Chapter 1
Multitemporal Remote Sensing: Current Status, Trends and Challenges

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Abstract Our planet is facing unprecedented environmental challenges including rapid urbanization, deforestation, pollution, loss of biodiversity, sea-level rising, melting polar ice-caps and climate change. With its synoptic view and the repeatability, remote sensing offers a powerful and effective means to observe and monitor our changing planet at local, regional and global scale. Since the launch of Landsat-1 in 1972, numerous Earth Observation satellites have been launched providing large volumes of multitemporal data acquired by multispectral, hyperspectral, passive microwave, synthetic aperture radar (SAR), and LiDAR sensors. This chapter first presents an overview of the Earth Observation sensors and trends in multitemporal observation capacity. Then the current status, challenges and opportunities of multitemporal remote sensing are discussed. Finally the synopsis of the book is provided covering a wide array of methods and techniques in processing and analysis of multitemporal remotely sensed images as well as a variety of application examples in both land and aquatic environments.

1.1 Introduction

Our planet is facing unprecedented environmental challenges including rapid urbanization, deforestation, pollution, loss of biodiversity, sea-level rising, melting polar ice-caps and climate change, just to name a few. The conversion of Earth's land surface to urban areas is one of the most irreversible human impacts on the global biosphere. It hastens the loss of highly productive farmland, affects energy demand, alters the climate, modifies hydrologic and biogeochemical cycles, fragments habitats, and reduces biodiversity (Seto et al. 2011). Deforestation, on the other hand, is a growing problem in the world's rain forests and has many negative effects on the environment including the loss of habitat for millions of species, the lessening of carbon sink, soil erosion and flooding, among others. Melting of the Arctic glaciers and ice-caps as well as rising of sea-level not only are manifestation

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of climate change but also have serious environmental consequences. Therefore, effective methods and tools are of critical importance to map, monitor and analyze environmental changes and evaluate their impact in a timely and reliable manner.

With its synoptic view and the repeatability, remote sensing offers a powerful and effective means to observe and monitor our changing planet at local, regional and global scale. Since the launch of Landsat-1 in 1972, numerous Earth Observation (EO) satellites have been launched providing large volumes of multitemporal data acquired by multispectral, hyperspectral, passive microwave, synthetic aperture radar (SAR), and LiDAR sensors. The increasing number of Earth Observation systems presents enhanced capability to acquire multitemporal data of the Earth surface with improved spectral, spatial, radiometric and temporal resolutions. Such new scenario significantly increases our ability to observe, monitor and predict the dynamics of natural and anthropogenic processes, thus helps to improve our understanding of environmental/climate changes and to support sustainable development.

In this chapter, the Earth Observation sensors and trends in multitemporal observation capacity are presented first. Then the current status, challenges and opportunities of multitemporal remote sensing are discussed. Finally the synopsis of the book is provided.

1.2 Multitemporal Earth Observation Satellites

The first Landsat, launched on July 23, 1972, marked a new era for Earth observations. Since then, seven Landsat satellites have been successfully launched providing data continuity for long-term observation and monitoring of regional and global change. By the end of 2013, a total of 197 earth observing polar orbiters were successfully launched and nearly 50 % were still operational. The number of launches of polar orbiting Earth Observation satellites per year also increased, especially in the past decade (Fig. 1.1). For examples, on 1st August 1972 there was one mission in orbit; by 1st August 1982 the number of satellites had increased to eight, by 1st August 1992 there were twenty such missions, by 1st August 2002 there were thirty-nine and by 1st August 2012 eighty-three. Out of the 197 satellites, only 19 missions carry SAR imagers (Belward and Skøien 2015).

The 44-year archive of the Landsat program is the most extensive, longest-running record of Earth observations from space. Through the Landsat open archives program, the long-term satellite time series data have been freely available since 2008 (Wulder et al. 2012). Free imagery enables reconstruction of the history of Earth's surface back to 1972, chronicling both anthropogenic and natural changes during a time when our population doubled and the impacts of climate change became noticeable (Woodcock et al. 2008). The Earth Resources Observation and Science (EROS) Center at USGS provided approximately 25,000 Landsat images in 2001, the prior record for annual distribution, at a price of $600 per scene. By comparison, EROS distributed approximately 2.5 million images for free in 2010.

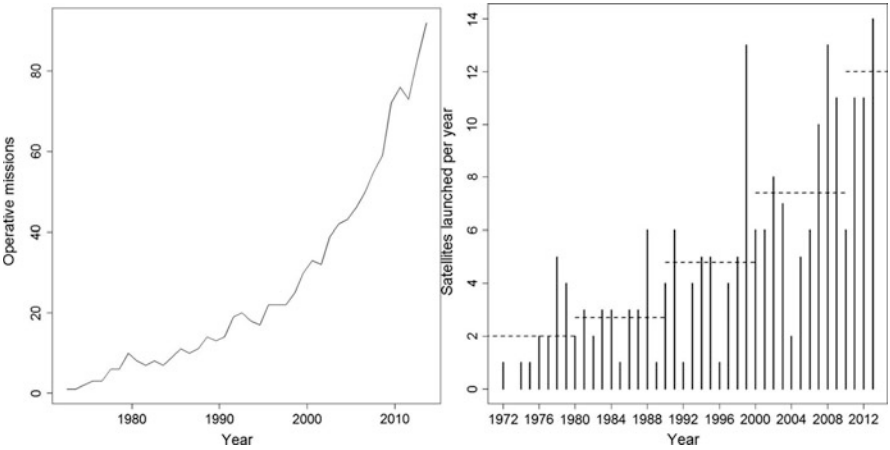

Fig. 1.1 The number of near-polar orbiting, land imaging civilian satellites. *Left*: # of operational satellites/year as of 1st August 1972 to 2013; *Right*: # of launches per year. The *horizontal dotted lines* denote the average number launched per decade (1970s–2010s) (Belward and Skøien 2015)

As a result of the free data policy, combined with notable advancements in technical capacity to analyze large datasets for long-term and large area investigations and applications, Landsat data are experiencing more widespread use by an ever increasing range of end users in a variety of disciplines (Wulder et al. 2012). This is reflected in the increasing number of publications as shown in the next section. One important application example is the production of bi-temporal global land cover maps at 30 m resolution for 2000 and 2010 that are also open access (Chen et al. 2014).

Multitemporal coarse-resolution satellite data (typically 250 m–1 km) have had a ‘free-and-open’ data policy for many years, the longest-standing example being the Advanced Very High Resolution Radiometer (AVHRR) data from the NOAA satellites (Belward and Skøien 2015). The satellite sensors at coarse resolution offer daily observations at global scales and provide the best possibility for cloud-free observations (Lasaponara and Lanorte 2012). In fact, AVHRR NDVI time series (1981–2015) were the first long time-series available for monitoring temporal changes and dynamic processes of Earth surface. The launches of Moderate Resolution Imaging Spectroradiometer (MODIS) on board Terra (2000-present) and Aqua (2002 to present) were another significant milestones in multitemporal remote sensing as they provide time series data in 36 spectral bands imaging the entire Earth’s surface every 1–2 days. The availability of the large volume time series data at 25 m resolution quickly expended the development of times series methodology and applications (Eklundh and Jönsson 2015), as reflected in the number of publications described in next section. Other time series data at coarse resolution include SPOT-4/-5 Vegetation (1998–2013), PROBA Vegetation (Follow-on to Vegetation, 2013-present), SeaWiFS (1997–2010), Suomi-NPP VIIRS (2012-present) (Pinzon and Tucker 2014) as well as ENVISAT Medium Resolution Imaging Spectrometer

(MERIS, 2002–2012). These time series data provide consistent, long-term satellite records to monitor trends in land surface dynamics as well as processes occurring in the oceans and the lower atmosphere.

The launch of SPOT-1 in 1986 marked a new era of commercialized Earth observation at high-resolution, i.e., 10 m and 20 m for panchromatic and multispectral images respectively. Since then, three generations of SPOT satellites have been launched with improved spatial resolution to 1.5 m for panchromatic and 6 m for multispectral images. Compared to Landsat data, however, SPOT images were much less used in multitemporal analysis primarily due to their higher-costs. The trend of increasing spatial resolution is apparent in the emergence of 'very high' resolution classes benefited from the declassified spy satellite technology. With the launch of IKONOS, the first commercial very high resolution satellite in 1999, panchromatic and multispectral images at spatial resolutions of 1 m and 4 m became available. The spatial resolutions are further improved by QuickBird (0.65 m/2.62 m), WorldVew-1/2 (0.46 m/1.84 m), GeoEye-1 (0.46 m/1.84 m), Pleiades-1A/1B (0.5 m/2 m). The highest resolutions were reached by WorldView-3 at 31 cm panchromatic resolution and 1.24 m multispectral resolution in 2014. Very high resolution multitemporal data enable new, strategic and challenging applications, such as monitoring illegal excavations in archaeological areas (Lasaponara and Lanorte 2012), precision farming, detailed disaster damage assessment and urban mapping, among others. However, the use of very high resolution data for multitemporal analysis are rather limited as reflected in the low number of publications (see next section) due to their high cost. Figure 1.2 shows then number of multispectral and panchromatic sensors at different spatial resolutions on board near-polar orbiting, land imaging civilian satellites per year (Belward and Skøien 2015).

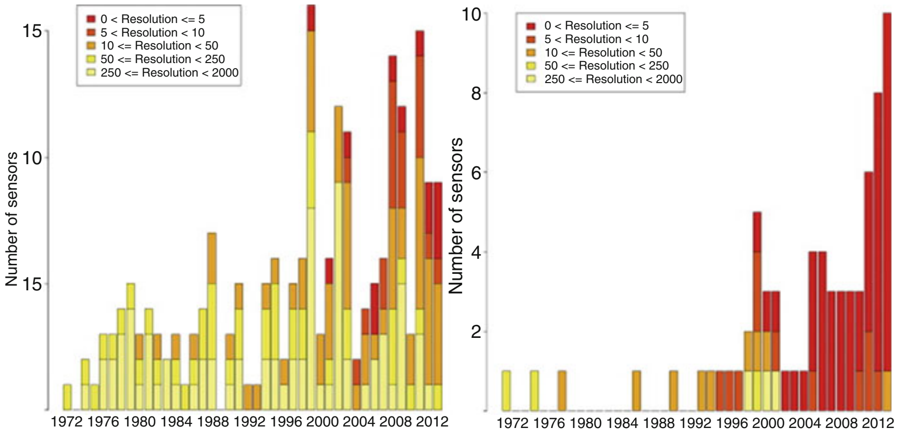

Fig. 1.2 Number of multispectral (*Left*) and panchromatic (*Right*) sensors at different spatial resolutions on board near-polar orbiting, land imaging civilian satellites per year (Belward and Skøien 2015)

One of the latest developments in the optical remote sensing is the use of the CubeSat concept in Earth Observation. Since 2014, Planet Labs have launched over 100 small satellites with the objective of having 150 satellites in a sun synchronous orbit by the end of 2016 collecting the entire land mass of the Earth every day at 3–5 m resolution in Red, Green, Blue and Near Infrared wavelengths (Planet Labs 2015). Terra Bella (formerly Skybox Imaging)'s SkySat-1/-2 are microsatellites carrying a two-dimensional sensor array capable of providing 0.9 m resolution imagery in red, green, blue, near-infrared and panchromatic bands as well as the first-ever commercial high-resolution video (1.1 m resolution) of Earth from a satellite (Terra Bella 2016). These data offer the potential to monitor land surface changes at high-spatial and high-temporal resolution, but cost is an obvious issue.

The first SAR imaging system is the Seasat mission, launched by the U.S. in 1978 with a L-band SAR at 25 m resolution on board. As the mission duration is only 105 days, Seasat SAR data had very little use in multitemporal remote sensing. The first multitemporal SAR dataset became available with the launch of the European Space Agency's ERS-1 in 1991 with C-VV SAR at 30 m resolution on board. This is followed by the launches of Russia's ALMAZ-1B S-band SAR at 30 m resolution in 1991 and Japan's JERS-1 L-band SAR at 18 m resolution in 1992. These early SAR sensors are in single frequency, single polarization, single incidence-angle and single resolution. The launch of Canada's RADARSAT-1 in 1995 marked the beginning of high-resolution SAR systems with multiple beams at various spatial resolutions (8 m–100 m). To provide data continuity, ESA launched ERS-2 in 1995 with the same sensor and ENVISAT in 2002 with C-band SAR in dual-polarization and multiple beam modes and resolutions. ESA's ERS SAR and ENVISAT ASAR data have been most used for multitemporal SAR remote sensing, as reflected in the number of publications (see next section). Another data continuity mission is Japan's Phased Array type L-band Synthetic Aperture Radar (PALSAR) in 2005, also with multiple beams and resolutions (10–100 m). Very high resolution SAR data became available with the launch of RADARSAT-2 with ultra-fine beam C-band SAR at 3 m resolution in 2007. Another advanced feature of RADARSAT-2 SAR is to acquire data in fully polarimetric mode at 10 m resolution, in addition to the continued multi-beam multi-resolution modes of RADARSAT-1. The highest resolution SAR became available in 2007 with the launches of Italy's CosmoSkymed and Germany's TerraSAR, both in X-band at 1 m resolution. Another advance is the launch of TanDEM-X in 2010 providing high-resolution SAR interferometry (InSAR) data for multitemporal applications from monitoring land subsidence to glacier retreats.

Time series data from very coarse resolution (25–50 km) passive microwave scatterometer have also been available since the early 1990s, including ERS-1/-2 scatterometer (SCAT), European Meteorological Operational Satellites (MetOp) Advanced Scatterometer (ASCAT), and NASA Quick Scatterometer (QuikSCAT). These data are mainly used to derive soil moisture, wind speed and direction, and for sea ice monitoring. Multitemporal thermal infrared data, on the other hand, are mainly from Landsat sensors, AVHRR, MODIS and AATSR. They have been used to analyze multiannual to multidecadal LST patterns as well as hotspots and anomalies in the context of urban heat islands and long-burning underground coal fires, etc. However, the analysis of time series of convincing length is rare in these contexts (Kuenzer et al. 2015).

One of the significant developments in multitemporal remote sensing is the open access to big EO data at high-spatial and temporal resolutions. With the recent launches of ESA Sentinel-1A/-B and Sentinel-2A, multitemporal SAR and optical data in 10 m and 20 m resolution with 6-day global coverage become freely available. The images acquired by the Sentinel satellites represent an enormous amount of data: whereas ENVISAT provided 0.3 terabyte (TB) per day, each Sentinel-1 provides 1.8 TB/day, with Sentinel-2 s providing 1.6 TB and Sentinel-3 s providing 0.6 TB (Showstack 2014). Processing and mining such huge volume of data presents both challenges and opportunities in multitemporal remote sensing.

1.3 Multitemporal Remote Sensing: Trend, Challenges and Opportunities

As discussed in the previous section, a large number of new spaceborne remote sensing systems have been launched in the past two decades. The enhanced capability to acquire multitemporal data of the Earth surface with improved spatial, spectral, radiometric and temporal resolution have significantly increased the interest in multitemporal remote sensing, time series processing and applications. As a result, various methods and algorithms have been development for change detection (e.g., Bruzzone and Prieto 2000; Lu et al. 2004; Bovolo and Bruzzone 2005; Gamba et al. 2006; Bovolo and Bruzzone 2007a, b; Ban and Yousif 2012; Yousif and Ban 2013; Liu et al. 2015) and time series analysis (e.g, Roerink et al. 2000; Jönsson and Eklundh 2004; Galford et al. 2008; Pinzon and Tucker 2014; Hermosilla et al. 2015; Kuenzer et al. 2015; Müller et al. 2015). Multitemporal remote sensing have been used for a wide range of applications including urban mapping (e.g, Gong et al. 1992; Gamba and Harold 2009; Pesaresi et al. 2013; Ban et al. 2015), urbanization monitoring (e.g., Taubenböck et al. 2012; Haas et al. 2015) and environmental impact assessment (e.g., Güneralp and Seto 2013; Haas and Ban 2014), Crop monitoring (e.g., Shao et al. 2001; Bouvet et al. 2009; McNairn et al. 2014), deforestation (e.g., Skole and Tucker 1993; Rignot et al. 1997; Tucker and Townshend 2000; Achard et al. 2002; Hansen et al. 2013), desertification (e.g., Yang et al. 2005; Dawelbait and Morari 2012), flooding (e.g. Martinez and Le Toan 2007), biodiversity monitoring (e.g., Turner et al. 2003; Kuenzer et al. 2014; Skidmore et al. 2015), land cover mapping (e.g., Anderson et al. 1976; Friedl et al. 2002; Bontemps et al. 2011; Ban and Jacob 2013; Chen et al. 2015) and change detection (e.g, Bruzzone and Serpico 1997; Zhu and Woodcock 2014), vegetation dynamics (Olsson et al. 2005; Hilker et al. 2014), land surface dynamics (e.g, Liang 2004; Kuenzer et al. 2015), natural disasters and hazards (Tralli et al. 2005; Bovolo and

Bruzzone 2007a; Gamba et al. 2007; Vu and Ban 2010), coastal monitoring (Arnone and Parsons 2005; Kratzer et al. 2008), Retreat of glaciers and ice shelves (e.g., Rignot 2001; Rack and Rott 2004; Rignot et al. 2014), as well as sea ice monitoring (e.g, Eriksson et al. 2010; Mahmud et al. 2016). Multitemporal remote sensing has demonstrated its enormous capability and potential for environmental change monitoring at various scales.

Driven by the increasing interests in studying the dynamics of environmental changes, improved sensor technology and image processing techniques as well as open data policy, the remote sensing community has witnessed a substantial increase in multitemporal remote sensing research, development and applications in the past two decades. As shown in Fig. 1.3, the number of journal articles (including review articles) on change detection has been increasing rapidly since 2000. Similar trends are observed when search for number of journal articles (including review articles) on multitemporal remote sensing or time series. This period coincides with the launches of high-spatial or high-temporal resolution optical satellite systems, advanced spaceborne SAR sensors, the development of innovative multitemporal image processing and analysis techniques as well as open access to Landsat data archive. The most relevant peer-reviewed journals for multitemporal remote sensing, change detection and time series analysis are presented in Table 1.1. It is apparent that all major remote sensing journals have published articles on these subjects. The top five journals are International Journal of Remote Sensing, Remote Sensing of Environment and IEEE Transactions on Geoscience And Remote Sensing, Remote Sensing, and IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (JSTARS). Started in 2009 and 2008 respectively, Remote Sensing

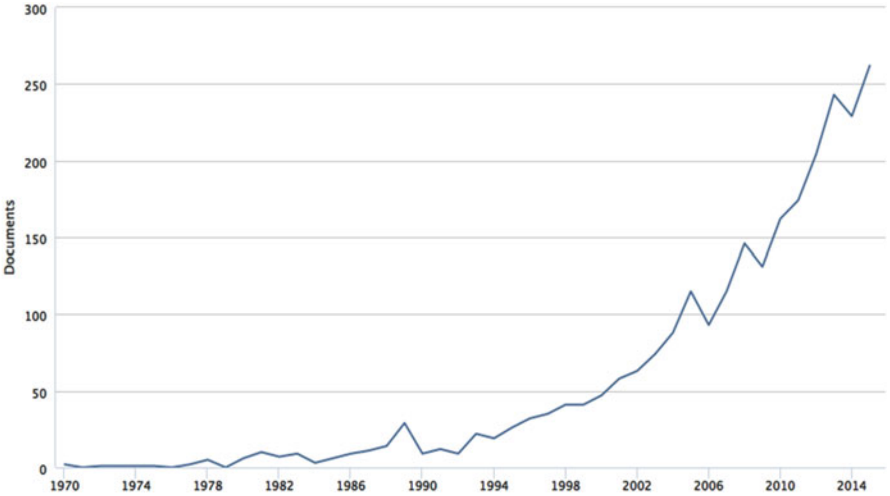

Fig. 1.3 The number of articles (including review articles) per year on change detection derived from a Scopus search on July 15, 2016, by the author

Table 1.1 Literature search results using Scopus on ‘Multitemporal Remote Sensing’, ‘Change Detection’, ‘Remote Sensing Time Series’

Number of journal papers on multitemporal remote sensing	Number of journal papers on remote sensing + change detection	Number of journal papers on remote sensing + time series
International Journal of Remote Sensing (*299*)	*International Journal of Remote Sensing* (432)	*Remote Sensing of Environment* (427)
IEEE Transactions on Geoscience and Remote Sensing (*242*)	*Remote Sensing of Environment* (403)	*International Journal of Remote Sensing* (277)
Remote Sensing of Environment (*213*)	*IEEE Transactions on Geoscience And Remote Sensing* (262)	*Remote Sensing* (191)
Remote Sensing (*135*)	*Remote Sensing* (165)	*IEEE Transactions on Geoscience And Remote Sensing* (150)
IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (78)	*IEEE Geoscience and Remote Sensing Letters* (128)	*IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* (97)
International Journal of Applied Earth Observation and Geoinformation (*58*)	*IEEE Journal of Selected Topics in Applied Earth Observations And Remote Sensing* (124)	*International Journal of Applied Earth Observation and Geoinformation* (74)
ISPRS Journal of Photogrammetry and Remote Sensing (*57*)	*Photogrammetric Engineering And Remote Sensing* (106)	*ISPRS Journal of Photogrammetry and Remote Sensing* (63)
IEEE Geoscience and Remote Sensing Letters	*ISPRS Journal of Photogrammetry And Remote Sensing* (88)	*IEEE Geoscience and Remote Sensing Letters* (53)
Journal of Applied Remote Sensing (*36*)	International Journal Of Applied Earth Observation And Geoinformation (65)	*Journal of Applied Remote Sensing* (38)
Canadian Journal of Remote Sensing (*35*)	Journal of Applied Remote Sensing (62)	*Canadian Journal of Remote Sensing* (37)
Photogrammetric Engineering and Remote Sensing (*31*)	Canadian Journal of Remote Sensing (55)	*Photogrammetric Engineering and Remote Sensing* (37)

Note: The search was conducted on July 15, 2016. A total of 2290 papers on ‘multitemporal remote sensing’, 3188 papers on ‘remote sensing + change detection’ and 3694 papers on ‘remote sensing + time series’ were found

and JSTARS, the two new journals, have managed to reach the top five. A number of special issues on multitemporal analysis or time series analysis have been published in these top journals except in Remote Sensing of Environment.

Figure 1.4 shows the Scopus search of publications for multitemporal optical data using the Keyword ‘Multitemporal’ or ‘Change Detection’ or ‘Time Series’ + ‘EO optical sensor/satellite’, All publications include all journal articles, review articles,

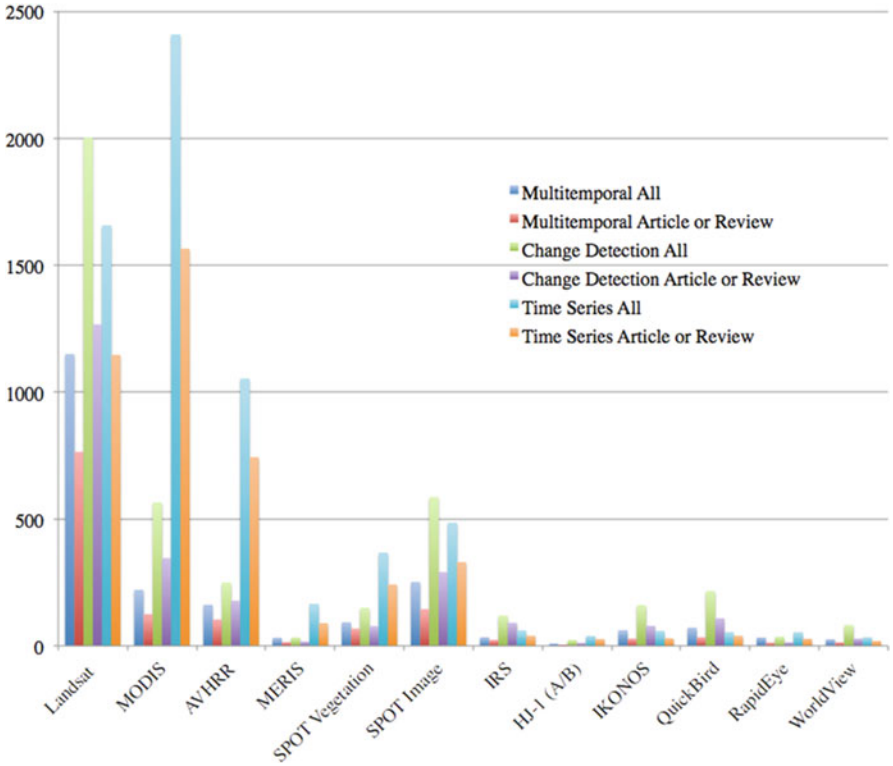

Fig. 1.4 Optical sensors: Scopus search of publications using the keyword 'Multitemporal' or 'Change Detection' or 'Time Series' + EO sensor/satellite', all publications include all journal articles, review articles, books, book chapters, conference papers, conference reviews, editorials, and letters. Article or review only includes journal articles and reviews

books, book chapters, conference papers, conference reviews, editorials, and letters. Article or Review only includes journal articles and reviews. With its longest time-series, Landsat has the highest numbers of publications for 'multitemporal' and 'change detection', significantly more than other EO sensors. However, MODIS has the top hit for 'time series' while Landsat in the second place and AVHRR in the third place. This could be attributed to that MODIS time series have been freely available since 2000 while Landsat's open data policy was only in place since 2008. Fewer publications were found on MERIS and SPOT Vegetation in comparison to MODIS. In spite of the high costs of SPOT images, the number of publications on 'change detection + SPOT image' gained number two place indicating interests high-resolution data in change detection methodology and applications. Limited number of publications on very high resolution sensors was due to their high costs while the low number of publications on IRS and HJ-1 data is due to their availability and accessibility.

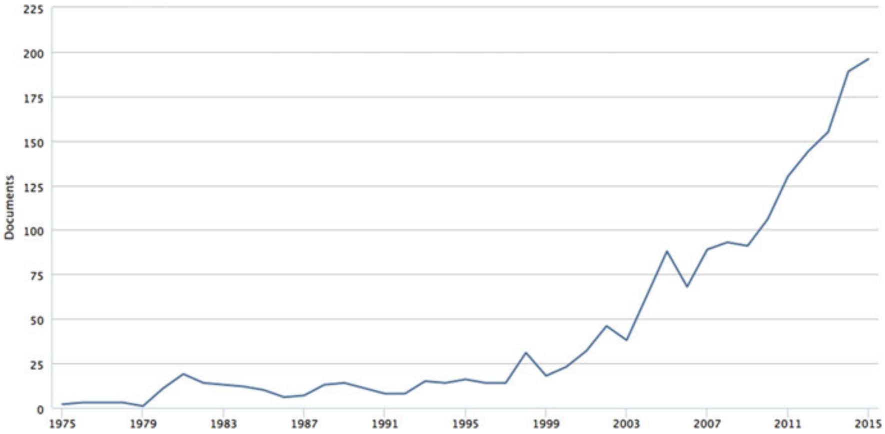

Fig. 1.5 Number of publications per year from Scopus search for 'Change Detection' and 'Landsat'

Figure 1.5 Shows that the number of publications per year from Scopus search for 'Change Detection' and 'Landsat'. It shows that the number of publications per year using Landsat for change detection/multitemporal analysis is relatively low in the early years. Since the launch of Landsat-7 in 1999 with a new panchromatic band at 15 m spatial resolution, the number of publications increased significantly, especially after the Landsat free data policy in 2008, the publications per year experienced exponential growth, from approx. 90 in 2009 to approx. 200 in 2015.

Scopus search of publications for multitemporal SAR data using the Keyword 'Multitemporal' or 'Change Detection' or 'Time Series' + EO sensor/satellite' is presented in Fig. 1.6. The total number of publications for SAR are much lower than optical data. With its longest SAR time series, ERS holds the top places for 'Multitemporal' and 'Time Series' as well as 'change detection' in journal and review articles. RADARSAT has the highest hit for all papers on 'change detection', second place in 'multitemporal' and third place in 'time series'. ENVISAT ASAR holds the second place for 'time series'. Compared to the top three, both ALOS PALSAR and TerraSAR-X also have good number of publications indicating interests in multitemporal L- and X-band SAR analysis and applications.

Multitemporal remote sensing has emerged as a new frontier for Earth observations. With the increasing number of Earth Observation systems with enhanced capacities and free access to terabytes and petabytes of multitemporal data with global coverage, the remote sensing community is presented with major challenges and ample opportunities. Big data analytics paradigm needs to be introduced to image processing and analysis frameworks, novel processing and data mining methods are necessary to handle longer and denser time series data, effective change detection techniques need to be developed to process VHR multispectral, SAR, hyperspectral images and for cross-sensor change detection. Data fusion methods need to be advanced to integrate multi-sensor multi-resolution data. Multi-scale

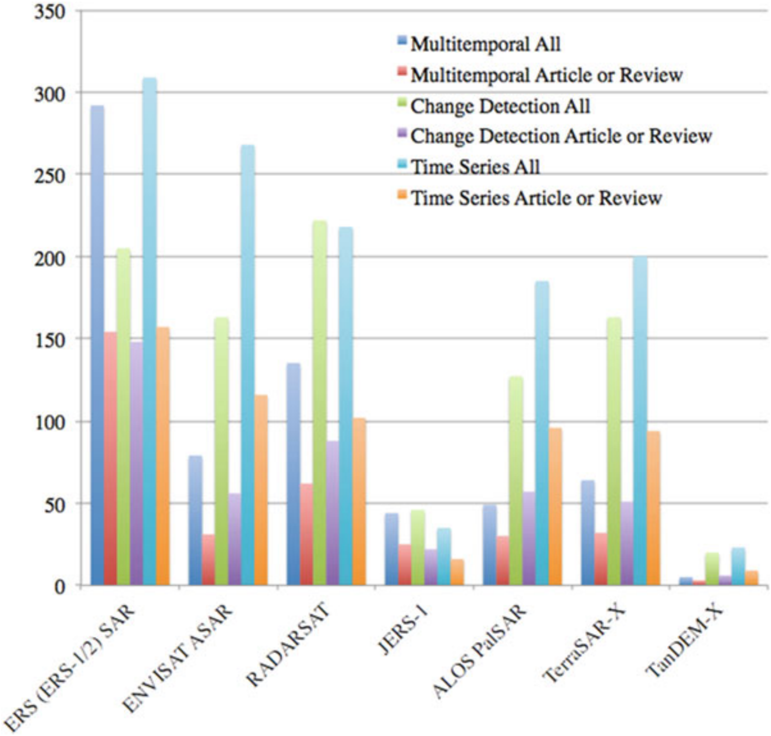

Fig. 1.6 SAR: Scopus search of publications using the keyword 'Multitemporal' or 'Change Detection' or 'Time Series' + EO sensor/satellite', all publications include all journal articles, review articles, books, book chapters, conference papers, conference reviews, editorials, and letters. Article or review only includes journal articles and reviews

analysis with a holistic approach is necessary for monitoring environmental changes from micro-level to macro-level. In addition, cloud-based data repository and processing such as Google Earth Engine could also facilitate global environmental change monitoring, with Global Forest Watch (Davis and Thau 2014) as an excellent example. Last but not least, new applications are expected to emerge from these new datasets, technological developments and paradigm shifts.

1.4 Synopsis of the Book

The book intends to provide an overview of a wide array of methods and techniques in processing and analysis of multitemporal remotely sensed images as well as a variety of application examples covering both land and aquatic environments. A broad range of multitemporal datasets is used in the methodology demonstrations and application examples. Multispectral and hyperspectral data include Landsat,

ASTER, HJ-1, MODIS, AVHRR, MERIS, SPOT Vegetation, SeaWiFS and Hyperion while SAR data include ERS, ENVISAT, Sentinel-1A, RADARSAT, ALOS PALSAR, TerraSAR-X and TanDEM-X. Passive microwave data is also used.

Chapter 1 provides a synopsis of Earth Observation sensors and trends in multitemporal observation capacity as well as the current status, challenges and opportunities of multitemporal remote sensing. Chapters 2, 3, 4, 5, 6 and 7 are focused on change detection. First, Chap. 2 provides a comprehensive review of the recent development in change detection techniques using both optical and SAR images. Various aspects of change detection processes were presented including data preprocessing, change image generation and change detection algorithms. Major challenges for change detection are also identified. Chapter 3 provides a detailed analysis of a number of the issues arising from urban change detection. Specifically, the role of very high resolution sensors and their relevance with respect to either fast or slow changes in human settlement is analyzed. The possibility to exploit long temporal sequences of coarser resolution data is also explored. Chapter 4 addresses the multiple-change detection problem in multitemporal hyperspectral remote sensing images in an agricultural landscape. First, an analysis of the concept of "change" is given from the perspective of pixel spectral behaviors, taking into account the intrinsic complexity of the hyperspectral data. Then a hierarchical change-detection approach is presented aiming at detecting multiple-change information in an unsupervised way. Satisfactory results obtained on both simulated and real bi-temporal Hyperion images confirm the effectiveness of the proposed hierarchical method. Chapter 5 investigates object-based unsupervised change detection in Beijing and Shanghai using very high resolution SAR images. Three thresholding algorithms, i.e., the Kittler-Illingworth algorithm, the Otsu method, and the outlier detection technique, are tested and compared. Promising results are presented and limitations are revealed. Chapter 6 evaluates multitemporal spaceborne SAR and optical data for urban land cover mapping and urbanization monitoring using KTH-SEG and KTH-Pavia Urban Extractor. The results indicate that carefully selected multitemporal SAR dataset and its fusion with optical data could produce nearly as good classification accuracy as the whole multitemporal dataset. The results also show that urban areas as well as small towns and villages could be well extracted using multitemporal Sentinel-1A SAR data while major urban areas could be well extracted using a single-date single-polarization SAR image. The results clearly demonstrate that multitemporal SAR data are cost- and time-effective way for monitoring spatiotemporal patterns of urbanization. Chapter 7 presents a processing chain for post-classification change detection in Arctic glaciers using multi-polarization SAR images. The method consists of terrain correction, segmentation using an unsupervised contextual non-Gaussian clustering algorithm, consistency analysis of the segmentation algorithm, post-classification change detection. A series of dual polarization C-band ENVISAT ASAR images over the Kongsvegen glacier, Svalbard, are used for demonstration.

The basic theory of SAR interferometry and Multi-Temporal InSAR is discussed in Chap. 8. InSAR is potentially a very powerful technology to estimate DEMs and ground movement, however, InSAR is affected by important limitations such as decorrelation, phase ambiguity and atmospheric biases. Multi-Temporal InSAR techniques offer a series of tools for lessening InSAR limitations, making it possible to process and analyze displacement time series, and also to precisely estimate ground elevation.

Chapters 9, 10, 11, 12, 13 and 14 present various processing and analysis methods for coarse-resolution time series with a focus on monitoring vegetation and land surface dynamics. Chapter 9 presents TIMESAT, a software package for processing time-series data from coarse resolution satellite sensors for land surface monitoring using asymmetric Gaussian fits, double-logistic fits, and Savitzky-Golay filtering. Example applications using TIMESAT are also given including phenology and phenological variations; ecological disturbances; vegetation classification and characterization; agriculture applications; climate applications; and for improving remote sensing signal quality. Chapter 10 presents PhenoSat, another software tool that extracts phenological information from satellite-based vegetation index time-series. The main characteristics and functionalities of PhenoSat are evaluated using multi-year NDVI derived from SPOT VEGETATION and NOAA AVHRR with six fitting methods: cubic splines, piecewise-logistic, Gaussian models, Fourier series, polynomial curve-fitting and Savitzky-Golay. The results show that PhenoSat is capable to extract phenological information consistent with reference measurements, and to adapt to different vegetation types, and different satellite data sources. Chapter 11 compares six methods to improve the temporal coherence and continuity of leaf area index (LAI) time series. A dedicated approach combining the local temporal smoothing gap filling (TSGF) filter with a climatology gap filling technique is then developed. This method constitutes the basis of the algorithm for the operational production of continuous and smooth time series of biophysical variables from VEGETATION data within the European Copernicus Global Land Service. Chapter 12 attempts to define metrics relevant for capturing the soil moisture dynamics from an annual series of wetness estimates derived from global MODIS images. Different algorithms for both smoothing and gap-filling the time series are tested with the results compared to in-situ data. Metrics capturing the global surface wetness phenology for 2011, extracted after smoothing using a simplified locally weighted scatterplot smoothing (LOWESS) model, are presented at a spatial resolution of 500 m for the calendar year 2011. Chapter 13 first discusses the potential and limitations of long-term time series analyses of land surface albedo using satellite-derived surface albedo products such as GLASS, GlobAlbedo, MERIS, MODIS. Then this chapter presents some recently developed methods to detect sensor change, to reduce data gaps, and to improve data consistency and accuracy of existing satellite products, followed by a case study on the temporal analysis of regional long-term land surface albedo changes. Chapter 14 analyzes vegetation response to climate variability using time series analysis of land surface temperature in two different spectral regions: Thermal Infrared (TIR) observations of land surface temperature to study the thermal behavior of the land surface in response to weather and climate; and 37 GHz observations of the polarization difference in brightness temperature to retrieve the fractional abundance of water-saturated soil. Two methods are applied to identify and remove anomalous observations (outliers) and to fill the resulting gaps: Harmonic ANalysis of Time Series (HANTS) and the Multichannel Singular Spectrum Analysis (M-SSA). Three applications of time series of land surface temperature are presented: (a) monitoring of spectral thermal admittance of the land surface; (b) estimation and mapping of air temperature and (c) monitoring of thermal load to assess the risk of forest fires.

Chapter 15 provides a comprehensive review of multitemporal SAR for crop monitoring. First, SAR's response to crop type and conditions are discussed, then SAR for crop classification and acreage estimation is presented. Temporal trends in SAR's response and sensitivity to crop phenology is then discussed and sensitivity of SAR to crop bio-physical properties including LAI, canopy biomass and crop height are presented. Chapter 16 highlights the opportunities and the challenges for integrating wildlife location data with high spatial and temporal resolution landscape disturbance datasets, available from remotely sensed imagery. The 16-day outputs from the Spatial Temporal Adaptive Algorithm for mapping Reflectance Change (STAARCH) disturbance maps are integrated with grizzly bear (Ursus arctos) telemetry data. The results indicate that males and females avoided same-year disturbances, while male bears were most likely to avoid recently disturbed areas in summer. When intra-year (disturbances mapped at a 16-day time-step) analysis of disturbance was compared to traditional annual time-step analysis, annual aggregation of disturbance data resulted in an increase in the observed selection of same-year disturbed habitat, although change was not statistically significant (α 0.05). The use of low-temporal resolution disturbance data to evaluate short-term impacts on wildlife is cautioned and the need for further development of probabilistic- and model-based techniques for overcoming spatial-temporal differences between datasets is highlighted.

Chapters 17, 18 and 19 present applications of multitemporal remote sensing in coastal and aquatic environment. Chapter 17 summarizes remote sensing applications in water and wetland monitoring, in particular in the topics of monitoring water quality, water surface areas and water fluctuation in wetland areas. The chapter then introduces two cases of monitoring studies in the Poyang Lake, the largest fresh water lake in China, in terms of monitoring of fluctuation and variation of water surface areas using MODIS data product, and monitoring of variation of natural wetlands corresponding to the changing water levels of Poyang Lake using Landsat data. Chapter 18 describes a bi-temporal study of global land surface water in China's Global Land Cover Mapping project. Through collection and processing of Landsat TM/ETM+, China's HJ-1 satellite imagery and other remotely sensed data, global water layers in 2000 and 2010 were extracted using a pixel-, object- and knowledge-based approach. Based on the GlobeLand30-Water 2000/2010 products, the spatial distribution patterns and temporal fluctuation trends of land surface water at global scale are analyzed in the chapter. Chapter 19 addresses some of the recent developments in marine coastal remote sensing with regards to the evaluation of water quality using spaceborne multitemporal data. First, a general introduction to marine remote sensing is provided. Then the chapter reports the recent results from remote sensing of several coastal and aquatic environments, including (1).

the Baltic Sea, that is optically dominated by the absorption of light by coloured dissolved organic matter (CDOM), and during summer months, by high standing stocks of filamentous cyanobacteria; (2). the Bay of Biscay in the north-eastern Atlantic Ocean west of France, which is an area highly influenced by river discharge and dinoflagellate blooms, and (3). a coastal area in the eastern Beaufort Sea in the Canadian Arctic that is influenced by a pool of CDOM. The chapter concludes with a synthesis on merging of satellite data from different ocean colour missions and discusses the limitations for coastal applications.

Chapter 20 investigates the integration of multitemporal medium resolution satellite images with and socio-economic field data for monitoring recovery of the tsunami-affected areas in Phanga, Thailand. Multitemporal landuse/landcover maps were produced using a supervised classification of ASTER images. Socio-economic data was analyzed to obtain information related to the recovery process on the ground. The two datasets presented a good agreement in detection of the recovery of tourism and expansion of agricultural activities. The rehabilitation of mangrove forest could be observed, but it was not possible to confirm whether a building was newly built. To some extent, the integration of ASTER images and ground data proved useful in providing a clear picture of the recovery process in an area like Phang Nga, Thailand.

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