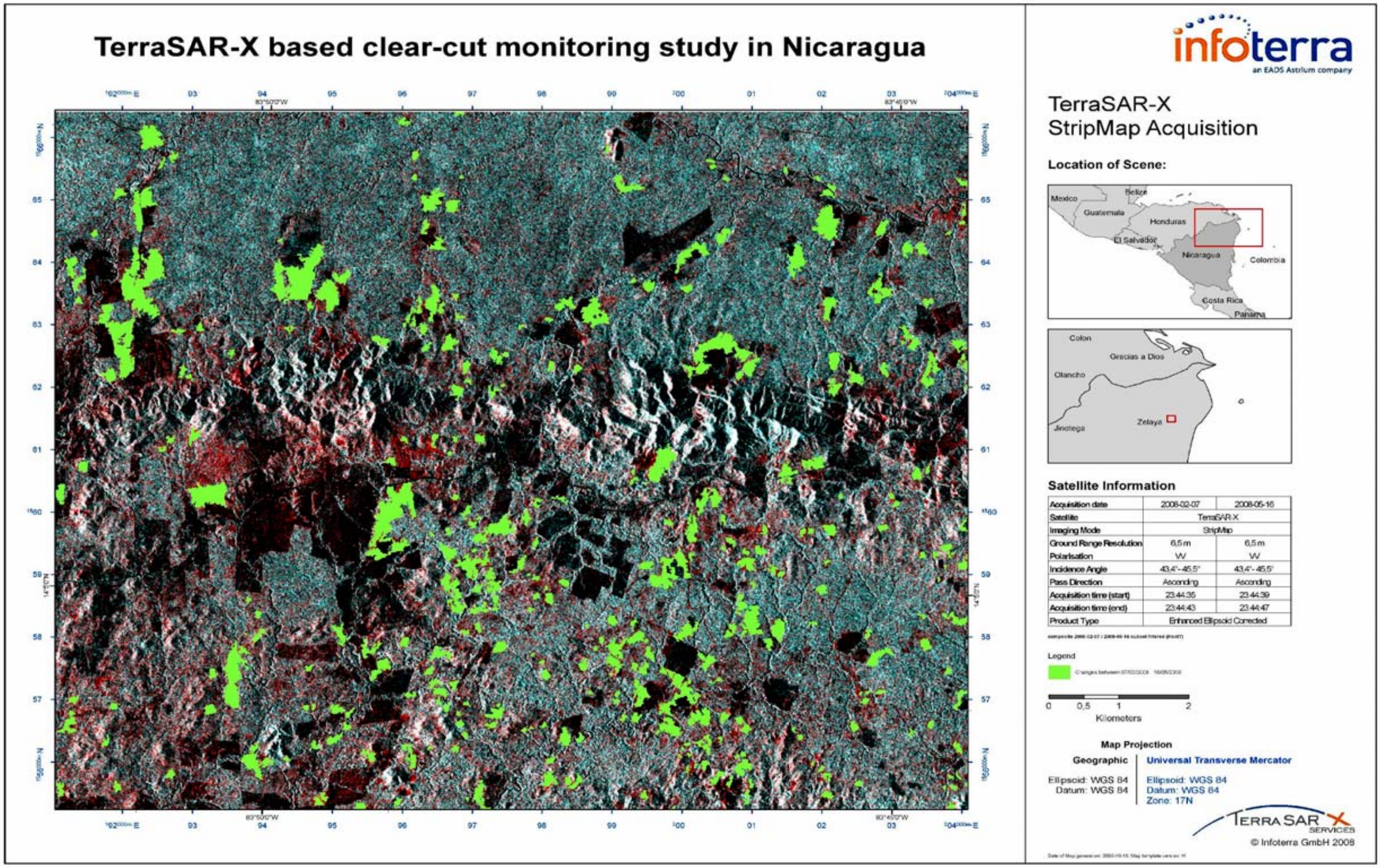


Fig. 4. Forest clear-cut mapping using multi-temporal TerraSAR-X StripMap data in Nicaragua. Light green areas indicate classified areas of clear cuts which occurred between 2008-02-07 and 2008-05-16 using object-based classification approaches.

Conclusions

With the advent of very high resolution SAR (synthetic aperture radar) systems such as the German TerraSAR-X, the Italian CosmoSkyMed and RADARSAT-2, new opportunities for improved mapping and monitoring of tropical environments are available. With these systems today environmentalists have powerful tools at hand to map and monitor regions with frequent cloud coverage at least weekly. Hence, it is possible to track fast changes (for instance in case fires or clear cuts) or the growth of plantations or other reforestation activities. The different acquisition modes of the different systems can be deployed for various application areas based on trade-offs between the level of details required and the budget available.

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