Application

2015-03-31

2015-05564	Ban, Yifang	NT-14

Information about applicant

Name: Yifang Ban

Doctorial degree: 1996-10-24

Birthdate: 19640826

Academic title: Professor

Gender: Female

Employer: Kungliga Tekniska högskolan

Administrating organisation: Kungliga Tekniska högskolan

Project site: Skolan för arkitektur och samhällsbyggnad

Information about application

Call name: Forskningsbidrag Stora utlysningen 2015 (Naturvetenskap och teknikvetenskap)

Type of grant: Projektbidrag

Focus: Fri

Subject area:

Project title (english): EO4Urban: Multitemporal Sentinel-1A SAR and Sentinel-2A MSI Data for Global Urbanization Monitoring

Project start: 2016-01-01

Project end: 2018-12-31

Review panel applied for: NT-14, NT-2, NT-15

Classification code: 20703. Fjärranalysteknik

Keywords: Sentinel-1A SAR, Sentinel-2A MSI , Data Fusion, KTH-SEG and KTH-Pavia Urban Extractor, Global Urbanization Monitoring

Funds applied for

Year:	2016	2017	2018
Amount:	830,376	820,376	855,376

Descriptive data

Project info

Project title (Swedish)*

EO4Urban: Multitemporal Sentinel-1A SAR and Sentinel-2A MSI Data för Global Urbanisering Övervakning

Project title (English)*

EO4Urban: Multitemporal Sentinel-1A SAR and Sentinel-2A MSI Data for Global Urbanization Monitoring

Abstract (English)*

With more than half of the world population now living in cities, and 1.4 billion more people expected to move into cities by 2030, urban areas pose significant challenges on the environment. Although only a small percentage of global land cover, urban areas significantly alter climate, biogeochemistry, and hydrology at local, regional, and global scales. Thus, accurate and timely information on urban land cover and their changing patterns is of critical importance to support sustainable urban development.

At present, the information urban planners and decision makers needed to support planning activities are either dated or collected through time-consuming field survey or visual interpretation of images. Through its synoptic view and the repeatability, satellite remote sensing can provide timely and accurate information necessary to map urban land cover and monitor urbanization. With the recent launch of Sentinel-1A and planned launch of Sentinel-2A in June 2015, high resolution SAR and optical data with global coverage and operational reliability become routinely available. They provide excellent opportunity to develop novel methods and algorithms for developing operational urban services and products to support planning decision-making. The overall objective of this research is to evaluate multi temporal Sentinel-1A SAR and Sentinel-2A MSI data for global urban services using innovative methods and algorithms, namely KTH-SEG, a novel object-based classification method for detailed urban land cover mapping, and KTH-Pavia Urban Extractor, a robust algorithm for urban extent extraction. Stockholm and nine cities around the world in different geographical and environmental conditions are selected as study areas. Sentinel-1A SAR and Sentinel-2A optical data will be acquired during vegetation season in 2015 and 2016. Historical ENVISAT ASAR and ERS-1/2 SAR data will be selected from the archives for monitoring of historical spatial temporal patterns of urbanisation.

KTH-SEG, an advanced segmentation method will be further developed for multi resolution segmentation of Sentinel-1A SAR and Sentinel-2A MSI data based on edge-aware region growing and merging algorithm using parallel computing. The post-segmentation classification is performed using support vector machines. KTHPavia Urban Extractor, the proposed processing chain for urban extent extraction includes urban extraction based on spatial indices and Grey Level Co-occurrence Matrix (GLCM) textures, an existing method and several improvements i.e., parallel computing, SAR and optical data preprocessing, enhancement, fusion and post processing. Both KTH-SEG and KTH-Pavia Urban Extractor will be adapted, improved and applied to Sentinel-1A SAR, Sentinel-2A MSI data as well as their fusion. Two users, the Urban and Regional Development Department at the Stockholm County Administrative Board (SCAB) in Stockholm and and National Geomatics Center of China (NGCC) at the National Administration of Surveying, Mapping and Geoinformation of China in Beijing, have committed to participate in the project. This gives us a unique opportunity to better understand the user needs and to develop much needed urban services to support planning decision making.

This research and development is expected to produce a pilot global urban services demonstrator using multitemporal Sentinel-1A SAR and Sentinel-2A MSI data. The project will contribute to i). better understanding of the urban products and services that the users require; ii). development of novel and robust methods and algorithms for improved urban information for planners to support smart and sustainable urban development; ; iii). better understanding of the capacity of Sentinel-1A SAR and Sentinel-2A optical data for detailed urban land cover mapping and urbanisation monitoring; iv). the goals and activities of GEO SB-04 Global Urban Observation and Information Task and GEO SB-02 Global Land Cover Task.

Popular scientific description (Swedish)*

Mer än hälften av världens befolkning bor nu i städer, och 1,4 miljarder fler människor förväntas flytta till städer år 2030, vilket medför betydande miljöutmaningar. Även om stadsområden bara utgör en liten andel av den globala ytan, förändrar stadsområden signifikant klimat, biogeokemi och hydrologi på lokal, regional och global nivå. Korrekt och aktuell information om urbant marktäcke och dess förändrade mönster är av avgörande betydelse för att stödja en hållbar stadsutveckling.

För närvarande är den information som stadsplanerare och beslutsfattare använder som stöd i planering antingen gammal eller uppdaterad genom tidskrävande fältundersökningar eller visuell tolkning av bilder. Genom sin synopsis och repeterbarhet, kan satellitfjärranalys ge aktuell och korrekt information som är nödvändig för att kartlägga urban marktäckning och övervaka urbanisering. Med den senaste lanseringen av Sentinel-1A och planerade lanseringen av Sentinel-2A i juni 2015 kommer högupplöst SAR och optiska data med global täckning bli rutinmässigt tillgängligt med hög driftsäkerhet. Dessa utgör ett utmärkt tillfälle att utveckla nya metoder och algoritmer för att utveckla operativa urbana tjänster och produkter som stödjer planering och beslutsfattande. Det övergripande målet med denna forskning är att utvärdera flera multitemporal Sentinel-1A SAR och Sentinel-2A MSI data för globala urbana tjänster med innovativa metoder och algoritmer; KTH-SEG, en ny objektbaserat klassificeringsmetod för detaljerad stadskartläggning av marktäcke; samt KTH-Pavia Urban Extractor, en robust algoritm för att utvärdera urban utsträckning. Stockholm och nio städer runt om i världen i olika geografiska och miljömässiga förhållanden väljs som studieområden. Sentinel-1A SAR och Sentinel-2A optiska data kommer att inhämtas under vegetationssäsongen 2015 och 2016. Historiska ENVISAT ASAR och ERS-1/2 SAR data kommer att väljas från arkiv för övervakning av historiska rumstidsmönster i urbanisering.

KTH-SEG, en avancerad segmentmetod vidareutvecklas för multiupplösnings-segmentering av Sentinel-1A SAR och Sentinel-2A MSI uppgifter baserade på kantmedveten regionstillväxt och sammanslagningsalgoritmer med parallella datorberäkningar. Post-segment klassificeringen utförs av av stödvektormaskiner. KTH-Pavia Urban Extractor, den föreslagna dataförädlingskedjan för utvinning av stadsutsträckning omfattar utvinning utifrån rumsliga index och s.k. Grey Level Co-occurrence Matrix (GLCM) mönster, en befintlig metod och flera förbättringar dvs, parallella beräkningar, radar och optiska data förbearbetning, förbättring, fusion och efterbearbetning. Både KTH-SEG och KTH-Pavia Urban Extractor kommer att anpassas, förbättras och tillämpas på Sentinel-1A SAR, Sentinel-2A MSI data samt fusion av dessa. Två användare, enheten för samhällsplanering på Länsstyrelsen i Stockholm och National Geomatics Center i Kina (NGCC) vid National Administration of lantmäteri, Kartläggning och Geoinformation i Peking, har åtagit sig att delta i projektet. Detta ger oss en unik möjlighet att bättre förstå användarnas behov och att utveckla välbehövliga urbana tjänster för att stödja planering och beslutsfattande.

Denna forskning och utveckling förväntas ge en pilot global urbana tjänster demonstrator genom att använda multitemporal Sentinel-1A SAR och Sentinel-2A MSI uppgifter. Projektet kommer att bidra till i). bättre förståelse av de urbana produkter och tjänster som användarna behöver; ii). utveckling av nya och robusta metoder och algoritmer för förbättrad urban information för planerare för att stödja intelligent och hållbar stadsutveckling; ; iii). bättre förståelse av kapaciteten i Sentinel-1A SAR och Sentinel-2A optiska data för detaljerad stadskartläggning av marktäcke och urbaniseringsövervakning; iv). Måluppfyllelse och aktivitet inom GEO SB-04 Global Urban Observation and Information Task and GEO SB-02 Global Land Cover Task.

Project period

Number of project years*

3

Calculated project time*

2016-01-01 - 2018-12-31

Classifications

Select a minimum of one and a maximum of three SCB-codes in order of priority.

Select the SCB-code in three levels and then click the lower plus-button to save your selection.

SCB-codes* 2. Teknik > 207. Naturresursteknik > 20703. Fjärranalysteknik

---

Enter a minimum of three, and up to five, short keywords that describe your project.

Keyword 1*

Sentinel-1A SAR

Keyword 2*

Sentinel-2A MSI

Keyword 3*

Data Fusion

Keyword 4

KTH-SEG and KTH-Pavia Urban Extractor

Keyword 5

Global Urbanization Monitoring

Ethical considerations

Specify any ethical issues that the project (or equivalent) raises, and describe how they will be addressed in your research. Also indicate the specific considerations that might be relevant to your application.

Reporting of ethical considerations*

Not applicable

The project includes handling of personal data

No

The project includes animal experiments

No

Account of experiments on humans

No

Research plan

EO4Urban: Multitemporal Sentinel-1A SAR and Sentinel-2A MSI Data for Global Urbanization Monitoring

1. Introduction and Research Objectives

For the first time in history, more than half of the people on the planet - roughly 3.5 billon human beings - live in cities. By 2030, the world is expected to add an additional 1.4 billion urban dwellers (United Nations, 2011). Stockholm, the largest city in Scandinavia, has experienced substantial urban growth over the past few decades with a population increase at 18% between 1990 and 2010. On the other hand, China, the most populous country on earth, has been in transition from a largely rural society to a predominantly urban one since 1980s (Fig. 1). With the urbanization rate at 50%, now China has 89 cities with a population of a million or more while the United States has 37 and India 32. As a result, huge areas of arable land, forest, and grassland, as well as numerous bodies of water, have been used in new ways to meet strong demand stemming from urbanization and industrial development. With rapid development of the economy and urban expansion, these areas have suffered environmental pollution, ecological deterioration, and loss of ecosystem services. Rapid urbanization is also an increasing trend in other Asian countries as well as in African, North and South America. Thus, accurate and timely information on the rate and distribution of urbanization around the world is of critical importance to support sustainable urban development.

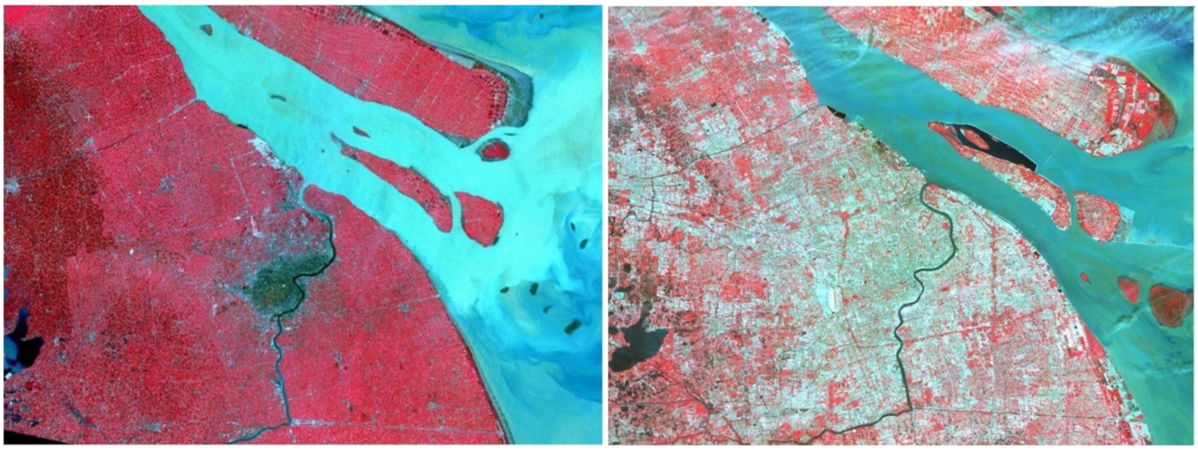

Fig. 1. Urbanization in Shanghai, Left: Landsat image from 1979; Right: HJ-1B image from 2010

Despite the growing importance of urban land in local, regional to global scale environmental studies, it remains extremely difficult to map urban areas at multi-scales due to the heterogeneous mix of land cover types in urban environments, the small area of urban land relative to the total land surface area, and the significant differences in how different groups and disciplines define the term 'urban'. *At present, the information urban planners and decision makers needed to support planning activities are either non-existent, dated or collected through time-consuming field survey or visual interpretation of images.* With its synoptic view and the repeatability, Remote sensing can reveal spatio-temporal growth trajectories of cities, thus allow a thorough understanding of the impacts of urbanization on ecosystems and ecosystem services. Since the launch of Landsat-1 in 1972, a large number of earth observation (EO) satellites have been launched. With the recent launch of ESA Sentinel-1A and planned launched of Sentinel-2A, high resolution SAR and optical data with global coverage and operational reliability become routinely available. They provide excellent opportunity to develop novel methods and algorithms for developing urban services and products at local, regional and global scales.

Various studies have investigated the magnitude, patterns, and types of changes in urban regions with remote sensing images and spatially explicit data (e.g., Liu *et al.* 2005a, Liu *et al.* 2005b, Durieux *et* *al.* 2008, Ban & Yousif, 2012, Ban & Jacob, 2013). However, the interpretation and analysis of urban land cover change using satellite imagery still presents many challenges because of the spatial and spectral heterogeneity of urban environment. Although urban areas could be extracted from time-series global land cover (GLC) databases, each of the datasets that have emerged during the last decade (e.g, GLC2000, GlobCover) suffers from limitations related to these scale and definitional issues (Fig. 2). Moreover, the maps differ by an order of magnitude in how they depict urban areas (0.3 million km^2 for Vector Map to 3.5 million km^2 for the Global Rural–Urban Mapping Project). The extreme variability in these estimates calls into question the accuracy of each map's depiction of urban and built-up land, and yet past efforts to validate the maps have been minimal (Schneider et al., 2009). Recently, China produced a 30m global land cover map using Landsat TM/ETM+ data with a promising overall accuracy of 65% (Gong *et al*., 2013). For the 2010 classification, however, 74% of all Landsat data were from 2006 to 2011 and majority of the data were from non-summer season. Several classes including impervious areas were poorly classified. Some of the accuracies for impervious lands fall below 20%.with a barely 10.5% producer's accuracy and 30.8% user's accuracy (Gong *et al*, 2013). Therefore, there is an urgent need to development effective method for extracting urban areas from satellite data in high accuracy.

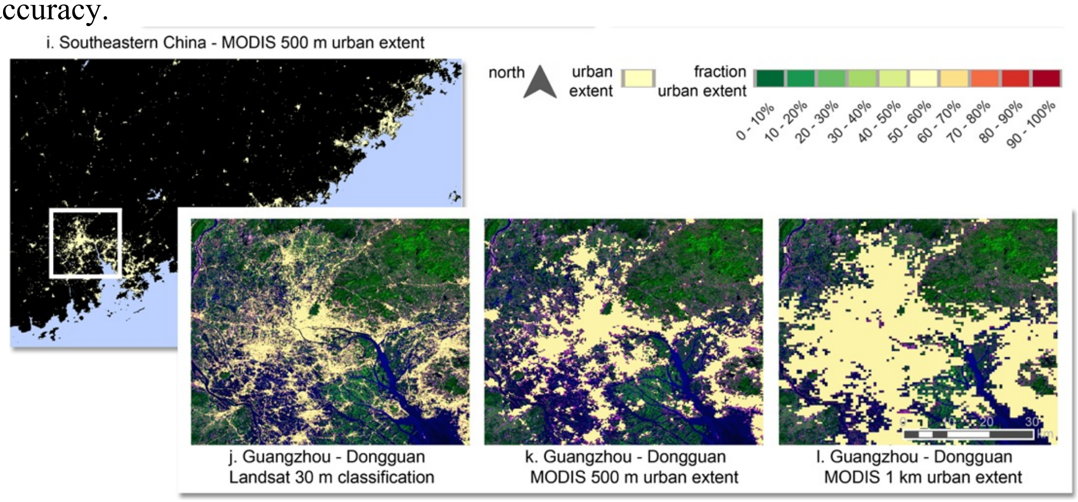

Fig. 2 Variations of Global urban maps due to Scale: e.g. Guangzhou, China (Schneider *et al*., 2009)

The overall objective of this research and development is to evaluate multitemporal multi-resolution Sentinel-1A SAR and Sentinel-2A MSI data for developing a pilot global urban services based on user requirements in support of sustainable urban development. The specific objectives are to:

- have a better understanding of user requirements for urban products and services;
- develop novel and robust methods and algorithms for producing user needed products and services, i.e., detailed urban land cover mapping and urbanization monitoring using Sentinel-1A SAR and Sentinel-2A data
- evaluate the capacity of multitemporal multi-resolution Sentinel-1A SAR and Sentinel-2A MSI data for urban extent extraction and detailed urban land cover mapping;
- develop a pilot urban services demonstrator
- investigate effective validation methods for validation of the urban products and services

2. State of the Art

Object-based Classification

As a traditional classification method, pixel-based methods are commonly employed for image classification and information extraction. However, for high resolution optical and SAR data, pixel-based approach often results in "pepper-salt" effects due to the high variance of the pixel values (Solaiman *et al.* 1998). Object-based methods, on the other hand, have been increasingly adopted in urban and land cover using high-resolution optical data (Blascke, 2010), SAR data, e.g. (Hu & Ban, 2012, Niu & Ban, 2012) and fusion of SAR and optical data e.g. (Ban et al., 2010, Vu & Ban, 2010) since more information such as object features and spatial relationships could be explored in the analysis thus improved classification accuracy. The existing automatic image segmentation techniques can be classified into four approaches, namely, 1) thresholding techniques, 2) boundary-based methods, 3) region-based methods, and 4) hybrid techniques (Fan et al., 2001, Carvalho et al., 2009)The pros and cons of the techniques are discussed in(Blascke, 2010) and (Fan et al., 2001). The most commonly used segmentation methods is region growing and merging in eCognition(Blaschke, 2010). Such method often results in segments growing across region boundaries. Boundary-based methods using edge detection such as Canny edge detector are also explored for image segmentation (Senthilkumaran & Rajesh, 2009). Several studies found that integrating edge and region detection can produce better segmentation of images (Tabb & Ahuja, 1997; Yu and Clausi, 2008; Yu et al., 2012) than region-based and boundary-based method. However, these studies used relatively simple images such as photographs of faces, flowers and buildings, not the complex Spaceborne SAR and optical data in challenging urban, land cover and coastal water environments. Therefore, further research is needed to develop robust methods for segmentation of SAR and optical data that integrates edge detection and region growing and merging. An initial study showed promising results using KTH-SEG (Fig. 3), an edge-aware region growing and merging algorithm (Ban and Jacob, 2013). Further development of this method will be carried out in this research to make it more robust, automatic and with multi-resolution segmentation capability using parallel computing.

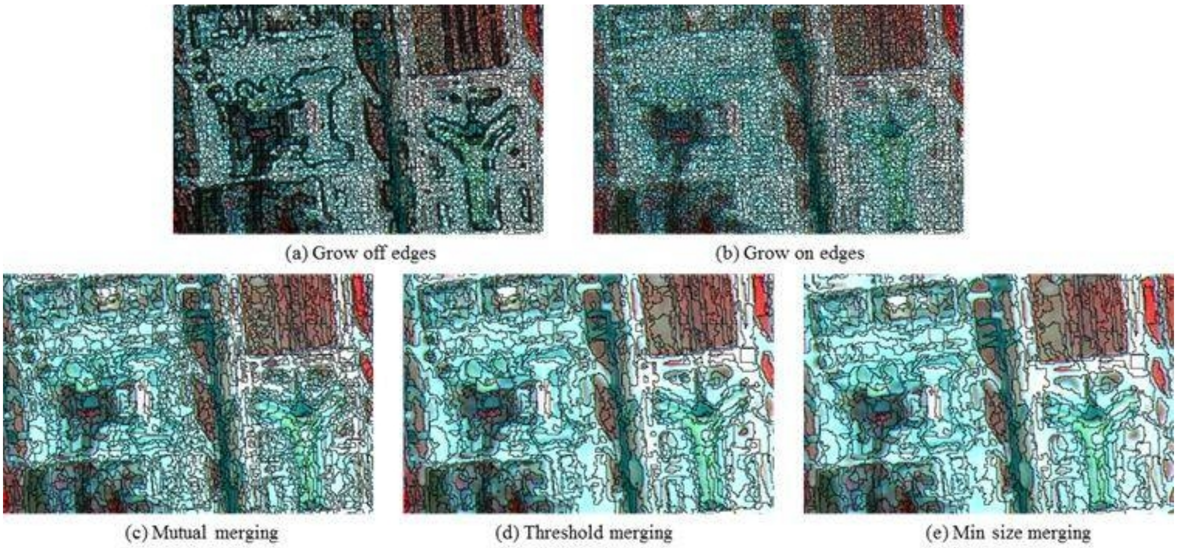

Fig. 3. KTH-SEG: an edge-aware region growing and merging algorithm

Urban Extent Extraction

Very High Resolution optical and/or SAR imagery and object-based approaches dominate urban remote sensing at the local level (e.g., Gong *et al*., 1992; Jacquin *et al*., 2003; Ban *et al*., 2010; Moran, 2010; Gamba *et al*., 2011; Niu and Ban, 2013) while Landsat, ENVISAT ASAR, MERIS as well as MODIS or nighttime light data and pixel-based techniques are mostly used for regional and global analysis (e.g., Lu *et al*., 2008; Elvidge *et al*., 2009; Esch *et al*., 2010; Arino, *et al*., 2010; Friedl *et al*., 2010; Schneider *et al*., 2010; Wang *et al*. 2010; Zhang and Seto, 2011, Chen *et al*., 2012; Taubenböck *et al*. 2012; Wang, *et al*., 2012; Gamba and Lisini, 2013). One of the recent developments are moving towards global urban extraction using optical data at very high spatial resolution. For examples, Pesaresi *et al*. (2011) developed a texture-based algorithm to extract urban extent of over 40 cities around the globe using Ikonos and QuickBird panchromatic data resampled to a nominal resolution at 10 m. The technique is promising, but true global mapping with such data remains a challenge due to the huge amount of data and computations involved as well as data availability issue due to cloud cover. Compared to optical data, SAR data have not been equally explored in urban applications due to the complexity of their interactions with diverse urban features. With its all-weather/illumination capability and its unique information content, however, SAR data have been increasingly investigated for global urban extent extraction at various spatial resolutions with promising results. For examples, Gamba *et al.* (2011) developed a method to extract global urban area extent from SAR images. The proposed approach utilizes a group of spatial indices, i.e., Moran's, Geary's, and Getis' together with GLCM-based textures (i.e., correlation and variance) for urban extent extraction. The method has been tested in different set of SAR images produced using different sensors (e.g., POLSAR, RADARSAT-1, TerraSAR-X, COSMO/SkyMed, etc.), with different spatial resolutions that cover different cities around the world with promising results. Esch *et al*. (2012 and 2013), on the other hand, developed a method to extract global urban settlement from TanDEM-X images at 12m spatial resolution. The method consists of three main steps: (1) textural information extraction that can be used to highlight built-up areas; (2) unsupervised classification of built-up/non built-up areas that takes into account both backscattered amplitude and the extracted textural information; (3) a final step that focuses on post-processing and mosaicking to produce a final urban map. The proposed methodology was evaluated using images that cover New Delhi, Munich, Buenos Aires, Nairobi, and Padang with an overall accuracy up to 94.8% achieved. On-going efforts are currently undertaken to produce a consistent global map of human settlements at a few meters' spatial resolution, but the final results are yet to be achieved. Even when these maps are released, it is still desirable to develop method for urban extraction using Sentinel-1A SAR, ENVISAT ASAR or ERS-1/-2 data since these data are easily available and free of charge, plus ENVISAT ASAR and ERS-1/-2 data could provide global urban maps from earlier time when TerraSAR-X or TanDEM-X data were not available.

As a comprise between the spatial details and the amount of data and computation, Gamba and Lisini (2013) developed an efficient method for urban areas extraction using ENVISAT ASAR wide swath mode at 75m resolution aiming to improve GlobCover 2009 urban mapping results. The method consists of three phases: (1) preprocessing, i.e., multitemporal images filtering, averaging, and equalization; (2) urban extraction, i.e., seed extraction and region growing; (3) post-processing, i.e., DEM-based correction, hole filling, and aggregation to 300m spatial resolution. Test areas from around the world were used to evaluate the efficiency of the proposed approach and overall accuracies up to 94.8% were achieved using validation data of 1000 randomly selected points. The results are very encouraging, but the method requires a large volume of multitemporal SAR data (10-50 images) as the algorithm is based on amplitude values only, thus the denser the time series data, the better the accuracy. The above literature analysis indicates a strong need of robust and operational methods for global urban extraction using a small number of SAR images at higher resolution. Therefore, it is desirable to evaluate Sentinel-1A SAR and fusion of Sentinel-1A SAR and Sentinel-2A MSI for improved global urban mapping using a robust processing chain, the KTH-Pavia Urban Extractor.

3. Study Areas and Data Description

3.1 Study Areas

Ten cities around the world were selected to represent developed and developing cities in various environmental conditions in all continents except Antarctica. Coastal cities include Jakarta, Lagos, Mumbai, New York, Rio de Janeiro, Stockholm, and Sydney while inland cities include Beijing, Mexico City and Milan. Several cities are mountainous or surrounded by mountains while the rest are in relatively flat areas. Some of the cities are under rapid urbanization while others grow relatively slowly. Among the 10 cities, urban services and products from Stockholm and Beijing will be assessed rigorously by end users while the rest will be evaluated by the project team.

3.2 Data Acquisition Planning and Description.

Multitemporal multi-resolution Sentinel-1A SAR and Sentinel-2A MSI data will be acquired for all cities in 2016-2018 during the vegetation season to maximize the difference between urban and rural areas. Ideally, multi-date, dual polarization data from both ascending and descending orbit are needed to evaluate the potential of SAR data for improved urban land cover mapping and urban extraction. Historial ENVISAT ASAR and ERS-1/2 SAR data will also be collected for urbanization monitoring. All data are available free of charge.

- Multitemporal multi-resolution Sentinel-1A C-band SAR data during vegetation season 2016-2018 (Strip Map Mode: 5 x 5 m spatial resolution, & Interferometric Wide Swath: 5x20 m spatial resolution)
- Multitemporal multi-resolution Sentinel-2A MSI data during vegetation season 2016-2018 (Visible +NIR: 10m and SWIR: 20m resolution)
- ENVISAT C-band ASAR, ESA archive, during vegetation season, 2003-2012
- ERS-1/2 C-band SAR, ESA archive, during vegetation season, 1991-2011
- Reference data: will be collected through User organization and/or and field Data in selected urban areas.

4. Methodology

The methodology to be employed in this research involves multi-scale analysis of multitemporal Sentinel-1A SAR, Sentinel-2A MSI and historical ESA SAR data (Fig. 4) including image processing, object-based image classification, urban extent extraction, change detection and validation/accuracy assessment.

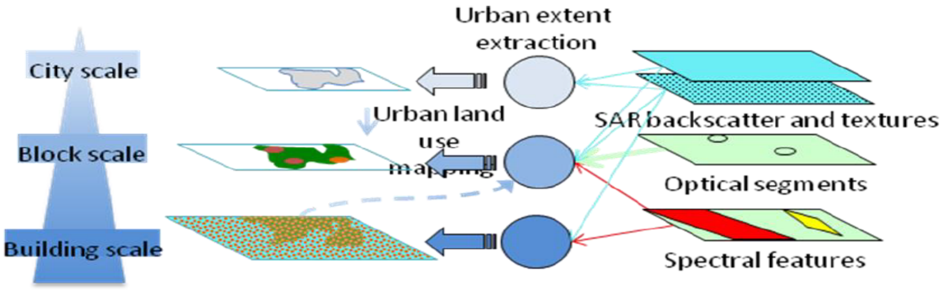

Fig. 4. Urban extent extraction & land cover classification (Adapted from Gamba et al., 2013)

4.1 Image Pre-processing

4.1.1 Geometric Correction: In order to evaluate and compare satellite data from different sensors and different dates, each image must be georeferenced to a common database by orthorectification using satellite orbital models and a digital elevation model (DEM).
4.1.2 Speckle Filtering: Multitemporal speckle filtering will be performed on all SAR data to remove speckle.

4.2 Object-based Classification of Multitemporal Multi-Resolution SAR & MSI Data

An initial study showed promising results using KTH-SEG, an edge-aware region growing and merging algorithm and the object-based classification accuracies are slightly better than eCognition, the most commonly used segmentation software (Ban and Jacob, 2013). Further development of this method will be carried out in this research to make it more robust and automatic, in multi-resolution to be processed in parallel.

4.2.1 KTH-SEG: An Edge-Aware Region Growing and Merging Algorithm
The proposed improvements of KTH-SEG is shown in Fig. 5, including the following: Edge Detection using Canny Edge Detector, Seed Selection, Multi-resolution Segmentation and parallel computing.

<u>SAR adapted homogeneity parameter:</u> Most segmentation tools are developed for optical data and are in general using statistical moments derived from normal distribution models. The nature of SAR data is fundamentally different with the presence of speckle. Log-normal distribution or fisher

distribution, for examples, would be better suited for SAR, especially in the high complex urban environments (Tison et al., 2004). It is expected that introducing statistical moments derived from these types of distributions for the computation of the homogeneity parameters for SAR will improve the segmentation result.

Edge Detection: Instead of the Sobel filter, the canny edge detector will be used for edge detection. The canny edge detector is based on a sequence of image processing procedures to extract the most significant edges and improve their quality with gap filling operations. It can be based on any kind of high-pass filter such as the Sobel filter.

Multi-Resolution Segmentation: As different ground features have different object size, multi-resolution segmentation is necessary. The idea is to start with a detailed segmentation, then these segments are used as the input for a second iteration through the segmentation starting from the mutual merging. The link between the initial detailed segments and the resulting coarse segments will be saved by a updated member list which saves only the primary key of the initial segment. Because the coarse segments are always based on the detailed ones there will be no conflict in terms of the outer border of the two sets of segments when superimposing them. Then both sets of segments will be classified individually and rules will be defined to decide what will be the final class.

Parallel Computing: The segmentation algorithm of KTH-SEG is designed to be processed in parallel making use of an advanced tiling scheme that avoids edge effects between the borders of two different adjacent tiles. The growing phase can hence easily be parallelized and every tile is segmented by itself first before merging into a bigger context of the adjacent tiles and regions. There are also ways of parallelizing the merging phase which are planned to be investigated further. It is planned to utilize GPU-computing and cluster-computing approaches for this parallelization.

4.2.2 Classification by Support Vector Machines (SVM)

SVM proved to be superior to other classifiers in classification of multispectral, hyperspectral and SAR data, this will be used for classificaiton in this research. SVM seeks to find the optimal separating hyperplane between classes by focusing on the training cases that lie at the edge of the class distributions, the support vectors, with the other training cases effectively discarded. Thus, not only is an optimal hyperplane fitted, but also the approach may be expected to yield high accuracy with small training sets, a very advantageous feature. The basis of the SVM approach to classification is, therefore, the notion that only the training samples that lie on the class boundaries are necessary for discrimination.

4.3 KTH-Pavia Urban Extractor

KTH-Pavia Urban Extractor, the proposed processing chain for urban extent extraction includes urban extraction based on spatial indices and Grey Level Co-occurrence Matrix (GLCM) textures, an existing method and several improvements i.e., SAR and optical data preprocessing, enhancement, and post-processing. The detailed methodology can be found in Fig. 6 below. The method has been preliminarily tested on ENVISAT ASAR data, and the results showed urban areas can be automatically extracted in good accuracy with only 1-2 ASAR images (Ban *et al.*, 2014). This method will be further developed for multitemporal multi-resolution Sentinel-1A SAR data and in combination with Sentinel-2A MSI data. It is expected that existing issues with missed detection of low-density built-up areas will be resolved using higher resolution Sentinel-1A SAR and integrating SAR texture features and Sentinel-2A NDVI. Senitnel-2A MSI data can also be utilized to robustly extract water bodies that planners need for flood risk assessment and climate change adaption. The water bodies can also be used as water mask in urban extraction.

4.4 Urban Land Cover Change Detection

Effective automatic pixel-based and object-based change detection algorithms developed within the ongoing project 'Change Detection in Urban Areas Using Multitemporal Spaceborne SAR and Fusion of SAR and Optical Data ' (funded by the Swedish National Space Board, 2012-2014, PI : Yifang Ban) will be used in this research to detect new built-up areas, monitor changes in urban green structures and temporal changes of water bodies as required by the end users.

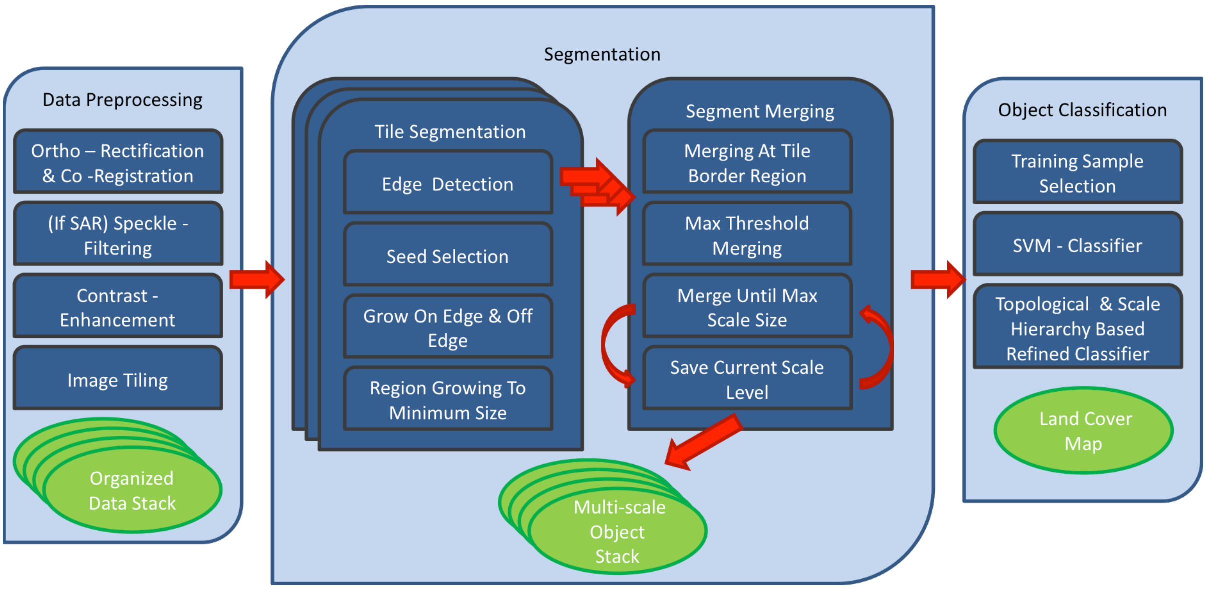

Fig. 5. KTH-SEG: Multi-Resolution Edge-Aware Region Growing and Merging Algorithm

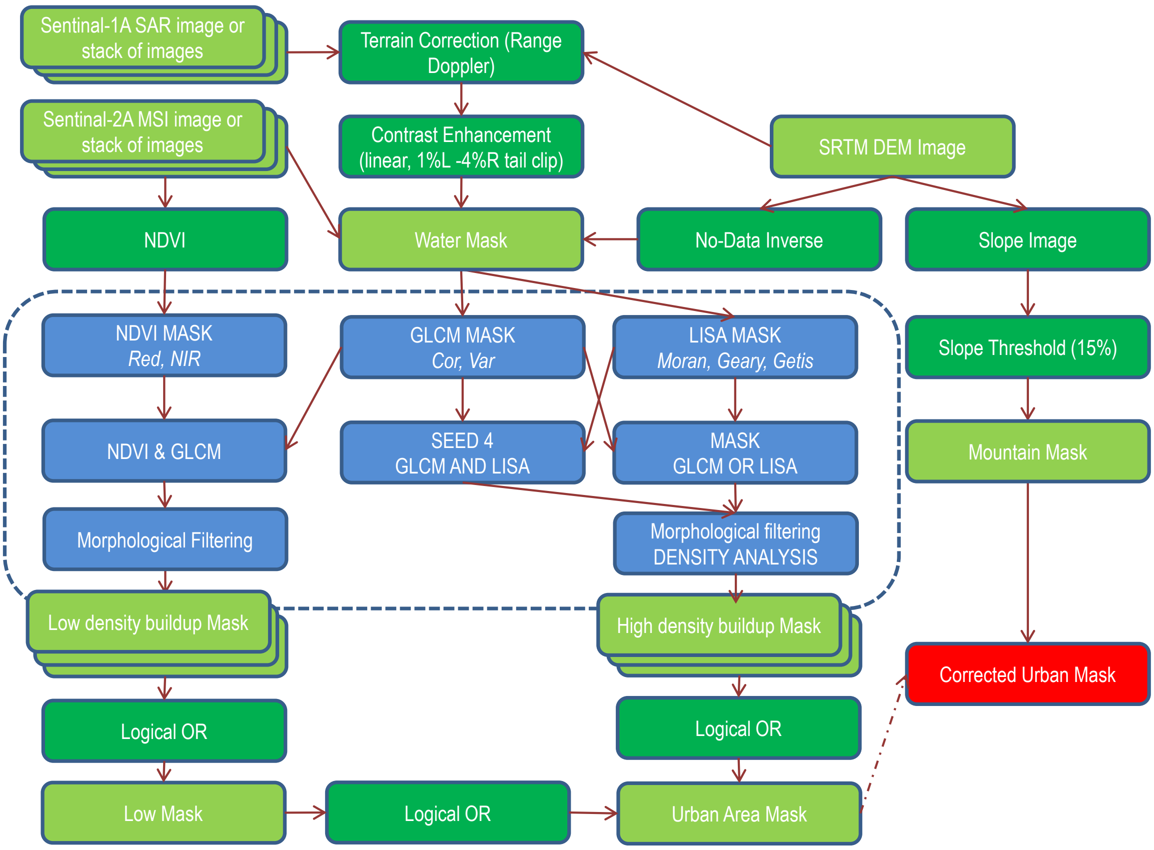

Fig. 6. Overview of the Methodology for Urban Extent Extraction

4.5 Validations and Accuracy Assessment

The land-cover classifications and changes will be validated based on the following three approaches: 1). Validation using existing reliable data such as Swedish and European CORINE land cover and NGCC's GlobalLand Cover at 30m resolution; 2). Random sampling based on high resolution

7

images and field survey; and 3). Validation using GeoWiki, a crowd sourcing tool; 2). The three validation methods will be compared for accuracy assessments of the urban land cover classification, urban extent extraction and change detection results. User evaluations will also be performed to assess the reliability, usability and benefits of the urban products and services.

5. Significance

This research and development is expected to produce a pilot global urban services demonstrator using multitemporal Sentinel-1A SAR and Sentinel-2A MSI data. The project will contribute to i). better understanding of the urban products and services that the users require; ii). development of novel and robust methods and algorithms for improved urban information for planners to support smart and sustainable urban development; ; iii). better understanding of the capacity of Sentinel-1A SAR and Sentinel-2A optical data for detailed urban land cover mapping and urbanisation monitoring; iv). the goals and activities of GEO SB-04 Global Urban Observation and Information Task and GEO SB-02 Global Land Cover Task.

6. Role of Researcher and Preliminary Results

Yifang Ban: project leader and methodology development

Alexander Jacob: methodology development and implementation

The preliminary urban extraction results (Figure 7) showed that urban areas and small towns could be well extracted using a single-date Sentinel-1A SAR data with the KTH-Pavia urban extractor. It is expected that the results will be further improved using multitemporal Sentinel-1A SAR data when more data become available.

7. International and national collaboration

KTH researchers is working closely with collaborators at University of Pavia in Pavia, Italy and two users, the Urban and Regional Development Department at the Stockholm County Administrative Board (SCAB) in Stockholm, Sweden and National Geomatics Center of China (NGCC) at the National Administration of Surveying, Mapping and Geoinformation of China in Beijing, China.

Yifang Ban is also collaborate with the international researchers through European Space Agency's Dragon 3 Program and GEO SB-04 Global Urban observation and information and GEO SB-02 Global Land Cover Tasks, for examples:

- Prof. Paolo Gamba, University of Pavia, Italy
- Prof. Peng Gong, Tsinghua University, China
- Prof. Qihao Weng, Indiana State University, USA
- Prof. Chen Jun, National Geomatics Center of China
- Dr. Thomas Esch and Dr. Hannes Taubenböck, German Aerospace Center (DLR), Germany.

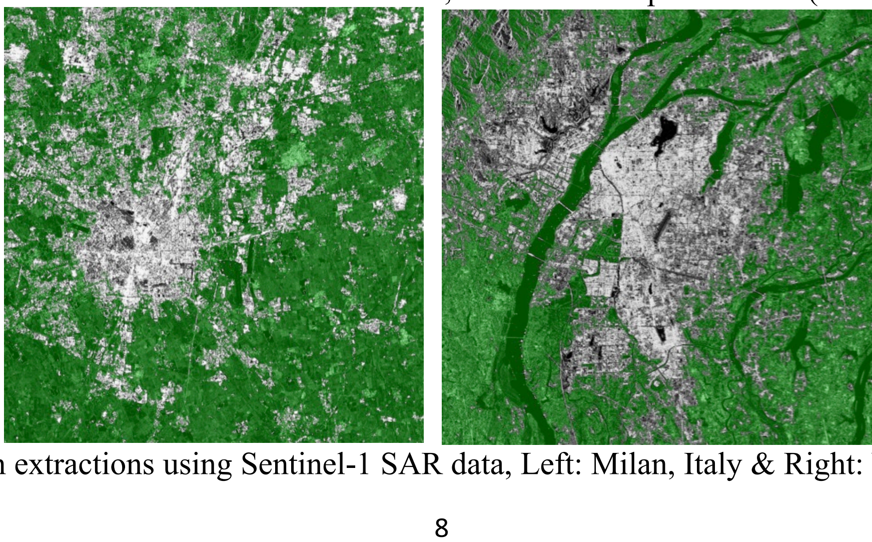

Fig. 7. Urban extractions using Sentinel-1 SAR data, Left: Milan, Italy & Right: Nanchang, China.

References

Arino, O. (2010). GlobCover 2009.

Ban, Y., Jacob, A., & Gamba, P. (2014). Spaceborne SAR Data for Global Urban Mapping at 30m Resolution Utilizing a Robust Urban Extractor. *International Journal of Photogrammetry and Remote Sensing, Special Issue on Global Land Cover* (in press).

Ban, Y., Hu, H., & Rangel, I. M. (2010). Fusion of Quickbird MS and RADARSAT SAR data for urban land-cover mapping: object-based and knowledge-based approach. *International Journal of Remote Sensing*, *31*(6), 1391-1410.

Ban, Y., & Jacob, A. (2013). Object-based fusion of multitemporal multiangle ENVISAT ASAR and HJ-1B multispectral data for urban land-cover mapping. *Geoscience and Remote Sensing, IEEE Transactions on*, *51*(4), 1998-2006.

Ban, Y., & Yousif, O. A. (2012). Multitemporal spaceborne SAR data for urban change detection in China. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of*, *5*(4), 1087-1094.

Blaschke, T. (2010). Object based image analysis for remote sensing. *ISPRS journal of photogrammetry and remote sensing*, *65*(1), 2-16.

Carvalho, E. A., Ushizima, D. M., Medeiros, F. N., Martins, C. I. O., Marques, R. C., & Oliveira, I. N. S. (2010). SAR imagery segmentation by statistical region growing and hierarchical merging. *Digital Signal Processing*, *20*(5), 1365-1378.

Durieux, L., Lagabrielle, E., & Nelson, A. (2008). A method for monitoring building construction in urban sprawl areas using object-based analysis of Spot 5 images and existing GIS data. *ISPRS Journal of Photogrammetry and Remote Sensing*, *63*(4), 399-408.

Elvidge, C. D., Sutton, P. C., Ghosh, T., Tuttle, B. T., Baugh, K. E., Bhaduri, B., & Bright, E. (2009). A global poverty map derived from satellite data. *Computers & Geosciences*, *35*(8), 1652-1660.

Esch, T., Marconcini, M., Felbier, A., Roth, A., Heldens, W., Huber, M., ... & Dech, S. (2013). Urban footprint processor—Fully automated processing chain generating settlement masks from global data of the TanDEM-X mission.

Esch, T., Taubenböck, H., Roth, A., Heldens, W., Felbier, A., Thiel, M., ... & Dech, S. (2012). TanDEM-X mission—new perspectives for the inventory and monitoring of global settlement patterns. *Journal of Applied Remote Sensing*, *6*(1), 061702-1.

Esch, T., Thiel, M., Schenk, A., Roth, A., Muller, A., & Dech, S. (2010). Delineation of urban footprints from TerraSAR-X data by analyzing speckle characteristics and intensity information. *Geoscience and Remote Sensing, IEEE Transactions on*, *48*(2), 905-916.

Fan, J., Yau, D. K., Elmagarmid, A. K., & Aref, W. G. (2001). Automatic image segmentation by integrating color-edge extraction and seeded region growing. *Image Processing, IEEE Transactions on*, *10*(10), 1454-1466.

Friedl, M. A., Sulla-Menashe, D., Tan, B., Schneider, A., Ramankutty, N., Sibley, A., & Huang, X. (2010). MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. *Remote Sensing of Environment*, *114*(1), 168-182.

Gamba, P., Aldrighi, M., & Stasolla, M. (2011). Robust extraction of urban area extents in HR and VHR SAR images. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of*, *4*(1), 27-34.

Gamba, P., Lisini, G., Trianni, G., & Angiuli, E. (2013, April). Urban area mapping using ASAR wide swath mode and Landsat data: A comparison on eastern China. In *Urban Remote Sensing Event (JURSE), 2013 Joint* (pp. 127-130). IEEE.

Gamba, P., & Lisini, G. (2013). Fast and efficient urban extent extraction using ASAR wide swath mode data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *6*(5), 2184-2195.

Gong, P., Marceau, D. J., & Howarth, P. J. (1992). A comparison of spatial feature extraction algorithms for land-use classification with SPOT HRV data. *Remote Sensing of Environment*, *40*(2), 137-151.

Gong, P., Wang, J., Yu, L., Zhao, Y., Zhao, Y., Liang, L., ... & Chen, J. (2013). Finer resolution observation and monitoring of global land cover: first mapping results with Landsat TM and ETM+ data. *International Journal of Remote Sensing*, *34*(7), 2607-2654.

Huang, X., Lu, Q., & Zhang, L. (2014). A multi-index learning approach for classification of high-resolution remotely sensed images over urban areas. *ISPRS Journal of Photogrammetry and Remote Sensing*, *90*, 36-48.

Hu, H., & Ban, Y. (2012). Multitemporal RADARSAT-2 ultra-fine beam SAR data for urban land cover classification. *Canadian Journal of Remote Sensing*, *38*(1), 1-11.

Lee, J. S., & Jurkevich, I. (1989). Segmentation of SAR images. *Geoscience and Remote Sensing, IEEE Transactions on*, *27*(6), 674-680.
Liu, J., Zhan, J., & Deng, X. (2005a). Spatio-temporal patterns and driving forces of urban land expansion in China during the economic reform era. *AMBIO: a journal of the human environment*, *34*(6), 450-455.
Lu, D., Tian, H., Zhou, G., & Ge, H. (2008). Regional mapping of human settlements in southeastern China with multisensor remotely sensed data. *Remote Sensing of Environment*, *112*(9), 3668-3679.
Lu, D., Hetrick, S., & Moran, E. (2010). Land cover classification in a complex urban-rural landscape with QuickBird imagery. *Photogrammetric Engineering & Remote Sensing*, *76*(10), 1159-1168.
Niu, X., & Ban, Y. (2012). An adaptive contextual SEM algorithm for urban land cover mapping using multitemporal high-resolution polarimetric SAR data. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of*, *5*(4), 1129-1139.
Niu, X., & Ban, Y. (2013). Multi-temporal RADARSAT-2 polarimetric SAR data for urban land-cover classification using an object-based support vector machine and a rule-based approach. *International Journal of Remote Sensing*, *34*(1), 1-26.
Pesaresi, M., Ehrlich, D., Caravaggi, I., Kauffmann, M., & Louvrier, C. (2011). Toward global automatic built-up area recognition using optical VHR imagery. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of*, *4*(4), 923-934.
Pesaresi, M., Ehrlich, D., Caravaggi, I., Kauffmann, M., & Louvrier, C. (2011). Toward global automatic built-up area recognition using optical VHR imagery. *Selected Topics in Applied Earth Observations and Remote Sensing, IEEE Journal of*, *4*(4), 923-934.
Schneider, A., Friedl, M. A., & Potere, D. (2009). A new map of global urban extent from MODIS satellite data. *Environmental Research Letters*, *4*(4), 044003.
Schneider, A., Friedl, M. A., & Potere, D. (2010). Mapping global urban areas using MODIS 500-m data: New methods and datasets based on 'urban ecoregions'. *Remote Sensing of Environment*, *114*(8), 1733-1746.
Senthilkumaran, N., & Rajesh, R. (2009). Edge detection techniques for image segmentation–a survey of soft computing approaches. *International Journal of Recent Trends in Engineering*, *1*(2).
Solaiman, B., Koffi, R. K., Mouchot, M. C., & Hillion, A. (1998). An information fusion method for multispectral image classification postprocessing. *Geoscience and Remote Sensing, IEEE Transactions on*, *36*(2), 395-406.
Tabb, M., & Ahuja, N. (1997). Multiscale image segmentation by integrated edge and region detection. *Image Processing, IEEE Transactions on*, *6*(5), 642-655.
Taubenböck, H., Esch, T., Felbier, A., Wiesner, M., Roth, A., & Dech, S. (2012). Monitoring urbanization in mega cities from space. *Remote sensing of Environment*, *117*, 162-176.
Tison, C., Nicolas, J. M., Tupin, F., & Maître, H. (2004). A new statistical model for Markovian classification of urban areas in high-resolution SAR images. *Geoscience and Remote Sensing, IEEE Transactions on*, *42*(10), 2046-2057.
United Nations (2012). World urbanization prospects the 2011 revision. *United Nations, Department of Economic and Social Affairs (DESA), Population Division, Population Estimates and Projections Section, New York*.
Vu, T. T., & Ban, Y. (2010). Context-based mapping of damaged buildings from high-resolution optical satellite images. *International Journal of Remote Sensing*, *31*(13), 3411-3425.
Wang, Z., Jensen, J. R., & Im, J. (2010). An automatic region-based image segmentation algorithm for remote sensing applications. *Environmental Modelling & Software*, *25*(10), 1149-1165.
Wang, K., Liang, S., Schaaf, C. L., & Strahler, A. H. (2010). Evaluation of Moderate Resolution Imaging Spectroradiometer land surface visible and shortwave albedo products at FLUXNET sites. *Journal of Geophysical Research: Atmospheres (1984–2012)*, *115*(D17).
Wang, L., Li, C., Ying, Q., Cheng, X., Wang, X., Li, X., ... & Gong, P. (2012). China's urban expansion from 1990 to 2010 determined with satellite remote sensing. Chinese Science Bulletin, 57(22), 2802-2812.
Yu, Q., & Clausi, D. A. (2008). IRGS: image segmentation using edge penalties and region growing. *Pattern Analysis and Machine Intelligence, IEEE Transactions on*, *30*(12), 2126-2139.
Yu, P., Qin, A. K., & Clausi, D. A. (2012). Unsupervised polarimetric SAR image segmentation and classification using region growing with edge penalty. *Geoscience and Remote Sensing, IEEE Transactions on*, *50*(4), 1302-1317.
Zhang, Q., & Seto, K. C. (2011). Mapping urbanization dynamics at regional and global scales using multi-temporal DMSP/OLS nighttime light data. *Remote Sensing of Environment*, *115*(9), 2320-2329

Interdisciplinarity

My application is interdisciplinary

☐

An interdisciplinary research project is defined in this call for proposals as a project that can not be completed without knowledge, methods, terminology, data and researchers from more than one of the Swedish Research Councils subject areas; Medicine and health, Natural and engineering sciences, Humanities and social sciences and Educational sciences. If your research project is interdisciplinary according to this definition, you indicate and explain this here.

Click here for more information

Scientific report

Scientific report/Account for scientific activities of previous project

---

Budget and research resources

Project staff

Describe the staff that will be working in the project and the salary that is applied for in the project budget. Enter the full amount, not in thousands SEK.

Participating researchers that accept an invitation to participate in the application will be displayed automatically under Dedicated time for this project. Note that it will take a few minutes before the information is updated, and that it might be necessary for the project leader to close and reopen the form.

Dedicated time for this project

	Role in the project	Name	Percent of full time
1	Applicant	Yifang Ban	20
2	Other personnel without doctoral degree	Alexander Jacob	60

Salaries including social fees

	Role in the project	Name	Percent of salary	2016	2017	2018	Total
1	Applicant	Yifang Ban	20	275,000	280,000	290,000	845,000
2	Other personnel without doctoral degree	Alexander Jacob	60	350,000	380,000	405,000	1,135,000
	Total			625,000	660,000	695,000	1,980,000

Other costs

Describe the other project costs for which you apply from the Swedish Research Council. Enter the full amount, not in thousands SEK.

Premises

	Type of premises	2016	2017	2018	Total
1	Offices	50,000	50,000	50,000	150,000
2	2 Computers with parallel processing capability	50,000	0	0	50,000
3	Travel to Conferences	35,000	40,000	40,000	115,000
4	Fieldwork	50,000	50,000	50,000	150,000
	Total	185,000	140,000	140,000	465,000

Running Costs

	Running Cost	Description	2016	2017	2018	Total
1	WIKS Fees	Computer Management Fees	20,376	20,376	20,376	61,128
	Total		20,376	20,376	20,376	61,128

Depreciation costs

Depreciation cost	Description	2016	2017	2018

Total project cost

Below you can see a summary of the costs in your budget, which are the costs that you apply for from the Swedish Research Council. Indirect costs are entered separately into the table.

Under Other costs you can enter which costs, aside from the ones you apply for from the Swedish Research Council, that the project includes. Add the full amounts, not in thousands of SEK.

The subtotal plus indirect costs are the total per year that you apply for.

Total budget

Specified costs	2016	2017	2018	Total, applied	Other costs	Total cost
Salaries including social fees	625,000	660,000	695,000	1,980,000		1,980,000
Running costs	20,376	20,376	20,376	61,128		61,128
Depreciation costs				0		0
Premises	185,000	140,000	140,000	465,000		465,000
Subtotal	830,376	820,376	855,376	2,506,128	0	2,506,128
Indirect costs				0		0
Total project cost	830,376	820,376	855,376	2,506,128	0	2,506,128

Explanation of the proposed budget

Briefly justify each proposed cost in the stated budget.

Explanation of the proposed budget*

Justification for Costs

Salary Cost:

Yifang Ban will spend 20% of her time on the project. The cost is based on her current KTH salary and projected increases.

Alexander Jacob will spend 60% of his time on the project. For 2016, he will work as a final-year PhD student with a salary at 30500kr/month. For 2017 and 2017, he will work as Postdoc. Fellow on the project and his salary will increase to 34000kr/month and 3600kr/month respectively.

Equipment, Travel and Premises Costs

1. Locality Cost: 20% of Yifang Ban's office cost and 60% of Alexander's office cost.
2. Computers: Two computers with parallel computing capacities and large monitors are needed for mage processing and algorithm development. The estimated cost is 25000kr/computer.
3. Travel to Conferences: Travel and registration fees for Yifang Ban and Alexander Jacob to present their research findings to a major international remote sensing conference per year. The estimated cost is 35000kr for 2016 and more expensive for 2017 and 2018 when Alexander Jacob has to pay full registration fee instead of student fee.
4. Fieldwork: fieldwork is planned for collecting ground truth data for calibration of satellite data and algorithms as well as for validation of the results. The estimated costs for fieldwork in 3 cities/year is 50000kr. No cost for calibration and validation in Stockholm.

Running Costs

KTH central computer management system WIKS costs 849kr/month/computer, so the total costs for 2 computers per year is 20376kr.

Other funding

Describe your other project funding for the project period (applied for or granted) aside from that which you apply for from the Swedish Research Council. Write the whole sum, not thousands of SEK.

Other funding for this project

	Funder	Applicant/project leader	Type of grant	Reg no or equiv.	2016	2017	2018	Total
1	European Space Agency	Yifang Ban	Contract		670,000	280,000	0	950,000
	Total				670,000	280,000	0	950,000

CV and publications

CV

Curriculum Vitae: Yifang Ban

1. **Higher Education Degrees**
   1984 Nanjing University, Nanjing, China, BSc (with Honors) in Computer Cartography
   1987 Nanjing University, Nanjing, China, MSc in Remote Sensing & GIS

2. **Doctoral Degree**
   1996 University of Waterloo, Waterloo, Canada, Ph.D. in Remote Sensing & GIScience
   Dissertation Title: Synthetic Aperture Radar for a Crop Information System: A Multipolarization and Multitemporal Approach.

3. **Postdoctoral Work**
   1998- Stockholm University, Dept. of Physical Geography, 80%
   2000 Research in Remote Sensing and Digital Image Processing

4. **Qualifications As Research Fellow/Associate Professor**
   2003 York University, Toronto, Canada

5. **Specialist Certification Or Equivalent:** N/A

6. **Current Position**
   2004- Chair Professor of Geoinformatics & Director, PhD Program in Geoinformatics
   Department of Urban Planning and Built Environment, KTH
   Share of Time Spent in Research: 50%

7. **Previous Positions and Periods of Appointment**
   2004 - 2010 Head, Division of Geoinformatics, KTH, Research Time Share: 40%
   2005 - 2008 Member, Board of Directors, School of Architecture & Built Environment, KTH
   2004 - 2009 Member, KTH Faculty Council
   2003 - 2004 Associate Professor, York University, Department of Geography, 40%
   2000 - 2003 Assistant Professor, York University, Department of Geography, 40%
   1996 - 1997 Senior Research Engineer, KTH, Geodesy and Photogrammetry, 50%
   1992 - 1996 Research Scientist/PhD Candidate, University of Waterloo, Canada, 80%
   1995 - 1996 Remote Sensing/GIS Consultant, Watts, Griffis and Mcquat Ltd., Toronto.
   1991 - 1992 GIS Analyst, PDM Information Technology Inc., Toronto, Canada
   1990 - 1991 Visiting Scientist, Ontario Centre for Remote Sensing, Canada, 80%

8. Interruptions In Research
1998-1999, nine months & 2003, four months, on maternity leaves

9. PhD & Postdoc. Under My Supervision (Main Supervisor)
2014 *Lars Skog* - Spatial Analysis and Modeling for Health Application, PhD completed.
Yuchu Qin - From LiDAR waveform to Urban Land Cover Map: Modeling, Processing and Application, PhD completed.
Alexander Jacob - Multitemporal Remote Sensing for Urban Mapping using KTH-SEG and KTH-Pavia Urban Extractor. Licentiate Degree Completed, Ongoing
2013 *Yikang Rui* - Urban Growth Modeling Based on Land-use Changes and Road Network Expansion, PhD completed.
Jan Haas - Remote Sensing of Urbanization and Environmental Impacts. Licentiate Degree Completed, Ongoing

Osama Yousif - Change Detection using Multitemporal SAR Images. Licentiate Degree Completed, Ongoing
Dr. Juan Deng, Postdoc.

2012 *Xin Niu* - Multitemporal Spaceborne Polarimetric SAR Data for Urban Land Cover Mapping, PhD completed.
Dr. Martin Sjöström, Postdoc.

2011 *Bo Mao* - Visualization and Generalization of 3D City Models, PhD completed.

10. Pedagogic Experience

- AG2416 Advanced Remote Sensing, MSc course
- AG2421 A GIS Project, MSc course
- 1E5590 Knowledge-based Remote Sensing Ph.D. course
- 1E5560 Visualization of Geoinformation, Ph.D. course
- 1E5580 Advanced Spatial Analysis, Ph.D. course

11. Other Information of Importance

Offices in Professional Organization

- *Chair*, ISPRS Inter-Commission (II/IV/VIII) Working Group on Global Land Cover Mapping and Services, 2012-
- *Vice President,* International Cartographic Association, Commission on Mapping from Satellite Data, 2013-present

Recent Journal Editing

- *Associate Editor*, IEEE Journal on of Selected Topics in Applied Earth Observations and Remote Sensing, Special Issue on Multitemporal Remote Sensing, 2014-2017.
- *Guest Editor*, ISPRS Journal of Photogrammetry and Remote Sensing, Theme Issue on Global Land Cover Mapping, 2013-2014
- *Guest Editor*, IEEE Journal on of Selected Topics in Applied Earth Observations and Remote Sensing, Special Issue on Multitemporal Remote Sensing, 2013-2014.

Recent Conference Organizations (Selected)

- *Conference Chair*, 35th EARSeL Symposium and Workshops, Stockholm, 2015.
- *Scientific Committee*, IGARSS 2014, Quebec City, Canada
- *Technical Committee,* the 35th International Symposium on Remote Sensing of Environment, 2013, Beijing, China.
- *Scientific Committee*, ESA Living Planet Symposium 2013, Edinburgh, UK.
- *Scientific Committee*, Urban Remote Sensing Joint Event, 2013, Sao Paulo, Brazil.

Recent Review / Referee Assignments (Selected)

- **E**U Expert, 2014 ERC & 2013 FP7 Marie Curie Proposal Evaluations
- Evaluation of Research Proposals submitted to the Belgian Earth Observations Programme, 2014 & 2011.
- Evaluation of Professorship in Remote Sensing, TU Munich, 2014.
- Evaluation of Professorship in GIS, Aalborg University, Denmark, 2014.
- Evaluation of Docent in Remote Sensing (1) & in GIS (1), Lund University, 2013.
- Evaluation for Research Proposal to STINT, Sweden, 2013.
- Evaluation of Professorship in Planning and GIS, Norwegian University of Science and Technology, 2011.
- Evaluation of Professorship in Geoinformatics, University of Helsinki, 2011
- Reviewing papers for major International Remote Sensing and GIS journals.

Publication list

Publications: Yifang Ban

Peer-reviewed Original Articles

Ban, Y., P. Gong and C. Giri. 2015. Global land cover mapping using earth observation satellite data: recent progresses and challenges. *ISPRS J. of Photogrammetry & Remote Sensing* (In press).

Huang, W. S. Li, X. Liu, and Y. Ban, 2015. Predicting human mobility with activity changes. *International Journal of Geographical Information Science* (In Press).

Haas, J., D. Furberg and Y. Ban. 2015. Satellite Monitoring of Urbanization and Environmental Impacts - A Comparison of Stockholm and Shanghai. *International Journal of Applied Earth Observation and Geoinformation.*

Ban, Y. and A. Jacob & P. Gamba, 2014. Spaceborne SAR Data for Global Urban Mapping at 30m Resolution Using a Robust Urban Extractor. *ISPRS J. of Photogrammetry & Remote Sensing*.

Chen J., Y. Ban and S. Li, 2014, China: Open access to Earth land-cover map, *Nature* 514, 434, DOI:10.1038/514434c.

Liu, X., Y. Ban and S. Li. 2014. An across-country comparison of the hierarchical spatial structures of cities, *Geomatica*, Vol. 68, No. 3.

Yousif O. and Y. Ban, 2014. Improving SAR-Based Urban Change Detection by Combining MAP-MRF Classifier and Nonlocal Means Similarity Weights*, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, DOI: 10.1109/JSTARS.2014.2347171.

Hu, H. and Y. Ban. 2014. Unsupervised Changed Detection in Multitemporal SAR Images over Large Urban Areas. *IEEE Journal on Selected Topics in Applied Earth Observations and Remote Sensing*.

Qin, Y., W. Yao, T. Vu, S. Li and Y. Ban. 2014. Characterizing Radiometric Attributes of Point Cloud Using a Normalized Reflective Factor derived from Small Footprint LiDAR Waveform. *IEEE Journal on Selected Topics in Applied Earth Observations and Remote Sensing*.

Haas, J., and Y. Ban, 2014. Urban growth and environmental impacts in Jing-Jin-Ji, the Yangtze River Delta and the Pearl River Delta. *International Journal of Applied Earth Observation and Geoinformation*.

Rui, Y. and Y. Ban, 2014. Exploring the relationship between street centrality and land use in Stockholm. *International Journal of Geographic Information Science*.

Bo M., Y. Ban and L. Harrie, 2014. Real-time visualization of 3D city models at street level based on visual saliency. SCIENCE CHINA Earth Sciences.

Ban, Y. and A. Jacob, 2013. Object-based Fusion of Multitemporal Multi-angle ENVISAT ASAR and HJ-1 Multispectral Data for Urban Land-Cover Mapping. *IEEE Transaction on GeoScience and Remote Sensing*, Vol. 51, No. 4, pp. 1998-2006.

Yousif, O. and Y. Ban, 2013. Improving Urban Change Detection from Multitemporal SAR Images Using PCA-NLM. *IEEE Transaction on GeoScience and Remote Sensing*, Vol. 51, No. 4, pp 2032-2041.

Deng, J and Y. Ban *et al.*, 2013. Hierarchical Segmentation of Multitemporal RADARSAT-2 SAR Data Using Stationary Wavelet Transform and Algebraic Multigrid Method. *IEEE Transaction on GeoScience and Remote Sensing*.

Niu X. and Y. Ban, 2014. A Novel Contextual Classification Algorithm for Multitemporal Polarimetric SAR Data. *IEEE Transaction on GeoScience and Remote Sensing Letters,* 11(3): 681-685.

Niu, X., and Y. Ban, 2013. Multitemporal RADARSAT-2 Polarimetric SAR Data for Urban Land Cover Classification using Object-based Support Vector Machine and Rule-based Approach, *International Journal of Remote Sensing*, 34(1):1-26.

Niu X. and Y. Ban. 2013. Multitemporal Polarimetric RADARSAT-2 SAR Data for Urban Land Cover Mapping Through a Dictionary-based and a Rule-based Model Selection in a Contextual SEM Algorithm. *Canadian Journal of Remote Sensing*, 39(02): 138-151.

Qin, Y., Z. Niu, F. Chen, B. Li & Y. Ban. 2013. Object-based land cover change detection for cross-sensor images. *International Journal of Remote Sensing*, 34(19): 6723-6737.

Liu. X and Y. Ban. 2013. Uncovering Spatio-Temporal Cluster Patterns Using Massive Floating Car Data. *ISPRS Int. J. Geo-Information*, *2*(2), 371-384.

Mao, B. and Y. Ban, 2013. Generalization of 3D building texture using image compression and multiple representation data structure. *ISPRS Journal of Photogrammetry and Remote Sensing,* Vol. 79, pp. 68–79.

Rui, Y., Y. Ban, J. Wang and J. Haas, 2013. Exploring the patterns and evolution of self-organized urban street networks through modeling. *The European physical Journal B,* 86:74. DOI: 10.1140/epjb/e2012-30235-7.

Lin, J. and Y. Ban, 2013. Complex Network Topology of Transportation Systems . *Transport Reviews: A Transnational Transdisciplinary Journal,* 33(6):658-685.

Ban, Y. and O. A. Yousif, 2012. Multitemporal Spaceborne SAR Data for Urban Change Detection in China. *IEEE Journal on Selected Topics in Applied Earth Observations and Remote Sensing*, 5(4): 1087-1094.

Furberg, D. and Y. Ban, 2012. Satellite Monitoring of Urban Sprawl and Assessment of its Potential Environmental Impact in the GTA between 1985 and 2005. *Environmental Management*, DOI: 10.1007/s00267-012-9944-0.

Hu, H. and Y. Ban. 2012. Multitemporal RADARSAT-2 Ultra-Fine-Beam SAR Data for Urban Land Cover Classification. *Canadian Journal of Remote Sensing,* 38(01): 1-11, 10.5589/m12-008.

Jia, T., B. Jiang, K. Carling, M. Bolin and Y. Ban, 2012. An empirical study on human mobility and its agent-based modeling. *Journal of Statistical Mechanics: Theory and Experiment*, P11024, doi:10.1088/1742-5468/2012/11/P11024.

Mao B., L. Harrie and Y. Ban, 2012. Detection and typification of linear structures for dynamic visualization of 3D city models. *Computers, Environment and Urban Systems*, 36(3): 233–244.

Niu, X. and Y. Ban. 2012. An adaptive SEM algorithm for urban land cover mapping using multitemporal high-resolution polarimetric SAR data, *IEEE Journal on Selected Topics in Applied Earth Observations and Remote Sensing,* 5(4):1129-1139.

Qin, Y., T. Vu and Y. Ban, 2012. Range Determination for Generating Point Clouds from Airborne Small Footprint LiDAR Waveforms, *Optics Express*.

Rui, Y. and Y. Ban, 2012. Non-linear Growth in Weighted Networks with Neighborhood Preferential Attachment. *Physics A*, Volume 391, Issue 20, p. 4790-4797.

Ban, Y., P. Gamba, P. Gong and P. Du. 2011. Satellite Monitoring of Urbanization in China for Sustainable Development, The Dragon 'Urbanization' Project. Earthzine.

Kuang W., Liu J., Shao, Q., He J., Sun, C., Tian H., Ban., Y. 2011. Dynamic Urban Growth Model at Regional Scale and Its Application, *Acta Geographica Sinica*, 66(2).

Mao B. and Y. Ban, 2011. Visualization of 3D City Model through the Internet using CityGML and X3DOM, *Cartographica*, vol. 46, No. 2, pp. 109-114.

Mao B., Y. Ban, L. Harrie, 2011. A Multiple Representation Data Structure for Dynamic Visualisation of Generalised 3D City Models*, ISPRS Journal of Photogrammetry and Remote Sensing, special issue on Quality, Scale and Analysis Aspects of Urban City models*, 66(2): 198-208.

Zhang, Q, Y. Ban, J. Liu and Y. Hu. 2011. Simulation and Analysis of Urban Growth Scenarios for the Greater Shanghai Area, China. *Computers, Environment and Urban Systems*, 35(2): 126-139.

Qin, Y., T. Vu and Y. Ban, 2011. Towards an Optimal Algorithm for LiDAR Waveform Decomposition. *IEEE Transactions on Geoscience and Remote Sensing Letters*, 9(3): 482-486

Ban, Y., H. Hu and I. Rangel, 2010. Fusion of QuickBird MS and RADARSAT-1 SAR Data for Land-Cover Mapping: Object-based and Knowledge-Based Approach. *International Journal of Remote Sensing,* 31(6):1391-1410.

Vu, T. T. and Y. Ban. 2010. Context-based mapping of damaged building from high resolution optical satellite images. *International Journal of Remote Sensing, Special Issue on Wenchuan Earthquake*, 31(13): 3411-3425.

Shao, Q., C. Sun, J. Liu, Y. Ban, J. He and W. Kuang. 2009. Impact of Urban Expansion on Meteorological Observation Data and Over-estimation to Regional Air Temperature in China. *Acta Geographica Sinica* (In Chinese).

Sarker, M., Y. Ban and J. Nichol. 2008. Comparison of Pixel-based, Object-Based and Sequential Masking Classification Procedures for Land Use and Land Cover Mapping using Multiple Sensors SAR in Sweden. *Asian Journal of Geoinformatics,* 8: 25-30

Peer-reviewed Conference Papers

Yousif, O. and Y. Ban. 2015. Object-Based Urban Change Detection Using High Resolution SAR Images. JURSE 2015, Lausanne, Switzerland.

Jacob A. and Y. Ban. 2014. Urban land cover mapping with TerraSAR-X using an edge-aware region-growing and merging algorithm. *Proceedings, IGARSS'2014*, Quebec City, Canda.

Ban, Y. **and** Yousif, O. 2011. Unsupervised Change Detection Using Multitemporal Spaceborne SAR Data - A Case Study in Beijing. *Proceedings, Joint Urban Remote Sensing Event, JURSE 2011* 161-164, Munich, Germany.

Niu, X. **and** Ban, Y. 2011. RADARSAT-2 polarimetric SAR data for urban land cover mapping using spatial- temporal SEM algorithm and mixture models. *Proceedings, Joint Urban Remote Sensing Event, JURSE 2011, 241-244, Munich, Germany.*

Zhang, Q. **and** Ban, Y. 2011. Evaluation of urban expansion and its impact on surface temperature in Beijing, China. *Proceedings, Joint Urban Remote Sensing Event, JURSE 2011* 357-360. Munich, Germany.

Ban, Y., P. Jakobsson, L. Kjelldhal, and U. Ranhagen. 2011. Visualization in ViSuCity, a tool for sustainable city planning. *Proceedings of SIGRAD2011* 105-109.

Parsanezhad, P.**,** Ranhagen, U.**,** Ban, Y. 2011. Towards an Integrated Web-based Visualization Tool - A Comparative Survey of Visualization Techniques for Enhancing Stakeholders' Participation in Planning. *Proceedings of SIGRAD 2011* 61-68.

Niu, X. and Y. Ban. 2010. Urban Land Cover Classification Using Multitemporal RADARSAT-2 Polarimetric SAR Data. *Proceedings, ISPRS TC VII Symposium '100 Years ISPRS-Advancing Remote Sensing Science'*, Vienna.

Zhang, Q. and Y. Ban. 2010. Monitoring Impervious Surface Sprawl Using Tasseled Cap Transformation of Landsat Data. *Proceedings, ISPRS TC VII Symposium '100 Years ISPRS-Advancing Remote Sensing Science'*, Vienna.

Ban. Y. and Q. Wu. 2005. "RADARSAT fine-beam SAR and GIS data for urban Landuse and land-cover mapping", *Proceedings, 8th AGILE Conference on GIScience*, Estoril, Portugal.

Books and Book Chapters

Ban, Y., O. Yousif and H. Hu. 2014. Fusion of SAR and Optical Data for Urban Land Cover Mapping and Change Detection. *Global Urban Monitoring and Assessment through Earth Observation*. Ed. Q. Weng. Taylor & Francis Group, LLC. In press.

Weng Q., P. Gamba, G. Mountrakis, M. Pesaresi, L. Lu, T. Kemper, J. Heinzel, G. Xian, H. Jin, H. Miyazaki, B. Xu, S. Quresh, I. Keramitsoglou, Y. Ban, T. Esch, A. Roth, and C. D. Elvidge. 2014. Urban observation sensors. In Weng, Q. editor. *Global Urban Monitoring and Assessment through Earth Observation*, Chapter 4. Boca Raton, FL: CRC Press/Taylor and Francis. In press.

Duc K. N., T. Vu, Y. Ban, 2014. Ushahidi and Sahana Eden Open-Source Platforms to Assist Disaster Relief: Geospatial Components and Capabilities. Geoinformation for Informed Decisions, 163-174, Springer International Publishing.

Furberg, D. and Y. Ban, 2013. Satellite Monitoring of Urban Land Cover Change in Stockholm between 1986 and 2006 and Environmental Impact Assessment through the Use of Indicators. *Earth Observation for Global Change 2011*, Springer Book.

Rui, Y. and Y. Ban, 2011. Urban Growth modeling with road network expansion and land use development. *Advances in Cartography and GIScience: Selection from ICC 2011,* Springer Book.

CV

Name: Yifang Ban	**Doctorial degree:** 1996-10-24
Birthdate: 19640826	**Academic title:** Professor
Gender: Female	**Employer:** Kungliga Tekniska högskolan

Research education

Dissertation title (swe)

Synthetic Aperture Radar for a Crop Information System: Multitemporal and Multiploarization Approach

Dissertation title (en)

Synthetic Aperture Radar for a Crop Information System: Multitemporal and Multiploarization Approach

Organisation	Unit	Supervisor
University of Waterloo, Canada Not Sweden - Higher Education institutes		Philip Howarth

Subject doctors degree	ISSN/ISBN-number	Date doctoral exam
20199. Annan samhällsbyggnadsteknik		1996-10-24

Publications

Name: Yifang Ban	**Doctorial degree:** 1996-10-24
Birthdate: 19640826	**Academic title:** Professor
Gender: Female	**Employer:** Kungliga Tekniska högskolan

Ban, Yifang has not added any publications to the application.

Register

Terms and conditions

The application must be signed by the applicant as well as the authorised representative of the administrating organisation. The representative is normally the department head of the institution where the research is to be conducted, but may in some instances be e.g. the vice-chancellor. This is specified in the call for proposals.

The signature*from the applicant*confirms that:

- the information in the application is correct and according to the instructions form the Swedish Research Council
- any additional professional activities or commercial ties have been reported to the administrating organisation, and that no conflicts have arisen that would conflict with good research practice
- that the necessary permits and approvals are in place at the start of the project e.g. regarding ethical review.

The signature *from the administrating organisation* confirms that:

- the research, employment and equipment indicated will be accommodated in the institution during the time, and to the extent, described in the application
- the institution approves the cost-estimate in the application
- the research is conducted according to Swedish legislation.

The above-mentioned points must have been discussed between the parties before the representative of the administrating organisation approves and signs the application.

Project out lines are not signed by the administrating organisation. The administrating organisation only sign the application if the project outline is accepted for step two.

Applications with an organisation as applicant is automatically signed when the application is registered.