Remote Sensing and Digital Image Processing

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Remote Sensing Time Series

Revealing Land Surface Dynamics

Springer

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Foreword

Our fragile planet experiences global change at unprecedented speed. Much of this change is man-made. We harness rivers and lakes, clear-cut forests, transfer natural ecosystems into agricultural land, and extract underground resources. Through urbanization as well as socio-economic transformation more and more pristine habitats come under pressure. Changes in climate variability impact the dynamics of snow cover and water bodies, soil moisture and vegetation phenology.

Satellite-based earth observation technology allows us to monitor and quantify these changes. Satellite remote sensing – and here especially the analysis of long-term time series – enables us to reveal land surface dynamics that otherwise might remain hidden to the human eye. The book *Remote Sensing Time Series Revealing Land Surface Dynamics* focuses on exactly this potential of space-borne earth observation.

What can earth observation contribute to the understanding of global change? Which satellite sensors exist? Which data really allow for long-term monitoring and time-series analysis? When is a time series long enough to shed light on climate variability? Which challenges face scientists who use remote sensing satellite data to further knowledge about our planet? How do different ecosystems change over time?

This book, which has been initiated by scientists of DLR's German Remote Sensing Data Center (DFD), addresses all these questions. Experts from all over Europe, the USA, and China have contributed to this comprehensive volume.

In recent years many satellite data archives have been made available to the public. The USA made nearly 40 years of Landsat data accessible free of charge. Data archives like this one, which allow us to look into the past for several decades,

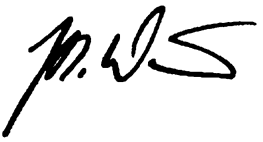
are of immense value. Medium resolution data collected by the US AVHRR sensor have also been available for several decades. Additionally, since the year 2000, MODIS data also allow us to monitor our entire planet at daily intervals. Europe has followed this lead to facilitate satellite data access. Free optical, thermal infrared, and radar data from sensors on board the ESA research satellite ENVISAT, enabled dense, multifaceted analysis of the land surface between 2002 and 2012. Furthermore, data of the novel and upcoming European Sentinel missions operated by the European Space Agency on behalf of the European Union are currently being made available free of charge both to scientific and commercial users.

Amongst other institutions, our German Remote Sensing Data Center will provide and operate the processing and archiving facilities for the data from Sentinel-1 C-band SAR sensors that grants continuity for ENVISAT-ASAR, as well as for Sentinel-3 OLCI data, continuing the ENVISAT MERIS instrument. Sentinel-5 precursor data will also be processed and archived at DFD.

However, the large amount of earth observation data contained in satellite data archives globally also poses great challenges for the science community. The analysis of time series of data is much more complex than just comparing a few multitemporal satellite scenes. Time-series analysis requires the processing of hundreds, thousands, or even a hundreds of thousands of data sets. This "big data" needs to be calibrated, preprocessed, harmonized, interpolated, and statistically analyzed. At frequent intervals – monthly or annually – time series have to be re-processed to derive updated mean, minima, maxima, variability and anomalies. This is an extremely demanding task. Additionally, the challenge of big data and the challenge to fully exploit all the wealth of information that is contained in data archives are getting bigger every day. More and more space nations launch satellites into orbit. The life span of sensors increases. And data access is eased further. The computer and programming literacy of scientists and young people in general is rapidly increasing. Envisioning this trend, one of our technical answers is that algorithms should rather come to the data instead of routing mass-data archives to the analysts. So, hopefully, as the challenges grow, so will our means to address them. I am confident that we will be able to manage the upcoming challenges, and that the European Copernicus program will help to blaze the trail.

I hope that this book will trigger or deepen your interest in remote sensing time-series analysis as a valuable means to assess the state of our Planet Earth.

I wish you stimulating reading.



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Contents

1 Remote Sensing Time Series Revealing Land Surface Dynamics: Status Quo and the Pathway Ahead 1
Claudia Kuenzer, Stefan Dech, and Wolfgang Wagner

2 Time Series Analyses in a New Era of Optical Satellite Data 25
Patrick Hostert, Patrick Griffiths, Sebastian van der Linden, and Dirk Pflugmacher

3 Calibration and Pre-processing of a Multi-decadal AVHRR Time Series 43
Martin Bachmann, Padsuren Tungalagsaikhan, Thomas Ruppert, and Stefan Dech

4 Analysis of Snow Cover Time Series – Opportunities and Techniques 75
Andreas J. Dietz, Claudia Kuenzer, and Stefan Dech

5 Global WaterPack: Intra-annual Assessment of Spatio-Temporal Variability of Inland Water Bodies 99
Igor Klein, Andreas J. Dietz, Ursula Gessner, and Claudia Kuenzer

6 Analysing a 13 Years MODIS Land Surface Temperature Time Series in the Mekong Basin 119
Corinne Myrtha Frey and Claudia Kuenzer

7 TIMESAT: A Software Package for Time-Series Processing and Assessment of Vegetation Dynamics 141
Lars Eklundh and Per Jönsson

8 Assessment of Vegetation Trends in Drylands from Time Series of Earth Observation Data 159
Rasmus Fensholt, Stephanie Horion, Torbern Tagesson, Andrea Ehammer, Kenneth Grogan, Feng Tian, Silvia Huber, Jan Verbesselt, Stephen D. Prince, Compton J. Tucker, and Kjeld Rasmussen

9 Assessing Drivers of Vegetation Changes in Drylands from Time Series of Earth Observation Data 183
Rasmus Fensholt, Stephanie Horion, Torbern Tagesson, Andrea Ehammer, Kenneth Grogan, Feng Tian, Silvia Huber, Jan Verbesselt, Stephen D. Prince, Compton J. Tucker, and Kjeld Rasmussen

10 Land Surface Phenology in a West African Savanna: Impact of Land Use, Land Cover and Fire 203
Ursula Gessner, Kim Knauer, Claudia Kuenzer, and Stefan Dech

11 Assessing Rainfall-EVI Relationships in the Okavango Catchment Employing MODIS Time Series Data and Distributed Lag Models 225
Thomas Udelhoven, Marion Stellmes, and Achim Röder

12 Land Degradation in South Africa – A Degradation Index Derived from 10 Years of Net Primary Production Data 247
Markus Niklaus, Christina Eisfelder, Ursula Gessner, and Stefan Dech

13 Investigating Fourteen Years of Net Primary Productivity Based on Remote Sensing Data for China 269
Christina Eisfelder and Claudia Kuenzer

14 The Utility of Landsat Data for Global Long Term Terrestrial Monitoring 289
David P. Roy, Valeriy Kovalskyy, Hankui Zhang, Lin Yan, and Indrani Kommareddy

15 Forest Cover Dynamics During Massive Ownership Changes – Annual Disturbance Mapping Using Annual Landsat Time-Series 307
Patrick Griffiths and Patrick Hostert

16 Radar Time Series for Land Cover and Forest Mapping 323
Christiane Schmullius, Christian Thiel, Carsten Pathe, and Maurizio Santoro

17 Investigating Radar Time Series for Hydrological Characterisation in the Lower Mekong Basin 357
Daniel Sabel, Vahid Naeimi, Felix Greifeneder, and Wolfgang Wagner

18 Land Surface Phenology Monitoring with SeaWinds Scatterometer Time Series in Eastern Asia 383
Linlin Lu, Huadong Guo, and Cuizhen Wang

19 Monitoring Recent Urban Expansion and Urban Subsidence of Beijing Using ENVISAT/ASAR Time Series Datasets 401
Xinwu Li, Huadong Guo, Huaining Yang, Zhongchang Sun, Lu Zhang, Shiyong Yan, Guozhuang Shen, Wenjin Wu, Lei Liang, and Meng Wang

20 SAR Time Series for the Analysis of Inundation Patterns in the Yellow River Delta, China 427
Claudia Kuenzer, Juliane Huth, Sandro Martinis, Linlin Lu, and Stefan Dech

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Abbreviations

a.s.l.	Above sea level
AATSR	Advanced Along-Track Scanning Radiometer
aET	Actual evaporation
AI	Aridity Index
ALOS	Advanced Land Observing Satellite
AMOC	Acoustic Monitoring of the Ocean Climate
ANPP	Aboveground net primary productivity
APOLLO	*A*VHRR *P*rocessing scheme *O*ver c*L*ouds *L*and and *O*cean
ARMA	Autoregressive moving average
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Advanced scatterometer
ASI	Italian Space Agency
AVHRR	Advanced Very High Resolution Radiometer
BETHY/DLR	Biosphere Energy Transfer Hydrology Model
BFAST	Breaks For Additive Seasonal and Trend
BISE	Best index slope extraction
BMBF	German Federal Ministry of Education and Research
BMWI	Federal Ministry for Economic Affairs and Energy
BOA	Bottom of atmosphere
BRDF	Bidirectional reflectance distribution function
BWI	Basin Water Index
CAO	Carnegie Airborne Observatory
CAS	Chinese Academy of Sciences
CBERS	China-Brazil Earth Resources Satellite
CCI	Climate Change Initiative
CEODE	The Center for Earth Observation and Digital Earth
CFV	Closest Feature Vector
CGIAR-CSI	Consultative Group on International Agricultural Research - Consortium for Spatial Information
CLASS	Comprehensive Large Array-data Stewardship System

CMAP	CPC Merged Analysis of Precipitation
CNES	French Space Agency
CONUS	Conterminous United States
Cosmo-SkyMed	Constellation of Small Satellites for Mediterranean Basin Observation
CRU	Climatic Research Unit
CSA	Canadian Space Agency
dB	Decibel
DEM	Digital elevation model
DFD	German Remote Sensing Data Centre
DFF	Danish Council for Independent Research
DFG	Alliance of Science Organisations in Germany
DGVMs	Dynamic Global Vegetation Models
DI	Disturbance Index
DIMS	Data and Information Management System
DInSAR	Differential Interferometric SAR
DLM	Distributed lag-model
DLR	German Aerospace Centre
DN	Digital number
DORIS	Delft object-oriented radar interferometric software
DOY	Day-of-year
DVT	Dynamic visible threshold
EBVs	Essential biodiversity variables
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ECV	Essential climate variable
ENSO	El Nino Southern Oscillation
ENVISAT	Environmental Satellite
ENVISAT/ASAR	Environmental Satellite/Advanced Synthetic Aperture Radar
EO	Earth observation
EOM	Earth observation monitor
EOS	End of season
EOST	End of season time
EROS	Earth resources observation and science
ERS	Earth Resources Satellite
ERS	European remote sensing
ESA	European Space Agency
ESA GMES	ESA Global Monitoring for Environment and Security
ESDB	European Soil Database
ETM	Enhanced Thematic Mapper
ETM+	Enhanced Thematic Mapper Plus
EVI	Enhanced Vegetation Index
FAO	Food and Agriculture Organization

FAPAR	Fraction of Absorbed Photosynthetically Active Radiation
FOMO	Remote sensing of the forest transition and its ecosystem impacts in mountain environments
FOV	Field of view
FPAR	Fraction of photosynthetically active radiation
FVC	Fraction of vegetation cover
FT	Functional types
GCOS	Global Climate Observing System
GDP	Gross domestic product
GEO BON	Earth Observations Biodiversity Observation Network
GIMMS	Global Inventory Modeling and Mapping Studies
GLASS	Global LAnd Surface Satellite
GLC2000	Global Land Cover
GLS	Generalized least square
GLS	Global Land Survey
GLWD	Global Lakes and Wetlands Dataset
GMES	Global Monitoring for Environment and Security
GPCC	Global Precipitation Climatology Centre
GPCP	Global Precipitation Climatology Project
GPP	Gross primary productivity
GSE	ESA GMES Service Element
GSV	Growing stock volume
HANTS	Harmonic Analyses of NDVI Time Series
HDF	Hierarchical data format
HDF-EOS	Hierarchical Data Format–Earth Observing System
HRPT	High resolution picture transmission
HWSD	Harmonized World Soil Database
IFOV	Instantaneous field of view
IGBP	International Geosphere-Biosphere Programme
IIASA	International Institute for Applied Systems Analysis
InSAR	Interferometric Synthetic Aperture Radar
INPE	Brazilian Space Agency
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
JAXA	Japan Aerospace Exploration Agency
JERS	Japanese Earth Resources Satellite
JPL	Jet Propulsion Laboratory
K.T.	Kaboré-Tambi
KML	Keyhole Markup Language
LAI	Leaf Area Index
LandTrendr	Landsat-based Detection of Trends in Disturbance and Recovery
LCC	Lambert conic conformal
LCU	Land capability unit

LDCM	Landsat Data Continuity Mission
LDI	Land Degradation Index
LiDAR	Light detection and ranging
LMB	Lower Mekong Basin
LNS	Local net primary productivity scaling
LSP	Land surface phenology
LST	Land surface temperature
LST_13year	Land surface temperature 13-year average
LTDR	Land Long Term Data Record
LUE	Light use efficiency
LULC	Land Use Land Cover
LUT	Look-up table
MACs	Multi-sensor Airborne Campaigns
MEA	Millennium Ecosystem Assessment
MEI	Multivariate ENSO Index
MB	Mekong Basin
MetOp	Meteorological Operational Satellites
MERIS	Medium resolution imaging spectrometer
MGET	Marine Geospatial Ecology Tools
MODIS	Moderate-resolution imaging spectroradiometer
MODIS NBAR	MODIS Nadir bidirectional reflectance distribution function adjusted reflectance
MODIS QA	MODIS Quality assessment
MODSCAGvMODIS	Snow-covered area and grain size
MSS	Multispectral Scanner System
MTCI	MERIS Terrestrial Chlorophyll Index
MTInSAR	Multi-Temporal Interferometric Synthetic Aperture Radar
MVA	Mean annual variation
MVIs	Microwave Vis
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NBR	Normalized Burn Ratio
NDSI	Normalized Difference Snow Index
NDVI	Normalized Difference Vegetation Index
NDWI	Normalised Difference Water Index
NEODASS	Earth Observation Data Acquisition and Analysis Service
NEODC	NERC Earth Observation Data Centre
NERC	Natural Environment Research Council
NESDIS	National Environmental Satellite, Data, and Information Service
NEST	Next ESA SAR Toolbox
NEX	NASA Earth Exchange
NIR	Near-infrared
NIR	Surface reflectances in the near infrared

NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defense Command
NPP	Net primary production
NPP	Suomi National Polar-orbiting Partnership
NRSC	Normalized radar cross-section
NSCAT	NASA scatterometer
NSIDC	National Snow and Ice Data Center
OA	Overall accuracy
OA	Overall agreement
OK	Over kappa
OLI	Operational Land Imager
OLS	Ordinary least-square
OSO	Office of Satellite Operations
OSPO	Satellite and Product Operations
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PAR	Photosynthetically active radiation
PATMOS-x	AVHRR Pathfinder Atmospheres Extended
PDO	Pacific Decadal Oscillation
PEM	Production efficiency modelling
POES	Polar Orbiting Environmental Satellites
PolInSAR	Polarimetric Synthetic Aperture Radar Interferometry
PPI	Plant Phenology Index
PPS	Precipitation Processing System
PS	Permanent scatterers
PSI	Persistent scatterer interferometry
QuickSCAT	Quick Scatterometer
RADI	Institute of Remote Sensing and Digital Earth
RBSI	Radar Backscatter Index
RCM	Radar Satellite Constellation
RED	Surface reflectances in the red
REDD	Reducing Emissions from Deforestation and Forest Degradation in Developing Countries
RESTREND	Residual Trend Analysis
RF	Random Forest
RLOS	Radar line of sight
RMSE	Root mean square error
ROIs	Regions of interest
RUE	Rain-use efficiency
SAFs	Satellite application facilities
SAR	Synthetic Aperture Radar
SAR-EDU	Radar Remote Sensing Education Initiative
SARs	Synthetic Aperture Radars
SBInSAR	Small Baseline Subset InSAR

SCAT	Scatterometer
SCD	Snow cover duration
SCD_{ES}	Early season snow cover duration
SCD_{LS}	Late season snow cover duration
SCF	Snow cover fraction
SeaWiFS	The Sea-viewing Wide Field-of-view Sensor
SGRT	SAR Geophysical Retrieval Toolbox
SIR	Scatterometer image reconstruction
SIR	Shuttle Imaging Radar
SOS	Start of season
SOST	Start of season time
SPARC	Separation of Pixels Using Aggregated Rating over Canada
SPOT	Satellite Pour l'Observation de la Terre
SPOT-VGT	Satellite Pour l'Observation de la Terre-Vegetation
SRM	Snowmelt Runoff Model
SRTM	Shuttle Radar Topography Mission
SSM	Surface soil moisture
SSM/I	Special sensor microwave/imager
SST	Sea surface temperature
StaMPS	Stanford Method for Permanent Scatterers
STARFM	Spatial and Temporal Adaptive Reflectance Fusion Model
STL	Seasonal trend decomposition by Loess
SVAT	Soil vegetation atmosphere transfer
SVD	Singular value decomposition
SVM	Support vector machines
SWBD	Shuttle Radar Topography Mission Water Body Data
SWI	Soil Water Index
SWIR	Short-wave infrared
TanDEM-L	TerraSAR-L add-on for digital elevation measurement
TC	Tasseled cap
TCW	Tasseled cap wetness
T-D	Threshold delay
TM	Thematic Mapper
TOA	Top-of-atmosphere
TRMM	Tropical Rainfall Measuring Mission
TS	Theil-Sen
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
USGS	United States Geological Survey
UTM	Universal Transverse Mercator

VCF	MODIS Vegetation Continuous Fields
VI	Vegetation Index
VIIRS	Visible/Infrared Imager Radiometer Suite
VIP	Vegetation Index and Phenology Earth Science Data Record
VIS	Visible
WCD	Water cover duration
WDC-RSAT	World Data Center for Remote Sensing of the Atmosphere
WELD	Web Enabled Landsat Data
WGS84	World Geodetic System 1984
WSM	Wide Swath Mode
WUE	Water use efficiency
$WUE_{instantaneous}$	Water use efficiency leaf level
WUE_{yield}	Water use efficiency crop level
WYSIWYG	What You See Is What You Get
WS	Wide Swath