International Journal of Applied Earth Observation and Geoinformation 57 (2017) 123–135

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Data assimilation of satellite-based actual evapotranspiration in a distributed hydrological model of a controlled water system

I.M. Hartanto[a,*], J. van der Kwast[a], T.K. Alexandridis[b], W. Almeida[c], Y. Song[a], S.J. van Andel[a], D.P. Solomatine[a,d]

[a] UNESCO-IHE Institute for Water Education, Delft, Netherlands
[b] Lab of Remote Sensing and GIS, Aristotle University of Thessaloniki, Greece
[c] CPTEC/INPE. Centre for Weather Forecast and Climate Analysis, National Institute for Space Research, Brazil
[d] Water resources Section, Delft University of Technology, Delft, Netherlands

ARTICLE INFO

Article history:
Received 15 March 2016
Received in revised form 15 October 2016
Accepted 22 December 2016

Keywords:
Hydrology
Data assimilation
Particle filter
Evapotranspiration
Controlled water system
Earth observation

ABSTRACT

Advances in earth observation (EO) and spatially distributed hydrological modelling provide an opportunity to improve modelling of controlled water systems. In a controlled water system human interference is high, which may lead to incorrect parameterisation in the model calibration phase. This paper analyses whether assimilation of EO actual evapotranspiration (ETa) data can improve discharge simulation with a spatially distributed hydrological model of a controlled water system. The EO ETa estimates are in the form of eight-day ETa composite maps derived from Terra/MODIS images using the ITA-MyWater algorithm. This algorithm is based on the surface energy balance method and is calibrated for this research for a low-lying reclamation area with a heavily controlled water system: the Rijnland area in the Netherlands. Data assimilation (DA) with the particle filter method is applied to assimilate the ETa maps into a spatially distributed hydrological model. The hydrological model and DA framework are applied using the open source software SIMGRO and PCRaster-Python respectively. The analysis is done for a period between July and October 2013 in which a high discharge peak followed a long dry-spell. The assimilation of EO ETa resulted in local differences in modelled ETa compared to simulation without data assimilation, while the area average ETa remained almost the same. The modelled cumulative discharge graphs, with and without DA, showed distinctive differences with the simulation, with DA better matching the measured cumulative discharge. The bias of simulated cumulative discharge to the observed data reduced from 14% to 4% when using DA of EO ETa. These results showed that assimilating EO ETa may not only be effective in the more common applications of soil moisture and crop-growth modelling, but also for improving discharge modelling of controlled water systems.

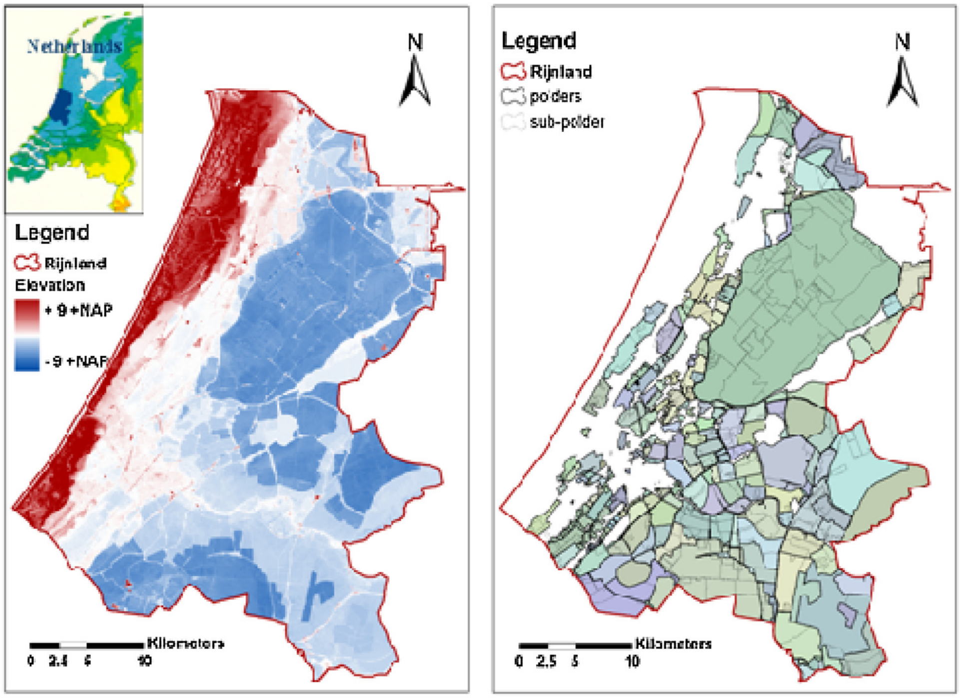
1. Introduction

In a controlled water system (CWS), hydrological variables and system states are partly determined by man-made control structures. Usually, in such systems the water flow is controlled by regulating structures aiming at maintaining the water level or discharge to a certain target level for a certain period. A typical example of a CWS is an irrigation system, with weirs, channels and gates to regulate the water flow. Inside the CWS, human influences highly affect the hydrological states. In low-lying land reclamation areas, such as in large parts of the Netherlands, human influence may be stronger still, for example because of the use of pre-pumping determined by forecasted heavy rainfall events, or because of flushing of the canals to maintain good water quality in the system. Modelling a CWS differs from modelling a natural water system since modellers should not only focus on the hydrodynamic and numerical challenges of the modelling system (Clemmens et al., 2005) but also take into account a high degree of freedom with many unknown events triggered by structures or human decisions (often unregistered). At the same time, data availability for CWS is typically higher than that for a natural system (van Andel et al., 2010).

Remote sensing images can provide additional data for distributed hydrological models. A number of satellite missions and platforms are of specific interest for hydrological studies. These are

* Corresponding author.
E-mail addresses: isnaeni@gmail.com, i.hartanto@unesco-ihe.org (I.M. Hartanto).

http://dx.doi.org/10.1016/j.jag.2016.12.015
0303-2434/



a b

Fig. 1. Rijnland maps: area boundary, location, and elevation (a), and polders map (b).

mainly sensor systems that combine thermal infrared and optical data, such as the Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM +), Operational Land Imager (OLI) and Thermal Infrared Scanner (TIRS) on board of the Landsat satellite series, the Advanced Very High Resolution Radiometer (AVHRR) on board NOAA (National Oceanic and Atmospheric Administration) satellite series, the Moderate Resolution Imaging Spectro-radiometer (MODIS) on board of the Terra and Aqua satellites, and the upcoming Sentinels (Sentinel-2 and Sentinel-3). Of equal interest are the active and passive radar systems, such as the RADARSAT, TerraSAR-X, COSMO-SkyMed, and Sentinel-1. Apart from the sensor's spectral definition, revisit time and spatial resolution are important considerations to determine the suitability of a sensor for hydrological monitoring and modelling.

Earth observation (EO) instruments measure the hydrological variables or parameters indirectly, so an interpretative model has to be used to estimate their actual values. The variables important for hydrological modelling that can be retrieved by EO imagery, are, e.g. land use/land cover, natural vegetation cover, leaf area index, biomass, ground surface elevation, and surface energy balance parameters (Schultz and Engman, 2000). However, the accuracy of estimated variables may vary, depending on the sensor, region, atmospheric conditions and local surface conditions, so the accuracy of EO products differs in space and time.

Data assimilation (DA) is expected to help in combining the strengths of the EO information and the hydrological model to better characterize the modelled state (Dorigo et al., 2007). EO provides the hydrological model with a measured estimation of a certain hydrological variable at the moments when the EO data is available (Errico, 1999; Errico et al., 2000), and the DA process modifies the model states to result in a hydrological state that is closer to the state as estimated by EO.

Use of DA of EO data for hydrological modelling has been demonstrated in a number of studies. For example, the soil moisture estimation from EO data has been assimilated in hydrological models by, amongst others, Hoeben and Troch (2000), Reichle et al. (2002, 2001), Lee et al. (2011), Han et al. (2012), and Lievens et al. (2015). Assimilation of soil moisture combined with leaf area index (LAI) has been shown to improve crop-growth model results (Pauwels et al., 2007). In addition, the combination of soil moisture with stream flow DA has been carried out, e.g. by Aubert et al. (2003) and Wanders et al. (2014). Snow cover area has been successfully assimilated to improve stream flow simulation, e.g. by Clark et al. (2006), Nagler et al. (2008), and De Lannoy et al. (2012). It should

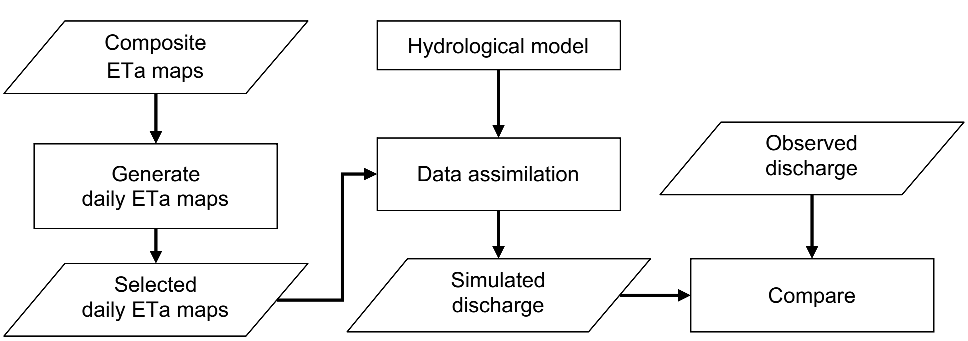


Fig. 2. Overview of modelling process with data assimilation of EO ETa maps.