Remote Sensing of Environment 216 (2018) 427–441

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Comparison of visible and multi-satellite global inundation datasets at high-spatial resolution

Filipe Aires[a,b,c,*], Catherine Prigent[a,b,c], Etienne Fluet-Chouinard[d], Dai Yamazaki[e], Fabrice Papa[f,g], Bernhard Lehner[h]

[a] LERMA/Observatoire de Paris, UPMC, CNRS, Paris, France
[b] Estellus, Paris, France
[c] Water Center/Columbia University, New York, USA
[d] Center for Limnology, University of Wisconsin-Madison, Madison, WI, USA
[e] Department of Integrated Climate Change Projection Research, Japan Agency for Marine-Earth Science and Technology, Yokohama 236-0001, Japan
[f] LEGOS, Université de Toulouse, CNES, CNRS, IRD, UPS, Toulouse, France
[g] Indo-French Cell for Water Sciences, IRD-IISc-NIO-IITM Joint Intern. Lab., IIS, India
[h] Department of Geography, McGill University, Montreal, QC, Canada

ARTICLE INFO

MSC:
00-01
99-00

Keywords:
Wetlands and Inundation
Remote sensing
Landsat
Passive microwaves

ABSTRACT

Several new satellite-derived and long-term surface water datasets at high-spatial resolution have recently become available at the global scale, showing different characteristics and abilities. They are either based on visible imagery from Landsat – the Global 3-second Water Body Map (G3WBM) and the Global Surface Water Explorer (GSWE) – or on the merging of passive/active microwave and visible observations – Global Inundation Extent from Multi-Satellite (GIEMS-D3) – that has been downscaled from a native resolution of 25 km × 25 km to the 90 m × 90 m resolution. The objective of this paper is to perform a thorough comparison of the different water surface estimates in order to identify the advantages and disadvantages of the two approaches and propose a strategy for future developments of high-resolution surface water databases. Results show that due to their very high spatial resolution (30 m) the Landsat-based datasets are well suited to retrieve open water surfaces, even at very small size. GIEMS-D3 has a better ability to detect water under vegetation and during the cloudy season, and it shows larger seasonal dynamics. However, its current version overestimates surface water extent on water-saturated soils, and due to its low original (i.e. before downscaling) spatial resolution, it is under-performing at detecting small water bodies. The permanent waters for G3WBM, GSWE, GIEMS-D3 and GLWD represent respectively: 2.76, 2.05, 3.28, and 3.04 million km^2. The transitory waters shows larger discrepancies: 0.48, 3.72, 10.39 and 8.81 million km^2.

Synthetic Aperture Radar (SAR) data (from ENVIronment SATellite (ENVISAT), Sentinel and soon the Surface Water Ocean Topography (SWOT)) would be a good complementary information because they have a high nominal spatial resolution and are less sensitive to clouds than visible measurements. However, global SAR datasets are still not available due to difficulties in developing a retrieval scheme adequate at the global scale. In order to improve our estimates of global wetland extents at high resolution and over long-term records, three interim lines of action are proposed: (1) extend the temporal record of GIEMS-D3 to exploit the full time series of microwave observations (from 1978 to present), (2) develop an approach to fuse the GSWE and GIEMS-D3 datasets leveraging the strengths of both, and (3) prepare for the release of SAR global datasets.

1. Introduction

The distribution and dynamics of surface water, i.e. permanently and temporarily inundated areas including lakes, rivers, and wetlands, are important because of their interaction with climate, ecology and human wellbeing. For instance, nearly 30% of global methane emissions (Bousquet et al., 2006) originate from wetland areas, risk management responds to inundation patterns (Winsemius et al., 2015), and food security and rice paddy cultivation relies, in certain regions of the world, on surface waters. In return, surface water ecosystems are

* Corresponding author.
E-mail address: filipe.aires@obspm.fr (F. Aires).
URL: https://vm-wordpress-lerma01.obspm.fr/faires/ (F. Aires).

https://doi.org/10.1016/j.rse.2018.06.015
Received 24 July 2017; Received in revised form 13 June 2018; Accepted 14 June 2018
0034-4257/

affected by human activity, land use, hydrologic alterations, and climate change. The complex feedback mechanisms between surface water and climate are difficult to assess and can potentially exacerbate the sensitivity and vulnerability of these regions to changes in precipitation, evapotranspiration, and flow regimes (Gleick, 1989; Chahine, 1992) putting lakes, rivers, and wetlands at risk of rapid deterioration in quantity and quality. Among the many topics about wetlands and climate change, sea level rise and carbon sequestration are major issues. But wetlands are also threatened by land use change and invasive species.

Global distribution and dynamics of surface waters at high-spatial resolution (around 100 m) are still not available, in particular over densely vegetated areas, to satisfy all the needs of the large community of potential users including hydrologists, water and disaster managers, or climate scientists. Indeed, the global, long-term, frequent, and high-resolution characterisation of all surface water types is beyond the capabilities of current satellite observations.

Visible satellite observations are a primary candidate for the detection of surface waters from space. Moderate Resolution Imaging Spectroradiometer (MODIS) observations have been used to derive global products every two days (http://oas.gsfc.nasa.gov/floodmap/) but visible/infrared observations suffer from the presence of clouds (about 70% of Earth surface at any time) (Wilson and Jetz, 2016) and vegetation. Despite the limitations from vegetation canopy and cloud cover, this type of data is of great value to the community to detect open water. Yamazaki et al. (2015) introduced the Global 3 arc-second Water Body Map (G3WBM) at a pixel resolution of 3 arc-sec (approximately 90 m at the equator) based on Landsat imagery. This dataset exploits multi-temporal acquisitions in order to distinguish permanent from temporal open water areas. However, no full dynamics of the wetland map are provided. Other datasets have been built from Landsat imagery: Feng et al. (2014) is global for the year 2000, Mueller et al. (2016) focused on Australia, Tulbure et al. (2016) created a three decade dataset over a semi-arid region, and Verpoorter et al. (2014) mapped an inventory of global lakes. Pekel et al. (2016) recently produced a new Global Surface Water Explorer (GSWE) dataset also from Landsat imagery but using the full 32-year record, allowing for a better description of the trends of surface waters and their occurrence.

Synthetic Aperture Radar (SAR) data has the potential to retrieve surface waters at high-spatial resolution (≃10 m) as well as capture sub-canopy inundation (L-band) as demonstrated by Santoro et al. (2010) using ENVISAT-ASAR, or more recently using the Sentinel 1 mission (Pham-Duc et al., 2017). Although existing SAR retrievals from a number of sensors cover a large extent of the globe, their use for mapping surface inundation has been protracted due to the local calibration needed for accuracy. The past or current availability of the data has not yet allowed for producing a full global high-spatial resolution surface water dataset from SAR data, although such initiatives have been suggested in the past, e.g. Westerhoff et al. (2013). There is clearly a need to invest more time in retrieval algorithms and potentially perform data fusion in order to obtain a global, long-term, reliable, and high-resolution dataset of water extent from this type of observations.

The NASA/CNES Surface Water and Ocean Topography (SWOT) mission, planned for launch in 2021, is specifically designed to provide high-spatial resolution (≃10 m) and good temporal sampling (22 days repeat) of the extent (and altitude) of continental surface waters (Prigent et al., 2016; Biancamaria et al., 2016) thanks to an interferometric Ka-band radar (Rodriguez, 2015). Although the SWOT data is expected to deliver a new generation of global water surface extents at unprecedented quality and resolution, the availability of this product is still years in the future. Meanwhile, alternative efforts should be pursued to provide the community with the best possible information about the spatial and temporal variations of global surface water extents. Such efforts would also allow for the extension of the SWOT temporal record backward in time, with existing past imagery; this will be a crucial step in assembling multi-decadal measurements of surface water variation.

A possible approach in this direction it to use the synergy from multiple satellite observations. Following this idea, the Global Inundation Extent from Multi-Satellites (GIEMS) database has been developed through a retrieval scheme that combines satellite observations in the visible, near-infrared, and passive/active microwaves (Prigent et al., 2007, 2012; Papa et al., 2010). GIEMS provides a monthly-mean water surface extent at a low spatial resolution (0.25° × 0.25° equal-area grid) over a 15-year period (1993–2007). In order to obtain global inundation estimate at high resolution, downscaling techniques have been developed on GIEMS (Aires et al., 2013, 2014). In particular, Fluet-Chouinard et al. (2015) exploited topographic and hydrographic information derived from the Shuttle Radar Topography Mission (SRTM) and trained on a global land cover map to produce a 15 arc-second (~500 m) resolution map of the minimum and maximum inundation extents at global scale (GIEMS-D15) (http://www.estellus.fr/index.php?static13/giems-d15). In Aires et al. (2017), an evolution of this downscaling methodology was proposed to obtain a global and dynamic inundation dataset GIEMS-D3, at even higher spatial resolution of 3 arc-sec (~90 m), over 15 years with a monthly time step.

Given the variety of remote sensing approaches, a cross comparison of existing products is needed to explore differences and combined uses of the resulting data. The objective of this paper is to compare and contrast two Landsat-based products (G3WBM and GSWE) and one multi-satellite-based product (GIEMS-D3). Section 2 presents the databases used in this work. A global-scale comparison of the three inundation datasets is performed in Section 3, and Section 4 presents regional comparisons. To evaluate inherent uncertainties, we contrast the differences among surface water databases with tree and cloud cover data. The advantages and disadvantages of each type of data are then investigated. Finally, Section 5 summarises the conclusions of this comparative study. We discuss ways forward to improve estimates of global, high-spatial resolution extents and long-term dynamics of surface waters of multiple types.

As the descriptions of original data sources are not always using identical vocabulary, this paper explicitly defines the following terminology: The expression “inundation” refers to all surfaces that are detected as water pixels in the original datasets, including lakes, rivers, temporarily inundated land, but also (by error or not) saturated soils. The expression “transient” is used throughout this paper for non-permanent inundation, including temporal, seasonal, intermittent, and ephemeral inundation, as well as spatio-temporal transitions such as moving river meanders or newly constructed reservoirs. The expression “wetland” is used only in descriptive terms without specific definition and may include all types of inundated areas (such as lakes, reservoirs, and rivers) but also wet soils or non-inundated areas such as peatlands.

2. Datasets

2.1. G3WBM

The Global 3 arc-second Water Body Map (G3WBM) uses an automated algorithm to process multi-temporal Landsat images from the Global Land Survey (GLS) database (Yamazaki et al., 2015). Over 33,000 scenes were used from four GLS snapshots at 5-year intervals between 1990 and 2010 in order to delineate a seamless water body map, without cloud and ice/snow gaps. Permanent water bodies were distinguished from transitory water-covered areas by calculating the frequency of water body existence from overlapping, multi-temporal Landsat scenes. By analysing the frequency of water body existence at 3 arc-second resolution, the G3WBM separates river channels and floodplains (http://hydro.iis.u-tokyo.ac.jp/~yamadai/G3WBM/). Despite distinguishing between permanent and transitory water surfaces, only permanent water bodies are believed to be comprehensively mapped, while not all transitory water bodies are captured by the four used scenes (Yamazaki et al., 2015). The seven different G3WBM