ViWA: Virtual Water Values

Multiscale monitoring of global water resources and options for their efficient and sustainable use

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ABSTRACT

For sustainable development it is imperative to use natural resources, like water, globally with the highest possible sustainable efficiency. ViWA aims at monitoring global water use efficiency (WUE) in agriculture using the hydro-agro-model PROMET and simulating its economic and ecological implications. ViWA extends the general-computable-equilibrium (CGE) economic model DART of global agricultural trade to consider virtual water. Scenarios for regulations of and incentives for global trade are developed and simulated to identify trade-offs and a global hot-spot sustainability analysis. Global methodologies are applied in the Danube and Zambesi basins and in smaller hot-spots to analyse allocation conflicts and the effects of improved WUE and to identify trade-offs on the way to proposing solutions. First hourly, 30 arcsec global simulations of WUEs have been carried out for different seeding dates, cultivars, fertilizer uses and irrigation for 18 crops on the HPC-facility SuperMUC. Time series of Sentinel-satellite images were assimilated into PROMET. Spatial studies were carried out for the Danube to extend CGE DART by determining the irrigation water demand, elasticity of yield towards green and blue water and sustainability of water use. They will spatially connect simulation of irrigation with water abstraction from surface and groundwater. A sustainability assessment will reveal the degree of sustainability of the virtual water connected to the different crops in specific locations. WUE results for maize show hot-spots of water waste in rainfed and irrigated maize and high-potential regions to improve WUE. The next decade will see huge investments for irrigation in the Danube basin. ViWA for the first time develops a comprehensive spatial picture of the Danube irrigation water demands which point at serious future upstream-downstream and ecological conflicts.

INTRODUCTION

98% of global water use is estimated to be allocated to producing food and biomaterials through green (rainfall) and blue (irrigation) water. Water- and food-related SDGs can therefore only be met through increasing efficiency and ensuring sustainability of the water used in agriculture. Two key parameters describe agricultural water use: use efficiency (WUE, kg yield/m^3 evapotranspiration) and sustainable water availability (mm/growing season). WUE generally increases when closing yield gaps, which we define as the difference between actual and sustainably achievable agricultural yields (t/ha). Sustainable water availability strongly varies across the globe and depends on the localization of a site both within a basin and within a climatic zone (precipitation, temperature, etc.). Agricultural commodities from different locations meet in a global market, in which currently neither WUE nor sustainable water availability influence pricing of agricultural commodities. In order to investigate different options to consider these parameters in pricing and thereby use trade to foster sustainable and efficient water use by agriculture ViWA aims at 1) developing ways to globally monitor the local WUE of agriculture and determine sustainable water availability using COPERNICUS Sentinel-2 times series data, 2) develop scenarios of trade incentives and regulations and investigate their respective trade-offs in promoting more efficient and sustainable water use in agriculture, 3) determine the sustainability of water use in agriculture for the identified scenarios. ViWA therefore addresses the following research questions: 1) What is the global state of local water use efficiency? 2) To what extent is the water that is diverted by agriculture supplied regionally from sustainably available surface and groundwater sources and what conflicts exist among water users in regional pilot basins? 3) How can agricultural trade contribute to foster water use efficiency and sustainable water use in agriculture? 4) Where are hot-spots of actual and potential water use efficiency and sustainable/unsustainable water use in agriculture? The developed methods can be applied to monitor year by year and, on a global basis, local changes in water use efficiency in agriculture considering climate variability and changes in land use and to determine potentials for its improvement. The monitored data will allow to investigate coupled agro-ecological-hydrological-economic scenarios of water use and agricultural trade regarding their local and global potential to increase the sustainability of agricultural use both of green and blue (irrigation) water use. The project addresses national and international decision makers in politics, administration and economy and intends to provide them with orientation knowledge.

METHODS

ViWA investigates the potential of large environmental remote sensing data sets, high performance computing resources and integrated scenario simulations to verify the water-related Sustainable Development Goals. ViWA uses a transdisciplinary approach of coupling environmental data with a sophisticated set of coupled agro-hydrological, water-food and economic simulation models and assessment approaches to investigate its research topic. In order to create the WUE monitoring system it combines global high-resolution Sentinel-2 times series and global crop growth modelling that is driven by ERA-re-analysis as well as dynamically downscaled meteo-drivers using REMO. An ensemble of global simulations provides LAI, WUE and yield for a broad range of agricultural management options; thousands of Sentinel-2 images of randomly selected global tiles were processed to determine for each 10 m sample point which member is implemented in reality. Within the irrigation ensemble, the members blue water demand is determined and connected to water abstraction from the river network and ground water to evaluate its up- and downstream ecological and economic effects. The monitoring results are analysed for global hot- and cold-spots of WUE in agriculture. A CGE-global-trade model is extended to consider water availability in agricultural trade with systematic studies of yield dependence on green rainwater and blue surface and groundwater water supply. A set of scenarios are developed together with stakeholders to investigate trade-offs of agricultural trade alternatives to foster water use efficiency and sustainable water use in agriculture by systematically using the global agri-management ensemble members. The results are carefully analysed with respect to their sustainability. The integrated methodology is applied to the Danube and Zambesi basin to demonstrate its regional usefulness and applicability. The complete water cycle is simulated there and conflicts of green and blue water alloca-tion, specifically with regard to agricultural yield, irrigation, domestic and industrial water use and ecological water demands are analysed. A more detailed description of the ViWA approach can be found at **www.viwa.geographie-muenchen.de.**

INTERIM RESULTS AND DISCUSSION

First results were achieved in developing the ViWA WUE monitoring system. Large ensembles of evapotranspiration, yield, WUE and LAI time-series were simulated for the 18 most important global crops (in terms of revenue). ViWA for the first time successfully demonstrated that a complex agro-ecological crop growth model can be globally parameterized in a consistent way. High-spatial (30 arcsecs) / high-temporal (1h) global simulations can be carried out to cover all major water-related agricultural management decisions including cultivar selection, seeding date, fertilization and irrigation. The 283-member ensemble was driven by statistically downscaled reanalysis meteo data and was simulated for 2016/17 on the SuperMUC using approx. 1.5 Mio CPU hours. Figure 1 shows a result for maize in 2017. Figure 1 was composed by selecting the WUE of the highest-yielding cultivar for each pixel both under local water stress (left) and full irrigation (right) and no nutrient stress. Hot-spots of high WUE are identified in Central America (origin of maize), tropical Western Africa and Indonesia. Large increase of WUE can potentially be achieved through irrigation in the N-American cornbelt, NE-China, SE-Europe, Australia and Sub-Saharan Africa.

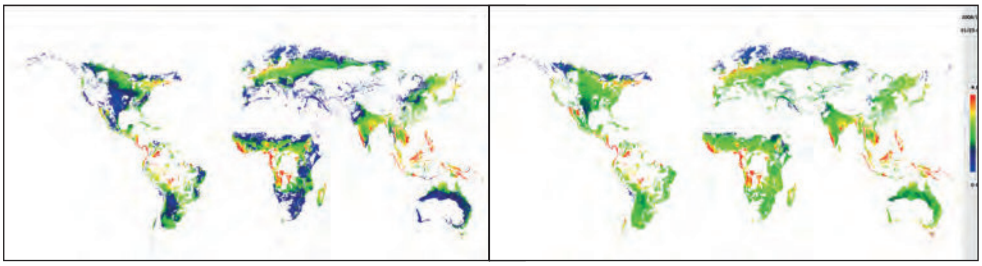

Figure 1: Global distribution of WUE of maize (kg yield/m³ ET) for 2016/17 simulated with PROM-ET. Left: rainfed WUE, right: max. irrigation WUE

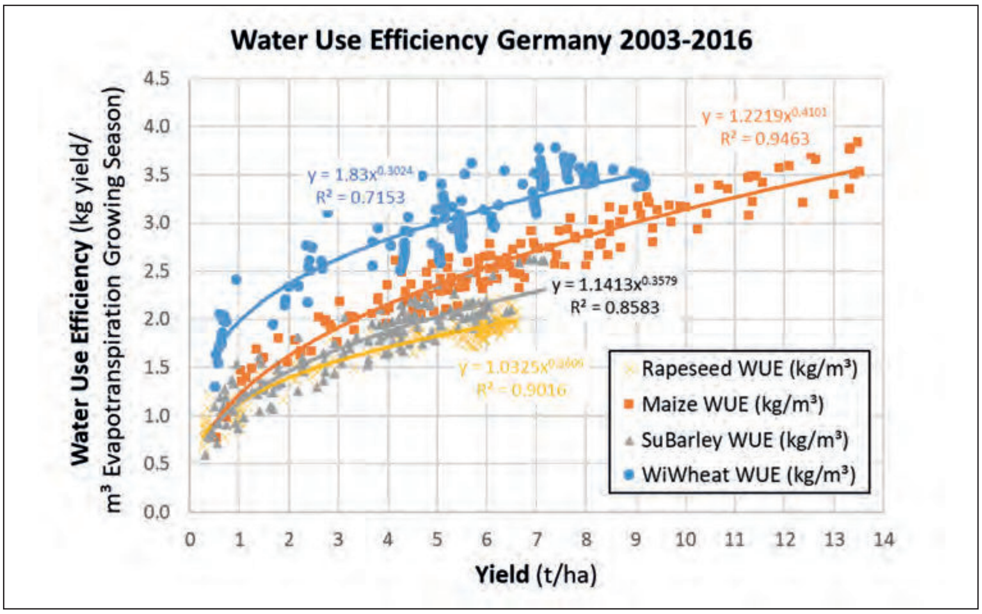

Figure 2: Water use efficiency of rapseed, maize, summer barley and winter wheat for Germany

Simulations were carried out with PROMET to determine the WUE-yield relation for a broad variety of environmental conditions around the globe. These relations are used to incorporate green and blue virtual water elasticities in the CGE DART and thereby enable to consider virtual water values in global trade. Figure2 shows the average relation for Germany for the years 2001-2015. They resemble the general shape of a saturation elasticity curve. The results of the full simulation ensemble is being systematically compared with the observations of LAI-times series results from selected Sentinel-2 tiles. Figure 3 shows the processed 100x100 km Sentinel-2 tile 33UUS in Saxonia (resolution: 10m) and identified maize pixels and two typical LAI-development curves for 2017 and 2018. The ensemble members most similar to the measured LAI-development determine which simulated yield and WUE (right) belongs to the observed pixel. Assimilated and observed average yields for 2017 differ by 0.2 t/ha. This kind of analysis will be carried out for 150 Sentinel-2 tiles, which were selected randomly to represent the global cropland. Figure 3 gives a first impression of the detail of the Sentinel observations, the interannual variations of a normal (2017) and drought (2018) year and of the variety of actual yield and WUE of maize in the Saxonia tile. The analysis addresses key questions of the Saxonian Ministry for Environment as ViWA stakeholder. Interest was also expressed by ViWA's stakeholders on irrigation and its WUE as well as on the sustainable availability of water resources for irrigation in river basins. This issue was taken up by the ViWA consortium and methodologies were developed as well as data analysed using the Danube basin as a pilot region. Agriculture was a key economic development perspective in the Lower Danube basin. National plans are drafted (independently) to expand irrigation which makes an overall strategy to maximize its benefit across the Danube basin desirable. ViWA develops a new approach to spatially simulate the water flows of the Danube basin for a variety of irrigation scenarios to analyse yield and WUE increases and water conflicts most likely arising from expanding irrigation. Figure 4 shows the simulated discharge with irrigation (% actual discharge) for the August 2017 season. The irrigation simulations results show a yield increase e.g. for maize of ~30 Mio. t p.a. across the basin with a WUE increase from 1.8 to 2.7 kg/m³. The red colour in Figure 4 shows that this yield increase would exceed the water availability of many downstream tributaries of the Danube and considerably decrease summer discharge of the Lower Danube. Figure 4 illustrates the upstream-downstream gradient in water demand for irrigation.

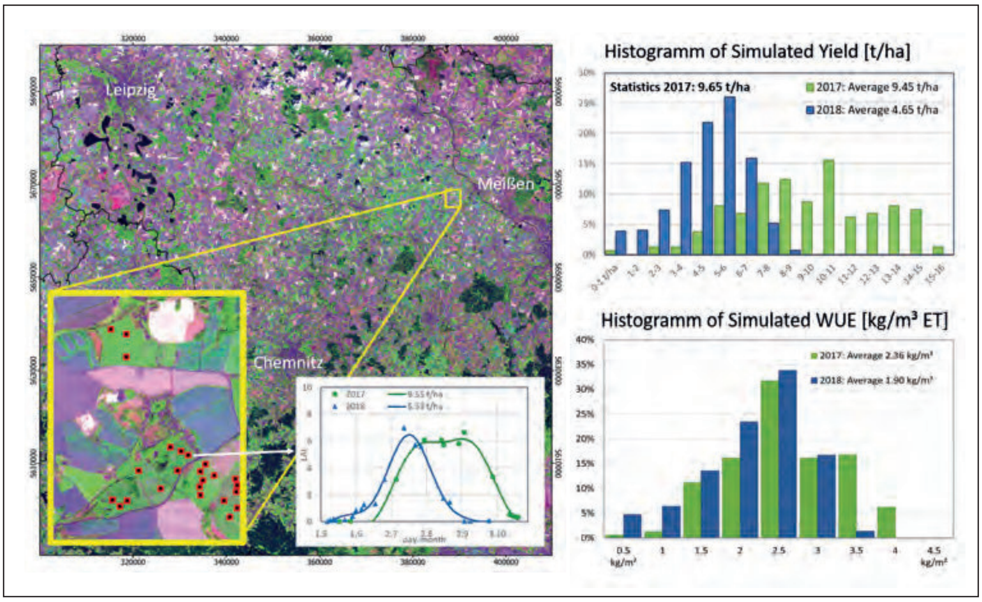

Figure 3: Sentinel-2 tile 33UUS in Saxonia on July 3 2018, inlays show identified maize pixels (left) and typical processed LAI time series for 2017 and 2018 (right). Histograms to the right show the tile's yield distributions estimated through assimilation of LAI in PROMET and resulting PROM-ET-WUE distributions of 2017 and 2018.

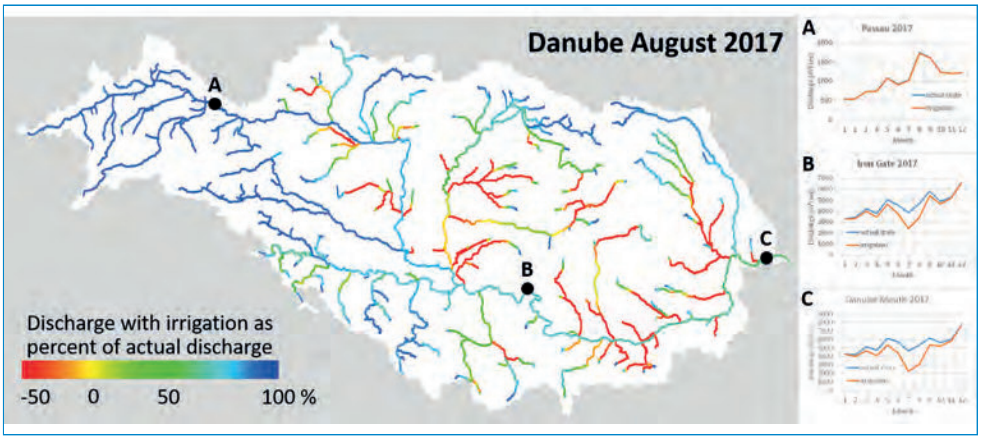

Figure 4: Simulated % change in runoff in the Danube river network in August 2017 due to irrigation (left) and actual and irrigated discharge for selected locations A, B and C (right).

CONCLUSIONS & OUTLOOK

ViWA has successfully established the basic tools to monitor WUE and to use Sentinel-2 time series. This big-data approach is new and challenging and will produce, once fully developed, deeper insights into the global water-food nexus as well as valuable practical applications in the context of achieving the water-related SDGs. It will be further used within ViWA to simulate scenarios, to analyse their sustainability and to identify agricultural WUE hot spots. Most efficient and sustainable basin wide irrigation was taken up by ViWA as result of stakeholder interactions. It completes the emerging global picture of the strongly varying WUE of green and blue water in agriculture as well as its value both in terms of economy and ecology.

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