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The changing face of Earth's surface water

High resolution satellite mapping of the Earth's surface water, covering the last 32 years, reveals the changing face of our planet's water systems, and how they are affected by both natural cycles and human influence. **SEE LETTER P.???**

Dai Yamazaki & Mark A. Trigg

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Everyone appreciates from personal experience that the water cycle can be quite variable, and at its extremes this can result in floods and droughts. The full range of this variability, as we see it in the planet's surface waters (e.g. rivers, lakes and wetlands), has been mapped by Pekel et al.[1], on page XXX, using over 3 million satellite images collected over the last 32 years. This globally consistent analysis documents natural water variability, as well as humankind's significant influence on the Earth's water systems, and will provide a valuable baseline for observing the effects of future climate change.

Detailed maps describing the location and extent of rivers, lakes and wetlands are needed for many earth science studies, however, their full global-scale distribution and variability has not been clearly understood. Scientists have developed methods to map waterbodies using satellite observations, for example by their characteristic reflectance of sunlight, but this is a particularly challenging task because the color of water has large variabilities related to differences in depth, suspended sediments, dissolved chemicals and sunlight angle (Figure 1). Add to this the fact that some land surfaces (e.g. snow, ice, lava, and shadows) have similar reflectance characteristics to water, detection algorithms need to be developed and calibrated carefully.

The first global surface water map using these methods was developed in 2009[3], although computational power restricted the spatial resolution to 250m, which is insufficient for smaller lakes and rivers, and statistical estimates suggest that millions of smaller lakes could account for half of global inland water area[2]. Global-scale analysis of waterbodies at a 30 m resolution using images from Landsat satellites was undertaken only very recently[4,5]. However, because the location and extent of waterbodies can change in time, due to natural processes such as flooding, sedimentation or channel migration, as well as human processes like dam construction and water abstraction, there is a need for multi-temporal high-resolution analysis at a global scale – a complete dynamic surface water map. This dynamics has recently been captured to separate permanent rivers and lakes from seasonal waterbodies like floodplains[6] and explore the long term trend of surface water changes[7], but these studies still only use a subset of all the images available.

The ambitious work by Pekel et al. utilizes the entire Landsat archive for the mapping of global surface waters, using more than 3 million Landsat images collected through 1984 to 2015[8]. To handle this Petabyte-scale dataset, Pekel et al. utilized Google Earth Engine (https://earthengine.google.com/), a freely-available cloud computing platform for big data analysis of satellite observations. Such a large dataset, acquired using 3 different satellites, with multiple operational issues affecting data collection and quality presents unique challenges, in addition to those presented by the variability of water's reflective properties. To overcome these challenges, a combination of expert systems, visual analytics and evidential reasoning was used to identify the existence or absence of surface water for every 30m-resolution image pixel on the earth, at a monthly time step over the 32 years period.

While water occurrence frequency is a worthwhile and useful output of such an analysis, more meaningful information and visualization of global-scale changes is required to cope with data gaps due to clouds and operational deficiencies, as well as allow logical interpretation of the data. In addition to persistence (sometime versus always water), these thematic maps include gain versus loss, reoccurrence frequency, permanent versus seasonal and finally, transitions between water types over the period (Figure 2). With the output of the analysis, and the thematic maps made openly available in an easy to use interface (https://global-surface-water.appspot.com), there is now the exciting prospect that it is possible for anyone to explore any location and understand what surface water changes have occurred, without the need for complex analysis or massive computing power.

These high quality analyses and visualizations of the data reveal that there were 2.78 million km^2 of permanent water and 0.81 million km^2 of seasonal surface waters on the earth in 2014-2015. Over the full period of analysis, they found 162,000 km^2 of permanent waters had been lost, while new permanent waters, totaling 184,000 km^2 were created, but in different geographical locations. Major losses were concentrated (70%) in just 5 countries (Kazakhstan, Uzbekistan, Iran, Iraq and Afghanistan), raising serious questions about water security and transboundary water management in the region. Most of the permanent water gain is correlated with reservoir construction worldwide, but the impact of climate change was also detected through lake expansion from melting glaciers in the Tibetan Plateau. As well as annual seasonal patterns and long term loss and gain, longer term decadal changes such as those due to the recent drought in Australia also stand out clearly.

Despite the impressive efforts of this study, there are still many limitations in any analysis quantifying surface waters from historical datasets. In particular, data gaps affect the accuracy of the seasonality, resolution prevents application to smaller waterbodies, vegetation obscures important wetlands and the repeat cycle of 16 days means shorter, but equally important events, such as floods may be missing. Going forward, these are being addressed by better optical and radar sensors, more satellites, and inclusion of other methods such as data assimilation. Despite the limitations, the results of this work provide our best understanding yet of the changing face of our planet's surface water and will be vital to many earth science studies as well as for global water management efforts.

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Figure 1 | Some more images from LandsatLook Viewer (ttp://landsatlook.usgs.gov/)

Figure 2 | Surface water maps created by Pekel et al., for Bangladesh. a, Water occurrence frequency over 32 years. **b,** water permanence and seasonality in 2014-2015. **c,** water occurrence frequency change (red: decrease, green increase). **d**, Water state transitions (blue: no change, pink: lost, green: gain). Using these maps helps to distinguish different causes of water area dynamics such as seasonal inundation, channel migration, and reservoir build-up (fishponds near the coast). The interactive maps can be accessed online (https://global-surface-water.appspot.com).

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Authors:

Dai Yamazaki is in the Department of Integrated Climate Projection Research, JAMSTEC – Japan Agency for Marine-Earth Science and Technology, Yokohama, Kanagawa 237-0061, Japan

Mark A. Trigg is in the School of Civil Engineering, University of Leeds, Leeds, LS2 9JT, UK

e-mails: d-yamazaki@jamstec.go.jp; m.trigg@leeds.ac.uk

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