Automated Object-Identification for Isolated Transient Landforms in Remote-Sensing Data

Lucia Tyrallova, Stephan van Gasselt, and Hartmut Asche

Abstract—Automated object identification and statistical characterization of morphometric key values are valuable tools in the field of geomorphology in order to identify processes and process-response systems related to climatic boundary conditions. The automated detection of primary climate-related landforms and the assessment of their change throuth time and three decades of remote-sensing observations allow and help to quantify and find predictors for the consequences of climate change. Approaches and concepts for object-catalog based detection of landforms within a commercial GIS suite are discussed and presented for the study cases of two major climate tracers: dunes and thermokarst features.

Index Terms—object-identification, transient landforms, thermokarst, dunes, remote-sensing data.

1 Introduction and Background

Automated object identifications in remote-sensing data are valuable tools that have been developed and employed in a number of different fields, such as civil engineering, land use, urban planning and cadastre as well as military services. In the field of geosciences, in particular in the field of geomorphology, automated feature detection and object identification supports mapping conduct as well as detection of changes when used in the context of multitemporal imagery or even terrain-model data. Furthermore, object identification and extraction of geomorphometric key values allow to systematically and automatically deriving quantitative information and spatial statistics over large areas and a large number of similar landform types. In order to allow automated object identification a general catalogue of criteria has to be established on which detection algorithms can build upon. In order to achieve this, a selection of basic landforms is being described by determinative parameters mathematically and by subsequently setting criteria for decision trees.

For this work two types of landforms have been chosen that are known to be variable on a scale of years and decades and that are prime indicators for changes induced by climate variability: (1) dunes as expression of local to global wind systems and (2) thermokarst degradational landforms as expression of thawing subsurface permafrost. Furthermore, these landforms usually have sizes and shapes that are identifiable in a wide range of imaging sensors and terrain model data and can also be mapped on MSS/TM/ETM+ scales to allow for detecting changes over the last three decades.

This work makes primarily use of multispectral imaging data in the resolution-range of 15 to 60 m/px as well as terrain-model data that have been derived either (a) photogrammetrically from the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) stereo sensor as GDEM data (Global Digital Elevation Model, 30 m/px) or (b) by radar ranging in the course of the Shuttle Radar Topography Mission (SRTM, 90 m/px). In the course of this work, the feasibility to include additional context data, such as wind parameters or temperature distributions, is evaluated in parallel.

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2 Landforms

Landforms and landscape geomorphology are a direct response to environmental boundary conditions and form important and characteristic tracers of recent or past climatic conditions [1]. Though there usually are a large number of characteristic landforms indicative of a certain climate, landforming processes, spatial dependences and response systems often cause highly complex patterns of surface features that cannot be identified and characterized unambiguously. Among such landforms, only few fulfil a number of requirements needed for automated object identifications in remote sensing data. Requirements are: (a) appropriate landforms should be primary indicators of climatic and/or other climate-induced environmental conditions; (b) features must occur as isolated landforms that can be delineated, traced and morphometrically characterized using a catalogue of appropriate criteria and significance levels of different criteria; (c) pixel scale of panchromatic and multispectral as well as topographic data must suffice in order to test different sample sites and identify landforms unambiguously; (d) landforms should be prone to change or move significantly within few years or decades as response to climate change in order to be analyzable; (e) characteristic landforms should be abundant on the Earth's surface and in larger sampling sites in order to establish a significant statistical basis at different locations; (f) landforms should occur in different size ranges and types in order to adapt detection algorithms according to remote-sensing data input characteristics and in order to be able to classify and detect subtypes, respectively. Among a large number of partially appropriate surface features, two types, dunes and thermokarst depressions have been selected initially to obtain a data basis for algorithm development and analysis.

Firstly, thermokarst depressions are associated with frozen ground and periglacial, i.e. basically cold and arid environments and are formed through seasonal surficial thaw-cycles. Depressions are initially filled with water but can fall dry on the scale of years and as response to permafrost degradation. They are often circular to elliptical in shape and occur in groups with a preferred long-axis direction. They are most frequent in the north-western Canadian Arctic and Northern Siberia which are two areas that are completely different in terms of their geomorphologic framework and thus form a perfect basis for comparative analyses [2]. Their instability and response to climatic change is documented by changes in distribution of water-filled depressions, i.e. thermokarst lakes and formation of new features at different locations (Fig. 1). Their geomorphologic appearance and unambiguity allows detecting them in multispectral image data at medium scale (e.g., infrared absorption) and by making use of terrain model data and derived morphometric key parameters in parallel.

Secondly, dunes are accumulations of fine to medium-sized silt or sand grains transported and sedimented by wind (aeolian) activity

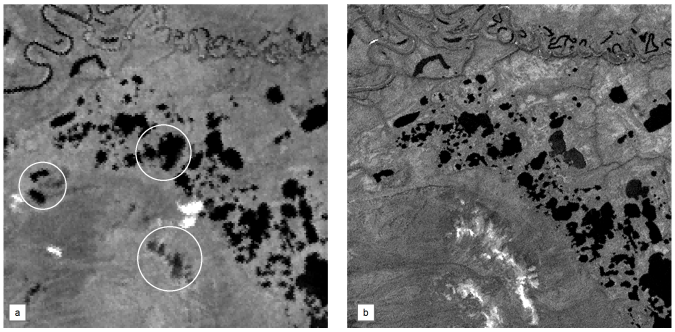

Fig. 1. Changes in the size and distribution of thermokarst lakes, [a] path/row 71/12, July 1976, Multispectral Scanner (MSS, Band 1, 60 m/px); [b] path/row 65/12, July 2002, Enhanced Thematic Mapper (ETM+ Band 1, 30 m/px); center pixel located at -139.7/67.8.

and are caused by differential velocity effects, i.e. turbulences at the boundary of the transporting medium (air) and the substrate. Dunes come in different flavours and a wide range of sizes from centimeter to decameter range and appear as either isolated or highly complex and coalescing landforms with a distinct lateral asymmetry dependent on preferred wind directions and moisture contents of the substrate. Dunes can migrate on the scale of months and since they are a direct function of - among others - wind directions and moisture contents they are prime indicators of changing climatic conditions [3]. Automated detection and subsequent characterization of key-morphometric parameters and changes over years and decades enable characterization of climatic regimes on a regional and global scale.

3 Approaches

As the flowchart (Fig. 2) depicts, an input into the automated object identification process are remote-sensing data, specifically: (D1) multispectral satellite-image data such as data from the Landsat-based camera suites MSS/TM/ETM+ or the RapidEye system or multispectral airborne image data from local airborne-mapping campaigns. For change detection we can also make use of multitemporal image data. Other important elements (D2) are terrain-model data that help to characterize surface features in the third dimension. Such data can be derived from a variety of sensors either stereophotogrammetrically or by employing radar or LIDAR techniques. D3 represents environmental data such as wind, temperature, moisture and precipitation as well as their derivatives. The object-identification process is GIS-integrated and is realized on Environmental Systems Research Institute?s (ESRI?s) commercial platform ArcGIS. The crucial part of the processing framework is formed by an object catalogue and the employment of a well-defined decision tree (D4) on which the spatial analysis is based upon. This object catalogue is implemented as external data source. Extraction of geomorphological parameters from terrain-model in combination with cell-based image-data calculations and spectral classifications form the core of the automated object-identification and can be fine-tuned within the ArcGIS-based development platform (e.g., profile curvatures can be used as an indicator for i.e. geomorphological change of sand dunes [4]). Output data of the spatial analysis enable identifying objects which represent isolated transient landforms as defined through vector-based delineations of positive detections. The automated object identification is suitable only for specific and designated landforms situated in the test area (D5) and specified in the object catalogue. Identification is followed by a objects characterization for the assessment of the spatial distribution and type classifications.

4 Conclusions and Outlook

Automated object identification will not completely replace manual object identification based on visual interpretation and on field data or secondary (thematic) maps. Objet identification and mapping has still to be carried out by an expert interpreter or, geomorphologist but detection tools help to identify and assess landforms on an a-priori level. If GIS-integrated, such tools are available for a wide range of researchers and object location takes place within a proper geospatial context required for data exchange and ongoing studies. Automated object identification is less time-consuming and provides means to extract statistical parameters over large areas and, if multitemporal, timespans. Our goal is to provide GIS-integrated object-identification tools to support experts by helping to identify and characterize landforms indicative of climate change and to allow extracting parameters required to assess climatic boundary conditions and their changes across time for which a number of other climate-tracer need to be defined to allow for combined approaches and improve detection qualities.

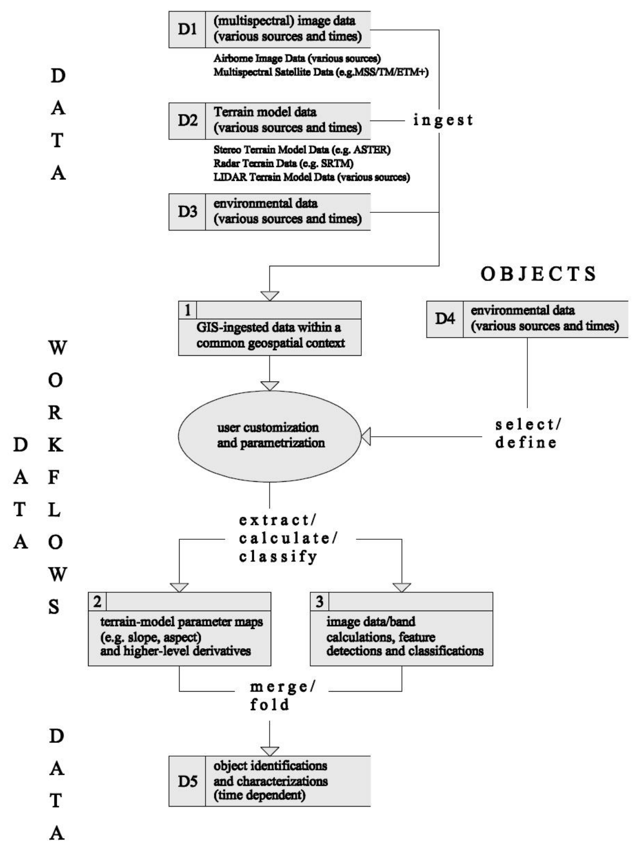

Fig. 2. Workflow of automated object identification.

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