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Donchyts, Gennadii; Baart, Fedor; Winsemius, Hessel; Gorelick, Noel; Kwadijk, Jaap; Van de Giesen, Nick

The Deltares aqua monitor

Hydrolink

THE DELTARES AQUA MONITOR

BY GENNADII DONCHYTS, FEDOR BAART, HESSEL WINSEMIUS, NOEL GORELICK, JAAP KWADIJK & NICK VAN DE GIESEN

Has the world become wetter or dryer? Can we see global trends in the changes of coastlines, and are these trends also apparent where we live? Is the total surface water storage on land growing or shrinking? These are rather simple questions, but have so far been hard to answer, and yet are important in order to understand the dynamics of our planet and the attribution of these dynamics to climate anomalies, and climate or man-made change. Answering these questions requires the availability of global maps at a very high resolution, which are very accurate and updated frequently. Remotely sensed Earth Observation (EO) data, such as satellite imagery, can obviously be used for this purpose. The volume of such data is increasing exponentially . To store, handle and analyse these data on a global scale requires a combination of access to enormous data storage and high-performance computers. It would require man-years working on the data preparation, exploring algorithms before the actual analysis, could be started. Until recently, such analyses could only be performed by highly specialized scientists and engineers, and on a case-by-case basis. The Deltares Aqua Monitor is a game changer showing that this situation is rapidly changing. It also shows that the way we analyse and use these data differs from what was common practice until very recently.

What is the Aqua Monitor?

The Aqua Monitor (DAM) is an open tool that analyses satellite data and visualizes land and surface water changes around the globe.

Where figure 1 shows a global picture, opening DAM on the internet allows the user to zoom-in to a maximum resolution of 30 meters and change the analysis periods to user-defined years. Downscaling (interpolation + smoothing) techniques are used to generate contours with an even higher resolution. DAM bridges the analysis from the global to the local scale. Those who live in a river delta can inspect erosion and accretion patterns over the last 30 years. In Egypt, one can inspect how lakes and reservoirs have varied in the Nile basin upstream. In Bangladesh, one can see how much the Brahmaputra River has changed its course over the last 5 to 30 years.
We used DAM to estimate the changes in the

Figure 1. Heat map of global surface water and land changes. Bright blue lighting shows where land was converted into water over the period 1985–2015. Bright green lighting shows where water was converted into land over the same period. The intensity of the colours highlights the spatial magnitude of the change

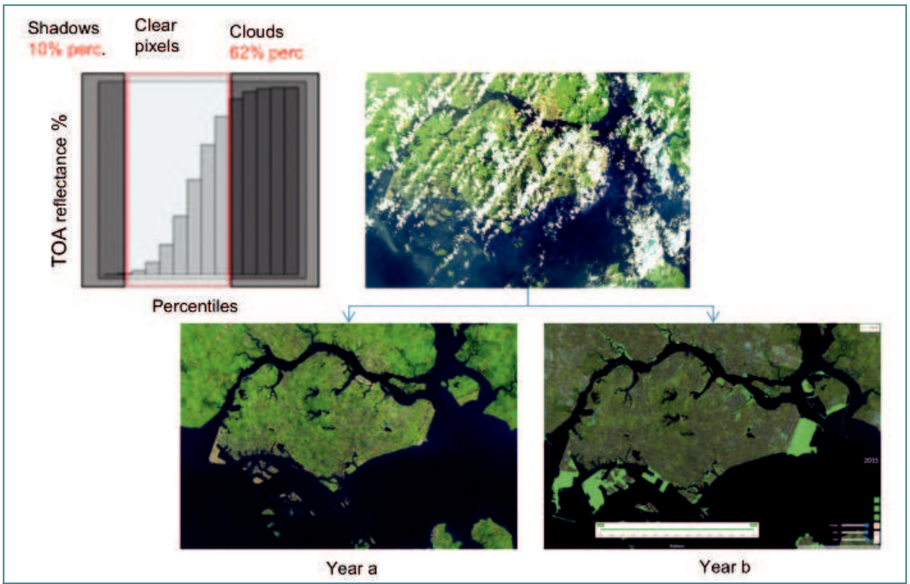

Figure 2. In Singapore the Aqua Monitor shows the effect of the land reclamation by combining information from different images covering the same area for each pixel, thus providing a probability for changes from land to water and vice-versa is calculated through linear regression analysis. Bright green colours represent areas where water was converted to land

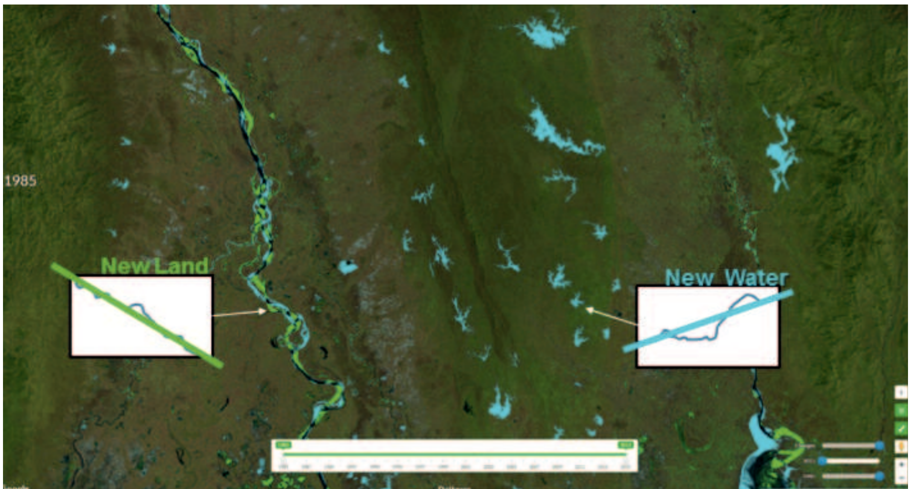

Figure 3. In the area of Myanmar the Aqua Monitor shows the transition of land and water between 1985 and 2000 due to changes in river courses (left) and damming of rivers (right)

earth's water and land surface over the last 30 years. According to our estimates, 115,000 km^2 of land disappeared and 173,000 km^2 of land emerged. In coastal areas 20,135 km^2 of land converted into water and 33,700 km^2 of new land emerged from the water. The large contributors to changes in the global surface water are the Aral Sea, where we find the largest inland transition from water to land, and the Tibetan Plateau where we find the largest increase in new permanent surface water at the cost of land. In the Chinese coastal areas we find large gains of land due to land reclamation from the sea.

How does the Aqua Monitor work?

DAM makes use of the complete Landsat satellite imagery . Landsat represents the world's longest continuously acquired collection of space-based moderate-resolution land remote sensing data. It spans almost 40 years of continuous monitoring from space at a resolution of 30 meters and imaging each location about once every two-three weeks. DAM approaches these data via Google Earth Engine. Google Earth Engine is a multi-petabyte scale processing platform that harmonizes access to various free satellite imagery acquired by multiple satellite missions such as NASA Landsat, MODIS and ESA Sentinel. The platform also makes analysis capabilities available free of charge for scientists, researchers, and developers to detect changes, map trends, and quantify differences on the Earth's surface.

DAM combines time series acquired by multiple Landsat missions covering the same area to identify transitions between surface water and land globally. Multiple images are needed because clouds are often hiding parts of the land surface. By combining information from different images covering the same area for each pixel, a probability for changes from land to water and vice-versa is calculated through linear regression analysis. By doing this repeatedly over all years, changes from land into water and vice versa can be determined. DAM highlights those areas where water has converted into land as bright green, and where land changed into water as bright blue. Figure 2 shows an example in Singapore where several water areas were converted to land due to land reclamation projects.

Another application of DAM is presented in Figure 3, which shows conversions from land to water and vice versa between 1985 and 2015 in Myanmar. In the western part of Figure 3 the changes are due to (natural) changes in the course of the river, while the eastern part of this image reveals new reservoirs originating from the damming of rivers. Most of these reservoirs are not reported in international dam and reservoir databases.

All calculations of the Aqua Monitor are performed on the fly by the Google Earth Engine infrastructure. In the past, satellite data were normally downloaded to a local computing environment for further handling. Here, all data used for the analysis remains where it is stored, i.e. in the cloud. The algorithms are written in the script language of Google Earth Engine allowing processing of large volumes of data on the fly, and reducing the amount of data to be transferred to the user. In Aqua Monitor the model is brought to the data, instead of downloading the data to use as input to the model. Through a smart data storage model, only the area zoomed into, and the pixels fitting on screen are considered for computation, which reduces the computation time and minimizes the data transfer over the web. In this way, many people do have access to the model and can perform analyses of their interest. The interface is such that people do not need any special knowledge of remote sensing and image analysis to handle DAM.

Aqua Monitor illustrates how emerging cloud platforms for large satellite data analysis, are rapidly removing the thresholds to the use of planetary-scale data. Successful platforms, such as Google Earth Engine, provide access to earth observation data in three ways: by (a) the storage of satellite data in the cloud; (b) provision of computational resources and (c) the availability of analytical tools to process data into a clear end product.

What does Aqua Monitor support

Bridging scales for everyone: Aqua Monitor bridges the global and the local scale. Using one freely available instrument, every internet-connected person can investigate changes in water on the global scale, as well as in their own neighbourhood. Aqua Monitor provides an objective source of information on surface water resources, coastal erosion and accretion, brought at everybody's fingertips, regardless of their knowledge of image processing.
For example, many countries report on their dam construction, but the information provided is far from complete. In Myanmar, the Global Reservoir and Dams database shows an increase in water surface between 1985 and 2010 of about 400 km^2. Using the Aqua Monitor, we have counted the appearance of 1,180 km^2 of new water.

It helps to identify (causes of) changes that were difficult to identify before: Aqua Monitor does not provide information on the cause of changes directly. But in some cases, the patterns it reveals help improve the under-standing of the causes of such changes.
An example is the case of some lakes on the Tibetan Plateau which are known to be growing. Different researchers have studied the history of these lakes on a case by case basis. Many suggested glacier mass loss as the cause of the increasing lake area. Using the Aqua Monitor one can visualize the vast extent of the growing lakes.

Figure 4 shows that almost all lakes have grown in size since the end of the last century. Since not all lakes are connected to rivers that drain glacial basins, glacier melt cannot be the single cause. Given the extent, a trend towards wetter climate conditions seems to be a more reasonable explanation .

What does the Aqua Monitor mean for science

In our view DAM is one of the first examples of how the increase in volume of EO data and ease of access to these data could lead to changes in the way environmental studies are performed. Due to its simplicity in use and openness, the Aqua Monitor allows for collaborative science. Aqua Monitor provides the means to perform crowd-sourced science and enables the development of public science. When we published the Aqua Monitor in August, 2016, we asked several researchers to review its results for areas where they do research and to provide ideas in what they could do with it.

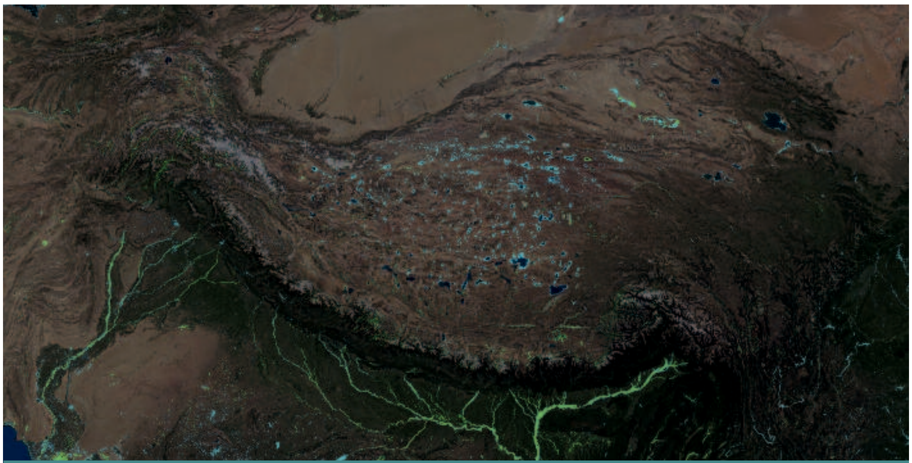

Figure 4. The Aqua Monitor shows the increase of surface water area on almost the entire Tibetan plateau between 1985 and 2015

Aart Kroon from Denmark, looked at some specific areas, where surface water changes occurred due to 'nature-reestablishment' (Filsø in Western Jutland). The changes include the creation of man-made barrier islands (Amager Beach Park in Copenhagen), the creation of the large bridges over the StoreBælt and Øresund (with Sweden), and the extension of harbour moles like those in Køge. The patterns of natural developments he studied were covered by Aqua Monitor and were in line with traditional monitoring techniques. He also looked into the shorelines of Alaska, as well as the mudflats of Guyana and Surinam. He concluded that the pattern of change according to Aqua Monitor is in line with those described by others (for Alaska recently by Gibbs and Richmond in 2015), although the Aqua Monitor may underestimate the recorded drowning at the Alaska coast.

Steffen Zacharias from Germany, tested Aqua Monitor around Leipzig. Here the fall of the iron curtain had tremendous implication on the East German lignite industry. As a result, the majority of the open pit mining activities were stopped. Most of the now redundant open-cast mines have been flooded since around 2000. This created many large lakes in the area around Leipzig. The increase of the lake areas is perfectly visible in Aqua Monitor and can be even visualized in time.

Tom Gleeson from Canada proposed a series of possible applications on groundwater. These applications included the role of springs and seeps in ecology and human evolution, the sustainability of oasis in regions where ground-water is being heavily used (e.g. North Africa) and the expansion of groundwater-irrigated agriculture. Figure 5 shows an example for the Lake Chad region illustrating that trends may be very complex. The blue colours southwest of

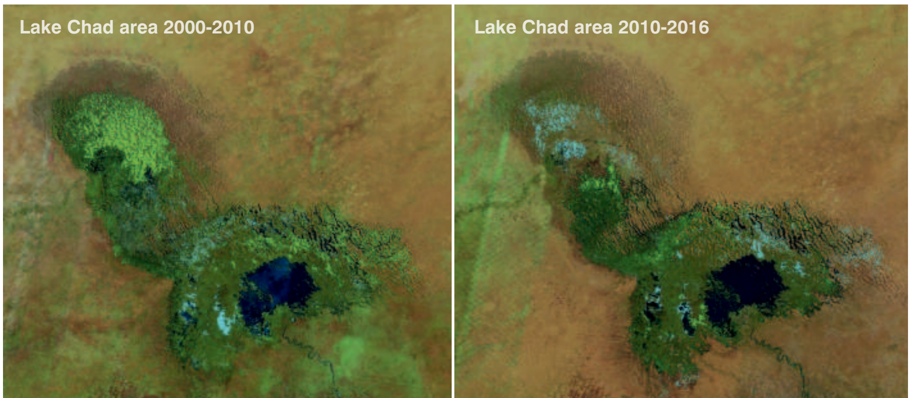

Figure 5. DAM shows the average changes in surface water over two distinctive periods in the Lake Chad area, illustrating trends in surface water areas can be complex, even in one area

Gennadii Donchyts **is a senior consultant at Deltares. He has a multidisciplinary background, covering the development of environmental modeling software and design of remote sensing algorithms for multi-spectral satellite data processing. Since 2013 Gennadii is pursuing a Ph.D. at the Technical University of Delft on a part-time basis, where he uses parallel satellite data processing platform Google Earth Engine to study surface water from space. He is the principal author of the Aqua Monitor algorithm and website.**

Dr. Fedor Baart **is an expert in the field integrated modelling. His goal is to make computer models data driven, interactive, visual attractive and exploratory. In his work he combines his unique academic background in technological and behavioural sciences, with his outstanding knowledge in information sciences and database technology. In his role as software architect and developer at Deltares, he plays a key role at Deltares in the development of information systems and user interfaces based on the latest technology.**

H.C. (Hessel) Winsemius, **received his PhD, Cum Laude, at the the Delft, University of Technology His research was aimed at the use of large-scale satellite observations, in particular of the gravity field and evaporation processes, as complementary data for the construction and calibration of hydrological models. Since 2009 he has been at Deltares where he acquired skills in working in developing countries and cooperating with governmental institutes. Hessel Winsemius has been active in several courses of the chair of Hydrology at the Delft, University of Technology. Currently he is also part-time researcher at the Faculty of earth and Life Sciences of the Vrije Universiteit Amsterdam**

Jaap Kwadijk **received his PhD from Utrecht University in 1993. Since 1997 he has been at Deltares (WL|delft-hydraulics). His expertise is climate change, flood and water management and worked on these issues in Europe, Iran, Hong Kong, Mongolia, Bangla Desh and Egypt, where he lived for two years. He was one of the founders of the Deflt-FEWS forecasting system, one of the most widely used forecasting systems in the world. Currently he is Director of Science of Deltares. Since 2012 he is also part time professor Climate and water management at the Twente University.**

Noel Gorelick **has been a software engineer at Google for nearly 10 years, having previously worked on a number of NASA Mars Missions and the Cassini mission to Saturn. He's the author of Google Moon, Google Mars and one of the founders of the Google Earth Engine project; a platform for planetary-scale analysis of remote sensing data, dedicated to helping solve society's biggest challenges.**

Nick van de Giesen **received his Ph.D. from Cornell University, after which he was post-doc in West Africa. In 1998, he moved to the Center for Development Research (ZEF), University of Bonn, Bonn, Germany. Since 2004, he has been with the Water Resources Section, Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands, where he currently holds the "van Kuffeler" Chair of Water Resources Management. He is chairman of the Delft Global Initiative, PI of the eWaterCycle Project (http://forecast.ewatercycle.org), and co-director of the Trans-African Hydro-Meteorological Observatory (www.tahmo.org).**

the main lake suggest that the area of surface water has increased between 2000 and 2010. On the other hand, the green colours in the northwest suggest that this area is becoming dryer.

Torbjorn Tornqvist and Jaap Nienhuis from Louisiana (USA), reviewed the application of Aqua Monitor in the Mississippi delta where it nicely shows the activity of the delta and the dramatic land loss at many locations. They proposed to use Aqua Monitor to validate a new approach to predicting the delta plan-view shape based on the dominance of fluvial flow, waves, or tide-driven sediment transport at the river mouth. An initial application was made to selected river deltas. The Aqua Monitor allows for testing the method to calculate sediment transport fluxes globally for all deltas (they proposed to consider approximately 14,000 delta's).

Open Source

Deltares Aqua Monitor is open-source software because we believe that making academic results fully reproducible will help to innovate the processing of satellite data for the extraction of valuable information regarding surface water and land changes.

Aqua Monitor helps create a level playing field in the access to information needed for water resources management, since everybody who is connected to the internet has access to it. To that end we believe that Aqua Monitor reduces the information gap that often exists between different competing parties in water resources. The Deltares Aqua Monitor was developed by Gennadii Donchyts working at Deltares as part of his PhD at the TU-Delft (NL). The source code of the algorithm, as well as the website, can be accessed on GitHub: http://github.com /deltares/aqua-monitor. When applying it please refer to "Gennadii Donchyts, Fedor Baart,Hessel Winsemius, Noel Gorelick, Jaap Kwadijk & Nick van de Giesen. Nature Climate Change 6, 810–813 (2016) doi:10.1038/nclimate3111". ■

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