Water channel detection from Sentinel-1 SAR images for large scale river monitoring

Télédétection du chenal en eau à partir d'images RSO de Sentinel-1 pour la surveillance des rivières à large échelle

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RÉSUMÉ

Dans le domaine de la télédétection appliquée aux systèmes fluviaux, le Radar à Synthèse d'Ouverture (RSO) est capable de fournir des données cohérentes, de bonne résolution, avec toutes conditions météo et d'illumination, qui sont complémentaires aux données optiques. La technologie RSO est encore peu exploitée dans l'étude des rivières, principalement en raison de la difficulté de pré-traitement et d'interprétation du signal. L'une des applications les plus intuitives et les plus prometteuses dans ce domaine est l'extraction du lit mineur, par exemple pour l'estimation du débit d'eau en fonction de la largeur du lit. Ce travail présente un cadre méthodologique pour la délimitation du lit mineur dans des tronçons de rivière de taille moyenne à grande (>20-25 m). La méthode se base sur la création d'un *short-stack* d'images RSO multi-temporelles en combinant différentes polarisations, l'intensité de la rétrodiffusion et la phase du signal afin de détecter une probabilité de localisation des chenaux en eau. Le travail est basé sur les images de Sentinel-1 du programme Européen Copernicus, une constellation de 2 satellites radar en bande C qui, dans sa configuration en mode TOPS, fournit une couverture globale avec une résolution temporelle de 6 jours et une résolution spatiale d'environ 5 par 20 mètres. Les études de cas sont situées dans le bassin du Po (Italie). La méthode permet une détection rapide du lit mineur dans toutes conditions et à large échelle. À l'avenir, cette classification pourra être affinée en combinant ces résultats avec des informations optiques provenant, par exemple, de Sentinel-2 pour la surveillance des largeurs d'eau, et donc des débits, tous les quelques jours.

ABSTRACT

In the remote sensing science applied to river systems, Synthetic Aperture Radar (SAR) is able to provide quite good resolution, all-weather, day and night, coherent data which is complementary to optical data. SAR technology is still poorly exploited in river science, mainly due to the demanding pre-processing tasks and the complexity of the signal interpretation. One of the most intuitive and promising applications in river science is the delineation of the water channel for example for water discharge estimation based on water channel widths. The present work presents a robust framework for the delineation of water channel in medium-large (>20-25 m) river reaches. The method is built on a short-stack of multi-temporal SAR data and combines different polarization signatures, the intensity of backscattering and the signal phase to detect the probability of water location. The work is based on the images from Sentinel 1 of the European Copernicus program, a constellation of 2 satellites that carry a C-band SAR that, in its TOPS mode configuration, provides global coverage with a temporal resolution of 6 days and a spatial resolution of about 5 by 20 meters. The case studies are located in the Po river basin (Italy). The method allows fast and all-conditions water channel location detection at large scale. In the future, this classification may be refined by combining the results with optical information from, for instance, Sentinel 2 for monitoring water channel width and then discharges every few days.

KEYWORDS

Copernicus programme, river monitoring, Synthetic Aperture Radar, water extraction

1 INTRODUCTION

River monitoring represents a key issue for river management science. Recent advances in remote sensing technologies opened up unprecedented opportunities to perform high quality monitoring program for a wide range of environmental fields including river systems (e.g. Bizzi et al., 2016). The possibility of observing rivers from a remote point of view by using different sensing technologies allows to analyse processes at spatial and temporal scales that were inconceivable through the traditional field survey techniques yet decades ago. In this context, the ambitious European program for Earth Observation "Copernicus" is providing a huge amount of quite good resolution (up to 10m) and recurrent (up to 5 days) remote sensed data for the analysis of rivers systems at the catchment and global scale. In particular; the constellation of 2 Sentinel-1 (S-1) SAR satellites is providing mean resolution (5 by 20m), all-weather, day and night, coherent data which is complementary to optical data and that could be applied for river surveys purposes. SAR technology is used, amongst other, for the analysis of water resources (e.g. reservoirs) and flood mapping (e.g. Armitrano et al., 2014). Unfortunately, few examples using SAR data in river science exist, mainly because of the complexity of the signal interpretation and of the pre-processing work. Indeed, a single SAR image presents a typical "salt and pepper" texture, the speckle, due to the presence of several elementary scatterers within the resolution cell, and hence it cannot be used for classification without any filtering, that often causes a reduction in image resolution. In this work we developed a framework for the delineation of the water channel in medium-large (wider than 20-25 m) river reaches that allows to preserve the original image resolution and that could be applied for example for water discharge estimation based on water channel width (e.g. Durand et al., 2016).

2 WATER MAPPING FROM S-1 SAR: METHODOLOGICAL FRAMEWORK

2.1 S-1 data

The S-1 system concerns a constellation of 2 satellites, S-1A and S-1B, that carry a C-band SAR each. In its TOPS mode configuration, S-1 provides global coverage with a temporal resolution of 6 days and a spatial resolution of about 5 by 20 meters (range and azimuth, respectively). Data are freely downloadable from the Copernicus Open Access Hub (https://scihub.copernicus.eu/) and available in two polarization mode, VV and VH. The proposed framework is based on Level 1 SLC (Single Look Complex) products, i.e. focused and geo-referenced data in slant-range geometry, acquired through the Interferometric Wide swath mode, about 250 km wide.

2.2 Overall image enhancement

Speckle suppression represents one of the most crucial pre-processing step of radar images, and an essential step for image classification purposes notable for water channel detection. It is worth noting that in the present work we aim at reducing speckle while preserving data resolution. This is achieved through the following steps: (i) Use of the intensity values of a short-stack of few observations (i.e. the number depends on the pattern of river dynamics; generally 3 in this study) and combining data from S-1A and S-1B, in order to have one observation each 6 days (i.e. the short-stack covers 12 days); (ii) Use of both available polarization modes, increasing the dataset from 3 to 6 observations and allowing the reduction of speckle of 1/sqrt6; (iii) Application of a spatial directional filter, according to the upstream-downstream river pattern. The results of these steps allow a significant reduction of the overlapping between the two modalities (i.e. one for water and the other for land) in the histogram of the probability distribution function of the radar image.

2.3 Water extraction

Once the two modalities of the distribution defined, the water is then extracted following a probabilistic approach based on the probability distribution function analysis. The pixels are assigned a probability to be "water" or "not water" (1 and 0, respectively) according to their position within the distribution, following two steps:

1. A first classification into one of the two classes based on pixel affinity with the innermost (water) or the outermost (not water) modality, while letting unclassified those pixels that populate the overlapping region of the histogram (i.e. biased pixels);
2. A second classification of the biased pixels into one of the two classes including the information on image phase between observations within the short-stack, accounting for the uncoherent behaviour and the reflectivity of water, hence attributing highest water probability

to those pixels with lowest coherence and lowest amplitude values.

The integration of 1 and 2 leads to a water probability map from which to extract the associated water mask based on fixed probability thresholds (i.e. from 0 to 1).

3 QUALITATIVE AND QUANTITATIVE VALIDATION

We selected 2 river reaches, one along the Po river (about 15 km long) and the other in the downstream part of the Sesia river (about 5 km long), a left-bank tributary of the Po. According to the framework described in section 2, the water channel was delineated for the period June 2017 to October 2017 attributing a probability threshold > 0.9. The extracted water masks were exported into a GIS for comparison with optical data and channel width calculation.

The water masks extracted from S-1 images, issue of the short-stack approach, seem to represent the external envelop of the water channel delineated from optical images (i.e. Sentinel 2) during the same observation period.

The channel widths extracted each 100m from the S-1 water masks were then compared to hydrological and rainfall data obtained in two gauging stations close to the study reaches over the entire period. The results clearly show an increase in channel widths both during and after high flow events according to the rainfall pattern.

4 CONCLUSIONS AND FUTURE PERSPECTIVES

The pre-processing framework, including the short-stack approach on 12 days combining S-1A and S1-B data and all available polarization and including a directional filter, revealed a good compromise for speckle suppression while preserving the original image resolution. The water channel extraction framework, combining probability thresholding operations and image coherence, shows precise and reliable results.

The overall method allows fast and all-conditions water channel detection that could be extended at large scale, given the global coverage of the S-1 data. In the future, this classification may be refined by combining the results with optical information from, for instance, Sentinel-2, the multi-spectral optical satellite of the Copernicus programme, for monitoring water channel width and then discharges every few days.

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