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A cloud mask methodology for high resolution remote sensing data combining information from high and medium resolution optical sensors

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This study presents a novel cloud masking approach for high resolution remote sensing images in the context of land cover mapping. As an advantage to traditional methods, the approach does not rely on thermal bands and it is applicable to images from most high resolution earth observation remote sensing sensors. The methodology couples pixel-based seed identification and object-based region growing. The seed identification stage relies on pixel value comparison between high resolution images and cloud free composites at lower spatial resolution from almost simultaneously acquired dates. The methodology was tested taking SPOT4-HRVIR, SPOT5-HRG and IRS-LISS III as high resolution images and cloud free MODIS composites as reference images. The selected scenes included a wide range of cloud types and surface features. The resulting cloud masks were evaluated through visual comparison. They were also compared with ad-hoc independently generated cloud masks and with the automatic cloud cover assessment algorithm (ACCA). In general the results showed an agreement in detected clouds higher than 95% for clouds larger than 50 ha. The approach produced consistent results identifying and mapping clouds of different type and size over various land surfaces including natural vegetation, agriculture land, built-up areas, water bodies and snow.

1. Introduction

Earth observation remote sensing studies largely depend on the availability of accurate cloud masks. Clouds not only limit the amount of valid land surface information in a scene, undetected cloudy pixels affect atmospheric correction procedures, aerosol retrievals and compromise the estimation of biophysical parameters. They pose a limitation in land cover classification. Cloud covers obstruct the training selection process for supervised and unsupervised classification algorithms and also hinder the interpretation of results (cluster labeling) in unsupervised classifiers.

Given the relevance of the problem, low and moderate resolution sensors such as AVHRR and MODIS have integrated cloud masking algorithms and have delivered cloud masks as one of their products. These algorithms have been mainly based on empirically tuned thresholds from a number of spectral channels with brightness temperature having a dominant role in the process (Stowe et al, 1999; Ackerman et al., 1998). In last years, several studies have proposed more sophisticated alternatives to adapt, refine and/or substitute the cloud masking approaches originally developed for these sensors. These strategies include for instance the use of neural networks (Jang et al., 2006), linear unmixing techniques and time series analysis (Gómez-Chova et al., 2007; Lyapustin et al., 2008) and parallel Markovian segmentation (Kussul et al., 2005).

The number of cloud mask studies for high resolution sensors has been sensibly smaller. Since high resolution remote sensing studies have mostly focused on smaller areas covered by a few scenes, the rejection and substitution of cloudy images and the manual delineation of clouds have been common options. When simple image replacement was not possible, thermal channel-based spectral thresholding has been the most common automatic cloud masking approach. For instance, the Landsat 7 ETM+ automatic cloud cover assessment (ACCA) established a set of threshold-based filters and prior knowledge on land surface properties for cloud detection (Irish, 2000; Irish et al., 2006). Some studies have developed modifications and adaptations of the original ACCA algorithm to other sensors such as ASTER (Hulley and Hook, 2008) or SPOT and IRS-LISS (Soille, 2008).

Today, the fast development of earth observation and aerospace industry has lead to a growing number of high resolution earth observation sensors (Sandau et al, 2008). The combination of imagery from several high resolution sensors presents an opportunity for high resolution land cover mapping for large areas (Cihlar,

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2000). While thermal bands represent the superior alternative for cloud making, the payload of several of these earth observation sensors does not include thermal channels in which cloud masking strategies have previously relied. Under this new scenario, there is a clear need for the development of cloud masking methodologies suited for the next generation of high resolution earth observation sensors. The new approaches must be able to operate without thermal bands and for large amounts of data from various high resolution sensors.

Recently some studies have proposed novel strategies for this problem using approaches such as Markov random fields, object oriented techniques (Le Hégarat-Mascle et al., 2009), and wavelet transforms, morphological operations and multitemporal analysis (Tseng et al., 2008). Some studies also anticipate the opportunities for cloud mask detection of the combination of observations from future high resolution sensors (Hagolle et al., 2010).

Building upon these studies, and in the context of large area land cover mapping activities, this study proposes a cloud making approach for the identification and delineation of clouds. The approach is designed for single date high resolution images for which thermal information is not available and relies on the complementary information provided by a second sensor with a higher revisit period. For demonstration purposes, this study uses high resolution images from SPOT4-HRVIR, SPOT5-HRG and IRS-LISS III and cloud free MODIS composites from almost simultaneously acquired dates as reference images.

The method is fully automatic and is suited for cloud masking of large amounts of scenes from various sensors.

This cloud masking approach relies on techniques widely used in remote sensing applications. However, our specific implementation of these techniques allows further exploiting the potential of sensor combination for this specific remote sensing challenge. The manuscript is divided in two sections. The first section describes a cloud identification procedure in which the combination of high and medium resolution remote sensing data provides a first approximation of cloudy pixels is provided. The second part proposes a simple, robust and automatic region growing-based cloud delineation alternative from the cloudy pixels identified in the previous stage.

2. Data

The performance of the method was evaluated for seven high resolution scenes from three sensors: SPOT4-HRVIR, SPOT5-HRG and IRS-LISS III (Table 1). The three sensors have four wavelengths green, red, near-infrared (NIR) and short wave infrared (SWIR) (Müller et al., 2009). The images were resampled to 25 m rasters in LAEA/ETRS89 projection (Annoni et al., 2003). The selected scenes included a wide range of different cloud types and surface features covering locations around Europe (Table 2). The original radiometrically calibrated and atmospherically corrected red wavelength reflectance MODIS daily images were provided by the German Aerospace Center in 250 m rasters in LAEA/ETRS89 projection.

Ideally, the input data for the method would have included BRDF corrected surface reflectance for the MODIS data and atmospherically corrected surface reflectance for the high resolution data. However in order to evaluate the robustness of the approach we have worked with sub-optimal non corrected MODIS BRDF data and non atmospherically corrected high resolution data. It is to be expected that would only retrieve more accurate results.

Cloud free MODIS composites were created for the extent of each of the high resolution scene. In order to create a red wavelength (620–670 nm) cloud free composite, daily 250 m resolution images both from Terra and Aqua sensors were successively included starting from the acquisition date of the high resolution image. The acquisition window for the composites covered a maximum of 17 days (8 days before and after the high resolution acquisition date). The 17 days window avoids major land cover changes during that period and it showed to be sufficient to obtain cloud free MODIS composites.

Several alternatives are possible for compositing the daily MODIS scenes. The most obvious being using the cloud mask provided for MODIS data. However MODIS cloud mask is only 1 km spatial resolution. Furthermore, since cloud mask might not always be present for other moderate resolution sensors, we applied a simple pixel selection criteria based on maximum normalized difference vegetation index (NDVI) (Tucker et al., 1981). For each pixel, the value in the red wavelength corresponding to the daily pixel with the highest NDVI value of the daily MODIS images of the composite was selected. The NDVI presents high values for surfaces with high contrast between NIR and red signatures. Since clouds have similar signatures in NIR and red bands cloudy pixels will have low NDVI values. On the contrary, cloud free pixels will present in most cases higher NDVI values. A limitation of the maximum NDVI criteria is that water bodies usually present lower NDVI values than clouds. This was overcome by applying a in-house water mask to inland water bodies, water surfaces and sea.

Because of their thickness and size, the NDVI values of low clouds at 250 m are not necessarily as low as those of other cloud types. This represents a limitation for the compositing strategy. However, this solution still showed consistent results for cloud free pixel selection within the composites.

3. Methods

3.1. Preprocessing

Our implementation of the seed identification process depends on a one to one relationship between pairs of pixels in the high resolution images and the corresponding MODIS cloud free composites. In order to achieve this correspondence, the high resolution and MODIS images were co-registered in a common grid for a better pixel to pixel comparison. Subsequently the high resolution images were resampled to 250 m pixel size. This operation was carried out applying a spatial filter resembling the MODIS point spread function (Tan et al., 2006). This spatial filter aggregates

Table 1
List of high resolution images.

Id	Sensor	High resolution image date	Location	Cloud type	Scene description
1	IRS-LISS III	20060702	Alpine region	Large and small clouds over mountainous areas	Mountainous area (snow and ice cover)
2	IRS-LISS III	20060724	Spain	Medium and small size clouds	Agriculture, bare soil and natural vegetation
3	SPOT5-HRG	20061108	Greece	Medium size clouds	Mountainous area with high reflectance bare soil slopes
4	IRS-LISS III	20060812	Spain	Medium size clouds	Bare soils and agriculture fields
5	IRS-LISS III	20060817	Greece	Clusters of small clouds	Agriculture, bare soil and natural
6	IRS-LISS III	20060905	France	High density of small clouds	Agriculture and natural
7	SPOT4-HRVIR	20060925	Bulgaria	Medium and small size clouds	Agriculture, bare soil and natural vegetation