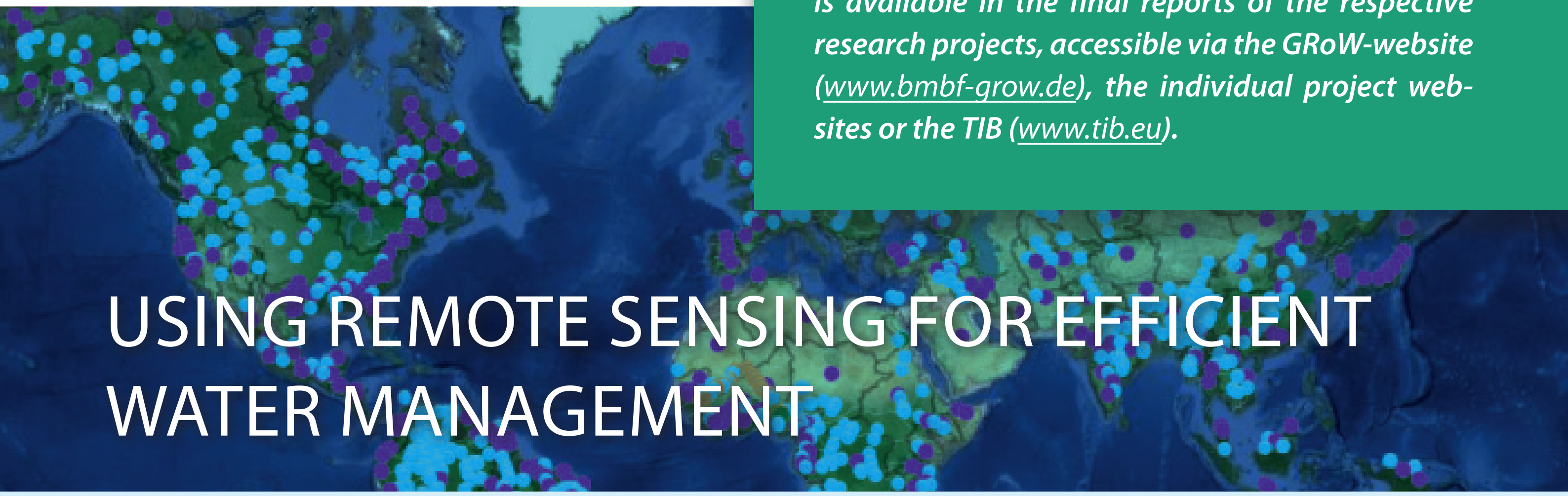
An Initiative of the Federal Ministry of Education and Research

GRoW

WATER AS A GLOBAL RESOURCE

TECHNICAL BRIEF #2

The BMBF funding measure "Water as a Global Resource" (GRoW) has produced a number of remote sensing products which contribute to more efficient water management. This technical brief presents a selection of these products. Further GRoW products related to the topic can be found in the BMBF Atlas of Water Innovations (www.innovationsatlas-wasser.de). In-depth information is available in the final reports of the respective research projects, accessible via the GRoW-website (www.bmbf-grow.de), the individual project websites or the TIB (www.tib.eu).



USING REMOTE SENSING FOR EFFICIENT WATER MANAGEMENT

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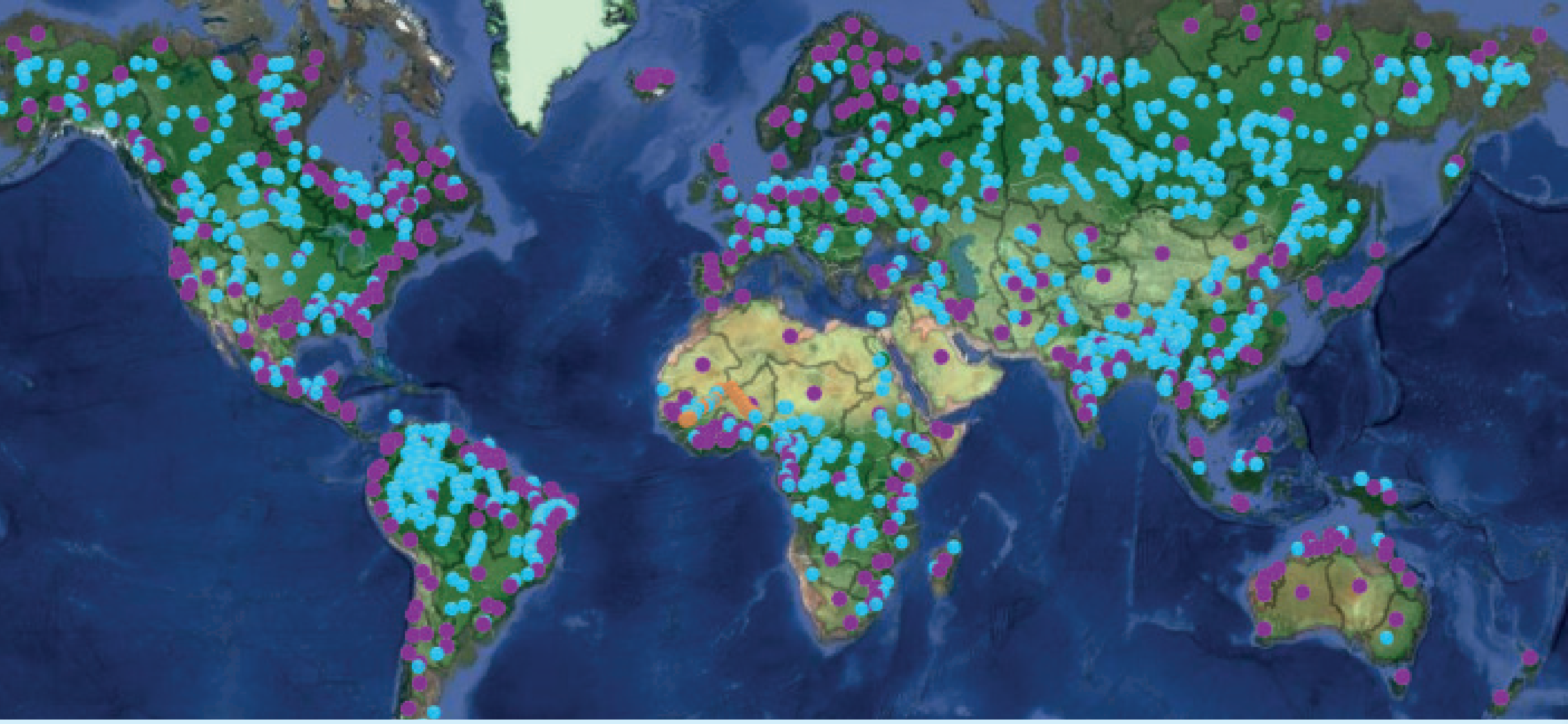

BACKGROUND

For a meaningful description of the state of global and local water resources including associated ecosystems, one of the main challenges is often low availability of locally collected hydrological measurement data. Remote sensing data and global data sets provide valuable sources of information to allow for evidence-based and comprehensible forecasts of water availability and water use. Therefore, publicly accessible information from satellites and global models can make a major contribution to improved water management, especially in regions with limited data or where an independent data source is needed.

GRoW projects made use of remote sensing in a number of innovative approaches, e.g. to better predict water scarcity and droughts, to create land use and soil moisture maps, and to determine and predict water use in different sectors, focussing particularly on agriculture as the world's largest consumer of water. Results achieved in GRoW show that remote sensing tools bear great potential to take advantage of the potential of the digital era to improve water management, as claimed in the GRoW science-based call for action (https://bmbf-grow.de/sites/bmbf-grow.de/files/documents/call_for_action_for_business_and_policy_leaders_web.pdf).

This Technical Brief presents selected products from the GRoW funding measure that show how to use remote sensing for efficient water management. Further innovative GRoW products on this topic can be found in the **BMBF Atlas of Water Innovations** (www.innovationsatlas-wasser.de) and include:

- SAMOS - Saltwater Intrusion Monitoring System
- Global Maps for the Characterization of Mediterranean karst aquifers
- Automated satellite data integration for water management
- MoRE Tool for regionalized emission modelling
- Decision Support Tool (Viewer) for seasonal Water management
- Model system for water and sediment transport
- Global Maps for agricultural water use efficiency
- Water Food Energy Nexus Tool

DROUGHT MONITORING IN CROPPING SYSTEMS WITH MULTISCALE REMOTE SENSING DATA

Remote sensing bears huge potential for drought monitoring in cropping systems. It provides information that is crucial to understand the resilience of the agro-ecological system to climate variability and produces land use data that is critical to land management policies on drought and food security – ultimately helping to gauge food supply.

Spatially explicit drought monitoring can ensure drought preparedness and help to provide preventive measures in vulnerable areas. Within the GlobeDrought project, several remotely sensed time series were used to characterise drought events on both regional and global scale in a spatially explicit manner, such as the Moderate Resolution Imaging Spectroradiometer (MODIS) based normalized difference vegetation index (NDVI), land surface temperature (LST), Normalized Difference Water Index (NDWI), Normalized Difference Infrared Index (NDII) and Albedo.

Furthermore, the ratio between actual to potential evapotranspiration (AET/PET) was extracted, which was later compared with an aridity index estimated using a process-based crop model. These indicators were compared not only at regional, but also at global scale to estimate drought risk, as well as the impact on yield. Other data, such as total water storage changes were derived from GRACE gravity measurements, which were assimilated into a global hydrological model. Information about the extent of rainfed and irrigated land are needed to inform risk and impact estimation, but the time-series data used for land use mapping exhibits data gaps and is inaccessible for many users due to its large data volume.

In order to close these data gaps and map the spatial distribution of irrigated and rainfed agriculture in southern Africa, harmonics curve parameters (representing crop phenology) and machine learning classification from Landsat time series data (2013 to 2018) have been optimized.

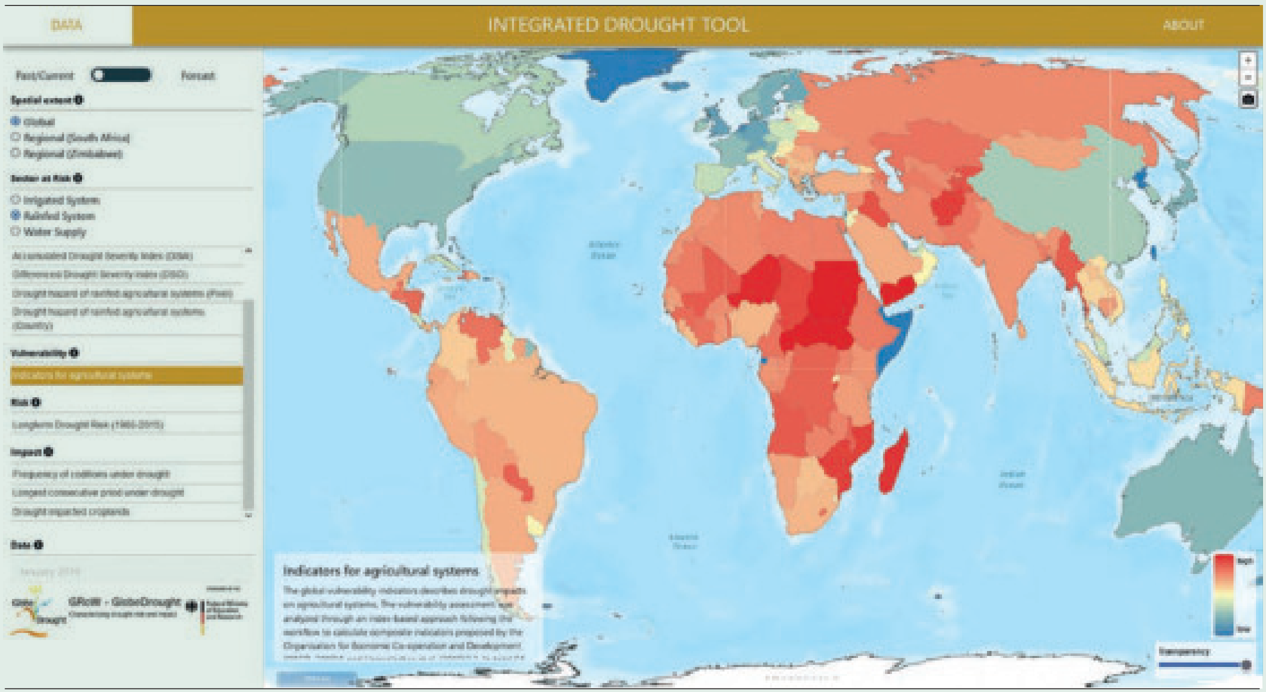

Figure 1: Integrated drought tool. Source: GlobeDrought.

INNOVATIVE ASPECTS

- Use of multisource/multiscale data
- Use of novel data-driven, hydrological and process-based crop models
- Use of past and current drought information
- Provision of drought information at different scales (regional/global), for different sectors (irrigated, rainfed, water supply) and on risk levels (risk, hazard, vulnerability, impact)

CASE STUDY ZIMBABWE AND SOUTH AFRICA

New ways to use remote sensing phenology and machine learning were shown for predicting irrigated and rainfed agriculture in Africa, especially by mapping spatial distribution and irrigated and rainfed agriculture in Zimbabwe. Furthermore, different remotely sensed data were used to estimate drought hazard, risk, vulnerability and impact in South Africa.

Drought monitoring based on remote sensing was carried out as part of the GRoW project GlobeDrought (Global information system on droughts and their impact), which presents an information system that gives systemic access to global and regional drought information. The GlobeDrought information portal is accessible for everyone and includes past and current drought information as well as forecasts. The drought information can be viewed at different scales and filtered by sector (irrigated, rainfed, water supply), as well as risk level (risk, hazard, vulnerability, impact). While conventional early warning systems are mostly limited to the (meteorological) drought risk, the GlobeDrought project has developed an innovative, international drought information system that takes into account not only hydrology but also the vulnerability to certain drought effects as well as drought exposure.

FURTHER INFORMATION

Contact:
Leibniz Centre for Agricultural Landscape Research (ZALF) e. V. & Universität Bonn, Dr. Gohar Ghazaryan
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Dr. Jonas Franke

Project website:
https://grow-globedrought.net/

REGIONAL ASSESSMENT OF WATER USE EFFICIENCY AND YIELD FOR WATER-FOOD-ENERGY NEXUS AWARENESS

For sustainable development it is imperative to use natural resources, like water, globally with the highest possible sustainable efficiency. Within ViWA a solution was developed to monitor global water use efficiency (WUE) in agriculture using the hydro-agro-model PROMET and simulating its economic and ecological implications.

A real time monitoring/modelling system for global agricultural WUE and sustainable water availability was developed using the latest globally available COPERNICUS Sentinel satellite data streams. The monitoring system provides deeper insights into the water-food-energy nexus as well as valuable practical applications in the context of achieving the water-related SDGs. The methods developed 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. In order to determine WUE also agricultural production (yield in t/ha) is a required, intermediate data product. This yield information was integrated and extended in the Yield Prediction Service YPSILON (https://ypsilon.services), that operationally offers regional yield forecasts for wheat, barley, rapeseed and maize for Europe on a weekly subscription basis.

INNOVATIVE ASPECTS

- Using satellite images in combination with the physically-based water balance model PROMET to calculate yield, evapotranspiration and water use efficiency
- Digital Twin for water-food-energy nexus studies

CASE STUDIES IN THE DANUBE RIVER BASIN

The Danube was chosen since in the next decades huge investments for irrigation in the Danube basin are expected. Systematic spatial studies were carried out in the Danube basin with focus on maize as one important commodity crop with significant irrigation demand.

The Sentinel data stream was analysed by first classifying the crop type, selecting representative maize samples (more than a hundred thousand fields), analysing their biomass and phenological development and assimilating this information in the agro-ecological model PROMET. For each sample this delivers simulated evapotranspiration amount, yield and resulting water use efficiency. Satellite analyses together with water balance simulations can also determine whether a field is rainfed or irrigated.

The effect of extending the irrigation of maize to its possible maximum was studied in a simulation exercise so that the impact on yield, water abstraction from rivers and hydropower production could be quantified. Concluding, WUE results for maize show high-potential regions to improve WUE in the Danube basin. ViWA for the first time exemplarily developed a comprehensive spatial picture of the irrigation water demands in the Danube basin, which point at serious future upstream-downstream and ecological conflicts.

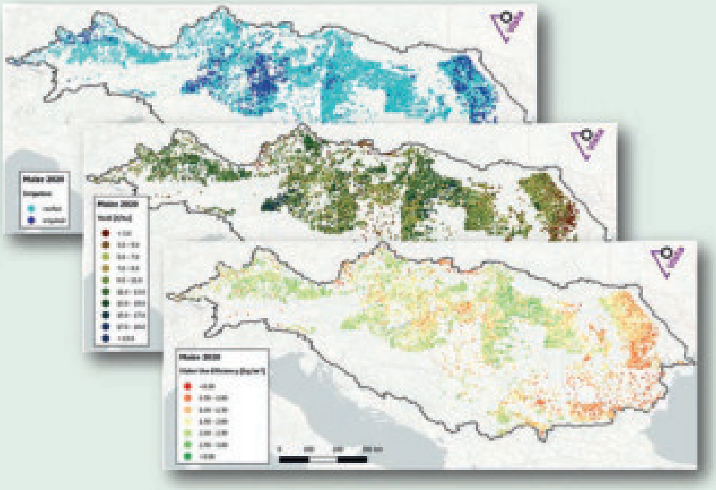

Figure 2: *ViWA Use Case "Maize in the Danube Catchment": classification of irrigated/rainfed maize fields (top), their yield (middle) and water use efficiencies (bottom). Source: ViWA.*

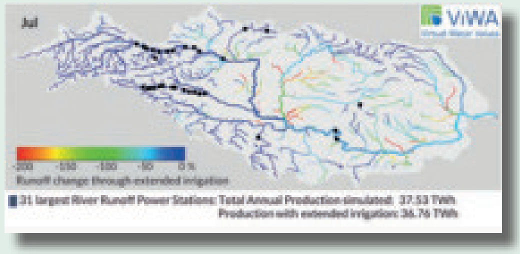

Figure 3: *ViWA Use Case "Maize in the Danube Catchment": water-food-energy nexus assessment for an extensive irrigation scenario. Source: ViWA.*

The products based on remote sensing data and tools to assess and increase regional water use efficiency were developed within the GRoW project ViWA (Virtual Water Values - Efficient and sustainable global water use). ViWA developed a global, high-spatial and -temporal resolution, remote sensing-based management and monitoring system for the efficiency and sustainability of water use in agriculture and competing sectors. Such a system will enable to assess transparently and neutrally the progress in achieving water-related SDGs through more efficient use of water. Using high resolution Sentinel-2 data as input to the system allows ViWA to consider both the "global" and the "local" scale in developing, formulating and analyzing trade-offs of practicable solutions for a more sustainable and efficient use of water resources.

FURTHER INFORMATION

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Company website: www.vista-geo.de

Project website:
https://viwa.geographie-muenchen.de

USING SENTINEL-2 DATA TO INCREASE WATER USE EFFICIENCY THROUGH SITE SPECIFIC IRRIGATION

Addressing the local level, one goal of the GRoW ViWA project was to reach an increased water use efficiency on farm-level. Utilizing globally available satellite data together with expert knowledge and crop modelling, irrigation water demand is calculated and used to operationally advise local irrigation systems.

Due to spatial variations in surface properties, even within single fields, crop conditions can vary considerably, but also the current weather conditions make a difference in plant water demand. One of the main points of this approach is to define the site-specific crop water demand as input for the calculation of the optimum irrigation amount. Leaf area [m^2/m^2] derived from Sentinel-2 satellite data via the radiative transfer model SLC (Soil-Leaf-Canopy) is used in combination with crop growth modelling using the highly detailed physically-based water balance and crop growth model PROMET. Based on soil and elevation data, as well as hourly meteorological data from various measurement stations, the model simulates plant growth and crop water demand. By updating the model with plant status from the latest satellite observations, the simulations produce site-specific maps showing an up-to-date status of the crop water demand, the field capacity or the soil moisture within a field. Additionally, through meteorological forecast data and simulations into the future, irrigation is planned for the next seven to ten days. From these findings, ready-to-use prescription maps for the irrigation control software are generated. This service is now offered commercially to farmers by BayWa under the service name *VariableRain*.

INNOVATIVE ASPECTS

- Using satellite images in combination with the physically-based water balance model PROMET to calculate crop water demand
- Increased water use efficiency on a local scale
- Optimization of irrigation on different scales (field level, sectoral level, 10 x 10 m)

CASE STUDY ZAMBIA

One of the case studies was a farm in a drought-prone part of Zambia (Africa). Due to the geographical location of the farm, cultivation of wheat during dry season (May to October) is only possible with intense irrigation. The irrigation water originates from a surface reservoir whose water levels have fallen during the last few years due to a harsh drought that makes the urgency of sustainable use of water even more obvious. The farm owns innovative irrigation systems that offer the possibility to adjust the amount of water applied in a site-specific way (Variable Rate Irrigation, VRI). With the adjustment of the irrigation system based on the site-specific crop water demand, the use of irrigation water could be decreased significantly (minus 30%), while the yield even increased compared to the last years.

> *„Our reservoir was only filled to two thirds. Nevertheless, with VariableRain we succeeded to optimize irrigation and obtain high yields on all our fields. Wheat production on our farm could thus be increased by 30% compared to our earlier farm management"*
>
> Jesper Lublinkhof, Mubuyu Farm, Zambia

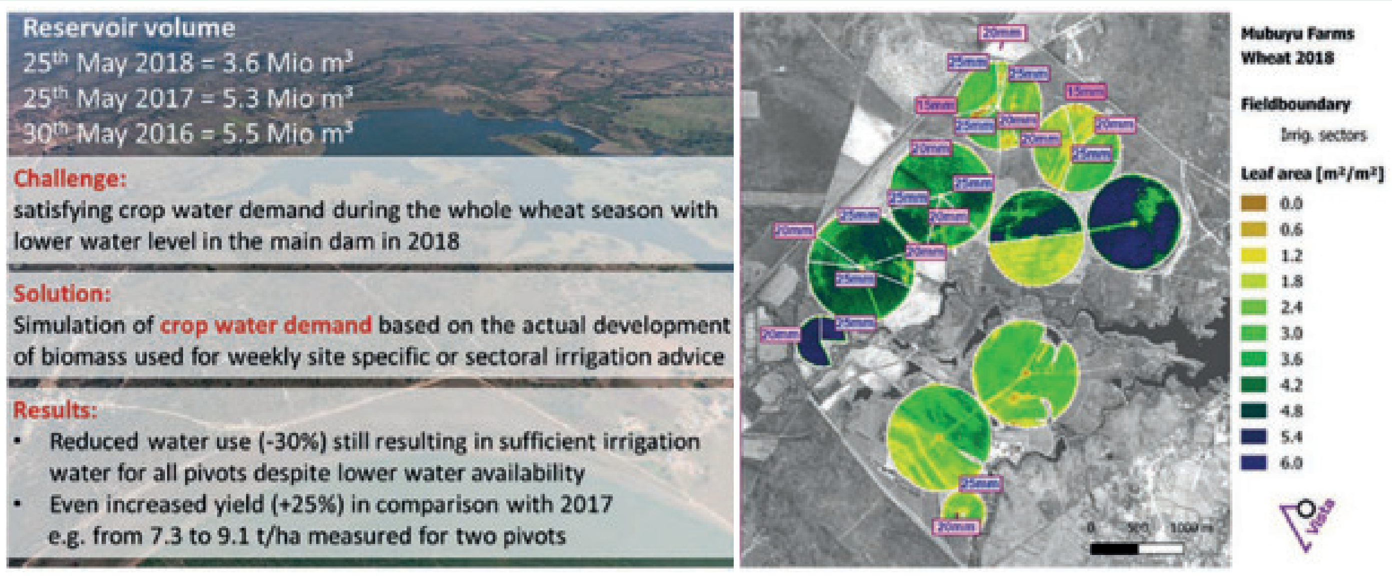


Figure 4: *Overview of the results obtained for Mubuyu Farm (Zambia). Source: ViWA.*

FURTHER INFORMATION

Contact:

VISTA Geowissenschaftliche Fernerkundung GmbH,
Franziska Brohmeyer

Company website:

www.vista-geo.de

Product website:

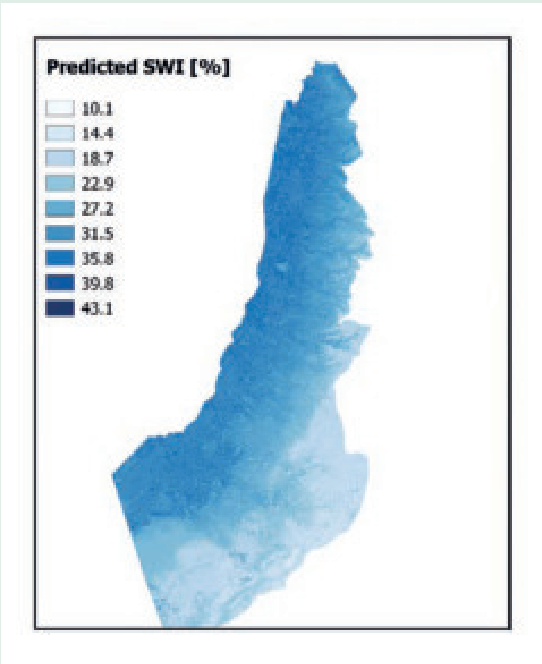
www.baywa.de/de/i/entdecken/bewaesserung/variable-rain

CREATING HIGH-RESOLUTION LAND USE AND SOIL MOISTURE MAPS FROM REMOTE SENSING DATA

Different remote sensing data was explored to create and provide accurate high-resolution (10 m - 20 m) land use and near-surface soil moisture maps using GIS and machine-learning methods. These maps were developed for the Western Mountain Aquifer (WMA) in Israel, the project's main study site.

In data-scarce regions, remote sensing can contribute valuable data sets such as high-resolution land use and soil moisture maps. They can serve as input to different models and are useful for management purposes, e.g., if integrated in information systems. Key remote sensing results of MedWater are highresolution land use maps (see figure on the back of this TechBrief, showing a land use map for the Western Mountain Aquifer 2016) and downscaled time series of ESA CCI Soil Water Index (SWI) (Figure 5).

The classification accuracy was almost 70% for the major land cover classes (Level 1) and achieved 65% for the detailed maps (Level 2). The complexity of land cover in dry climate conditions such as Mediterranean karst areas introduced high spectral confusion between soil and settlement bodies, water and foil cover of fields, and different vegetation classes. Land use classifications benefit from SAR data. For instance, integration of Sentinel-1 SAR data into the classification of optical Sentinel-2 data enormously improved the quality of the detailed crop maps.



The aggregated land use map was directly integrated together with SRTM data, spectral indices from Sentinel-2, in the approach to downscale the ESA CCI SWI from 25 km pixel size to higher resolution. The internal validation of the SWI approach resulted in an average coefficient of determination (R2) of 0.96 and a mean square of variation (RMSE) of 1.5%. Analysis of the resulting time series indicates spatial variations of soil moisture in the study area. For some land use classes, prediction quality can be assessed to be reduced, e.g., in the case that water bodies or impervious areas characterize the SWI pixel under consideration. Agricultural use or sparse vegetation that is typical in arid climates, as well as bare soils allow for comparatively good predictions.

Figure 5: *Predicted SWI [%]. Author: Löw (2020); Source: ESA CCI SWI, SRTM, Sentinel 1/2; Projection: WGS84 UTM 36N.*

INNOVATIVE ASPECTS

- Optical Sentinel-2 systems provide high-resolution land use/land cover maps that can be enhanced at higher levels of detail (crop maps) by the integration of SAR-systems such as Sentinel-1.
- A procedure for downscaling the global Soil Water Index from ESA-CCI using Sentinel-1 data is implemented.
- Geodata integration and machine-learning workflows can improve the quality of remote sensing-based results, which can serve as additional information for applications in data-scarce regions.

CASE STUDY WESTERN MOUNTAIN AQUIFER, ISRAEL AND THE WEST BANK

High-resolution land use mapping relied on multi-temporal data from Sentinel-2 and Sentinel-1 (2016-2018). Google Earth provided training data to distinguish between basic land use classes (e.g., settlement, water, forest, desert, cropland). Crop data was obtained from the Israeli Ministry of Agriculture and Rural Development. The developed ESA CCI downscaling approach was applied for the derivation of soil moisture time series. As spectral indices, the normalized difference vegetation index (NDVI) and the normalized difference wetness index (NDWI) were utilized. The indices were selected to account for both the vegetation and water dynamics in the Sentinel pixels. The downscaling was applied to 20m Sentinel resolution in a one-step approach. The land use maps were commonly elaborated with project partners to supply the demand for the assessment of ecosystem services. For this purpose, detailed information on crop classes in the cropland extent and wetlands were required (Level-2 classification). Both land use maps and soil moisture time series were made available for hydrological modeling and assessments, and can for instance be used for the parameterization and calibration of the models.

The high-resolution land use and soil moisture maps were created based on remote sensing data as part of the GRoW project MedWater (Sustainable use of politically and economically relevant water resources in hydraulically, climatically and ecologically highly dynamic hard-rock aquifers in the Mediterranean region). These data were used to calibrate two climate projection models, according to which groundwater recharge may decrease between 16% and 25% in the karstified Western Mountain Aquifer in Israel and the West Bank. Karst aquifers are highly vulnerable to potential decreases in precipitation and recharge caused by climate change. Awareness of a possible recharge deficit is therefore important to adjust future pumping rates and to identify alternative freshwater sources in order to limit water stress in Israel and the West Bank.

FURTHER INFORMATION

Contact:
Universität Halle-Wittenberg, Prof. Dr. Christopher Conrad

MedWater Technical Note:
http://grow-medwater.de/home/wp-content/uploads/2021/06/TN_Remote_sensing.pdf

INLAND WATER LEVEL TIME SERIES FROM SATELLITE ALTIMETRY

Water level time series of rivers, lakes and reservoirs are derived for semi-arid basins of Karun (Iran), Blue Nile and Upper Atbara (Sudan), and São Francisco (Brazil) from the altimetry missions Envisat, Saral/ AltiKa, Jason-1, Jason-2, Jason-3, Sentinel-3A, and Sentinel-3B.

Each water level time series is calculated for a single virtual station. A virtual station is the average position of intersection between an altimetry ground track and the inland water body of interest.

Depending on the sampling rate of the altimeter and the geometry of the virtual station, multiple range measurements are collected during each overfly. Range measurements are first corrected for path delays caused by the atmospheric (wet tropospheric, dry tropospheric, ionospheric, and inverse barometric) and geophysical effects (solid earth tide, ocean tide, pole tide, and sea state bias). The water level is then calculated by subtracting the corrected range from the satellite altitude. In the final time series, the water level at each date is defined to be the mean (or median) of all estimations for that date. Ultimately an iterative outlier rejection algorithm is applied to the output time series in order to identify and remove the outlying measurement.

Virtual altimetry gauging stations help water authorities monitor rivers, lakes, and reservoirs, especially when establishing an actual gauging station is not feasible – e.g. around inaccessible or politically sensitive areas. This will enrich the water monitoring databases, and provide valuable information during hazards – e.g. the mid-March to April 2019 flooding in Iran which destroyed several water gauging stations. Moreover, the altimetry-derived water heights are shown to be effective in hydrologic and hydrodynamic modelling and discharge estimation. Another less emphasized application is the potential in resolving transboundary water disputes – e.g. the conflict between Sudan, Egypt, and Ethiopia over filling of the Grand Ethiopian Renaissance Dam (GERD).

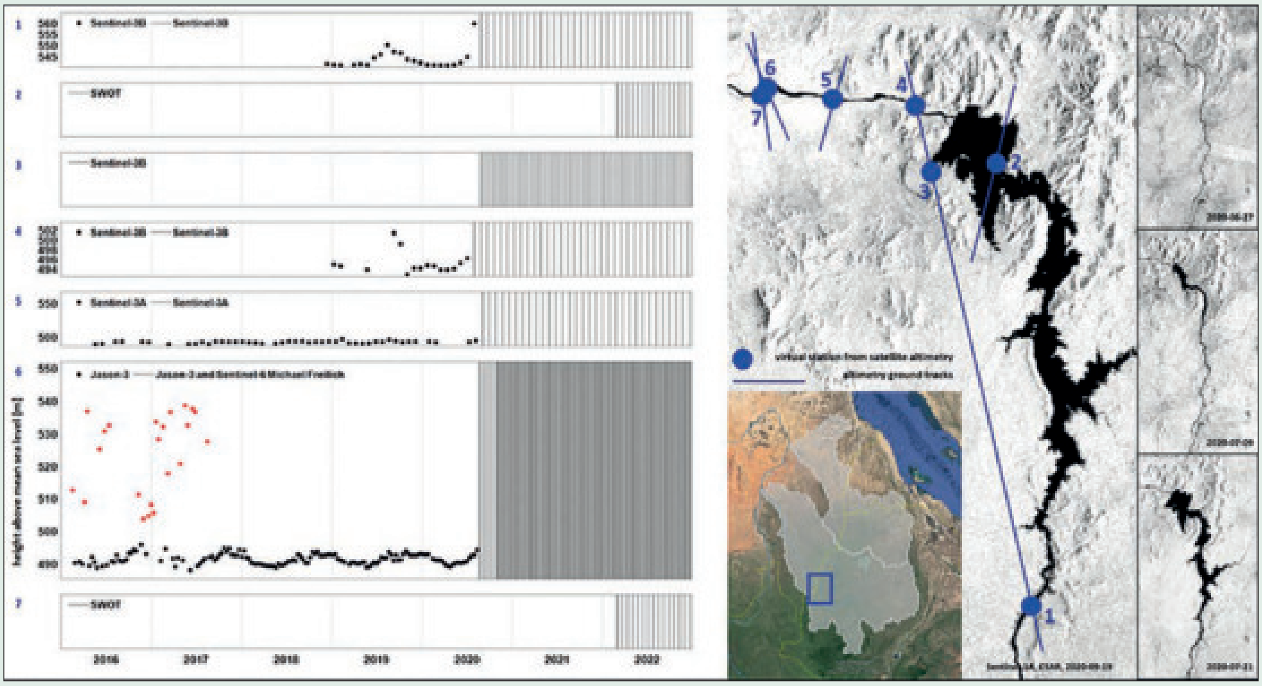


Figure 6: *Monitoring water level variation up- and downstream the Grand Ethiopian Renaissance Dam. Left: Past, present, and future state of altimetry time series at different virtual stations. Right: Distribution of virtual gauging stations upstream and downstream of the dam. Source: Institute of Geodesy, University of Stuttgart.*

Both inland water level time series from satellite altimetry and high-resolution satellite-based precipitation data were used within the project GRoW SaWaM (Seasonal water management in semi-arid regions), which provided evidence that in six drought-prone, semi-arid regions in South America, Africa and Asia, the relative frequency of drought months increased significantly from 10% to 30% between 1981 and 2018. A model system for regionalized improved seasonal forecasts was developed to provide information on water resources and long-term hydrometeorological extreme events at a resolution of 10 km and up to seven months in advance. A model chain that includes hydrology and vegetation dynamics, combined with these remote sensing-derived water-related data, provides additionally retrospective and near-real-time information. This system thereby supports critical drought management and reservoir management decisions.

FURTHER INFORMATION

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BMBF Atlas of Water Innovations:
https://www.innovationsatlas-wasser.de/de/produkte/altimetrie-basierte-wasserstandzeitreihen

All water level time series generated in the frame of the SaWaM research are (will be) available via the **SaWaM online tool:** https://sawam.gaf.de and the data repository maintained by Institute of Geodesy at University of Stuttgart, HydroSat: http://hydrosat.gis.uni-stuttgart.de/php/maps.php?d_content=2&-source=1

HIGH-RESOLUTION SATELLITE-BASED PRECIPITATION DATA IN NEAR REAL-TIME

High-resolution precipitation information in near real time is crucial for water management in semi-arid regions. Second-generation GEO systems are combined with the GPM IMERG precipitation product to generate regional precipitation information in high spatio-temporal resolution.

Precise high-resolution precipitation information in near real time is crucial for sustainable water management in semi-arid regions. This demand, however, contrasts with a decline of in-situ measurement equipment in meteorological networks worldwide. In this context, satellite-based precipitation products provide comprehensive precipitation information to overcome the limitations of the sparse observation network. Here, the created product combines the advantages of the second-generation GEO systems and the new GPM IMERG precipitation product using machine learning algorithms in order to generate regionally adapted precipitation information with a high spatio-temporal resolution.

The algorithm is based on the infrared bands of the GEO satellites. Random forest models were created with microwave-based GPM IMERG precipitation data as a reference in order to (i) delimit the precipitation area and (ii) estimate the rainfall rate. The method was validated with independent, microwave-based GPM IMERG precipitation data that was not used for model training. The validation results show the promising potential of the new satellite-based precipitation estimate. The algorithm was adapted for the GEO systems over the respective research regions in the SaWaM project (Iran, Brazil, Ecuador, Sudan and West Africa) and provides input for hydrological models in the research areas.

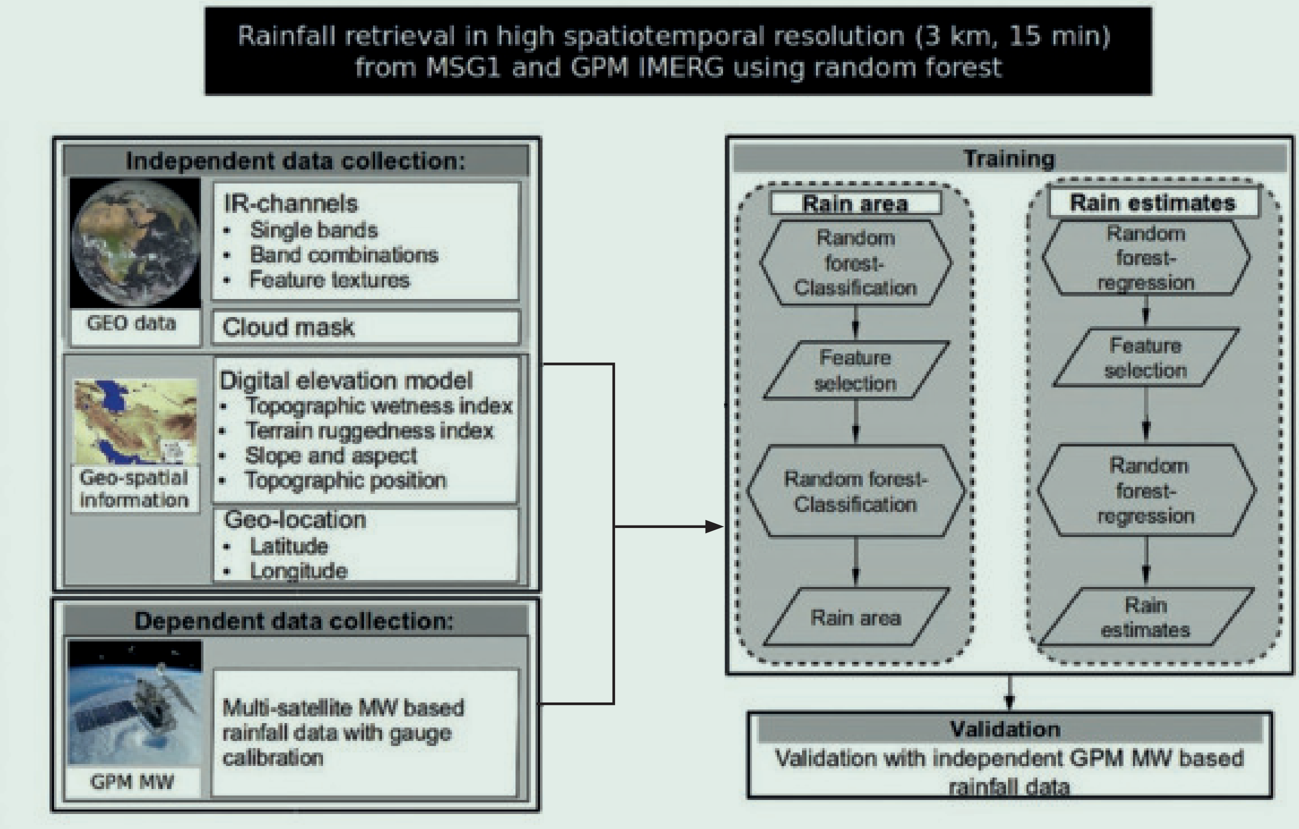

Figure 7: Schematic illustration of the workflow for recording precipitation. Source: Laboratory for Climatology and Remote Sensing, Philipps-Universität Marburg.

The flow chart (Figure 7) shows the data and the workflow of the satellite-based rainfall retrieval. The data include the infrared bands of geostationary satellites, from which band combinations and texture metrics are calculated. Furthermore, a cloud mask, a digital terrain model and geographical longitude and latitude are used as input data for the retrieval. The rainfall rate from the GPM IMERG product is used for model training and validation in the random forest models, for which the data set is divided into a training and an independent validation subset. First, random forest models are created to delimit the rain area. Then random forest models are created to estimate the rain rate. Finally, the results are checked with independent validation data.

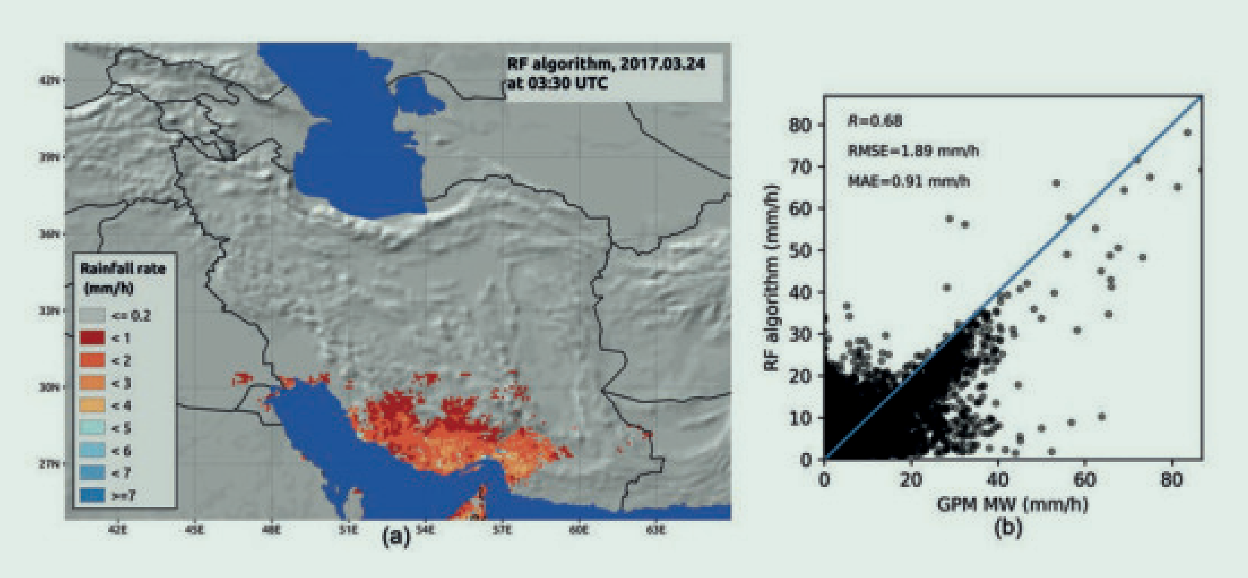

Figure 8: *(a) Example of the satellite-retrieved rain rate for a scene from March 24, 2017 03:00 UTC. (b) Validation results for the developed method for satellite-based rainfall retrieval in Iran for the period February 2017 to February 2018. Source: Laboratory for Climatology and Remote Sensing, Philipps-Universität Marburg.*

Figure 8 (left) shows an example of the results of the developed rain retrieval method for a scene over Iran from March 24, 2017 03:00 UTC. The unit is millimetres per hour. On the right, the results of the retrieval are compared with independent validation data from the GPM IMERG rainfall product over Iran in a scatter plot for the period from February 2017 to February 2018.

FURTHER INFORMATION

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BMBF Atlas of Water Innovations:

https://www.innovationsatlas-wasser.de/de/produkte/hochaufgeloeste-satellitenbasierte-niederschlagsinformationen-in-nahe-echtzeit

WEB-BASED EARTH OBSERVATION ANALYSIS AND GEODATA MANAGEMENT - WEOMERGE

Spatial data, e.g. land use, soil moisture, precipitation, solar radiation and temperature, are essential to addressing many issues. WEOMerge enables the easy digital access and multi-purpose analysis of this data.

Most information systems with spatial reference are limited to the management of geodata and visualisation in interactive maps. In addition, there are various systems that allow access to the free satellite data of the European Commission and other providers, but the user is left to their own devices when it comes to analysing the data.

The geoportal WEOMerge from mundialis is equipped with integrated satellite image processing and combines the best of both worlds: modern geodata management based on the internationally recognised standards of the Open Geospatial Consortium and the downloading of current satellite images and their analysis based on scientifically recognised algorithms. Central data storage and geoprocessing in the cloud enable rapid, decentralised work.

WEOMerge was developed as part of the GRoW project WANDEL (The impact of water availability on a global energy transition). WEO Merge which simplified geodata management and satellite image analysis, making them suitable for practical use in the project. Tried and tested free and open source software components were used to create a customised solution. WANDEL analysed how different decarbonisation strategies affect the direct water demand for electricity generation on a global and regional level. Through a combination of global modelling and case study analyses, the project determined the direct and indirect effects of various energy systems (coal, biomass, solar thermal and hydropower) on water scarcity at the local and regional levels.

FURTHER INFORMATION

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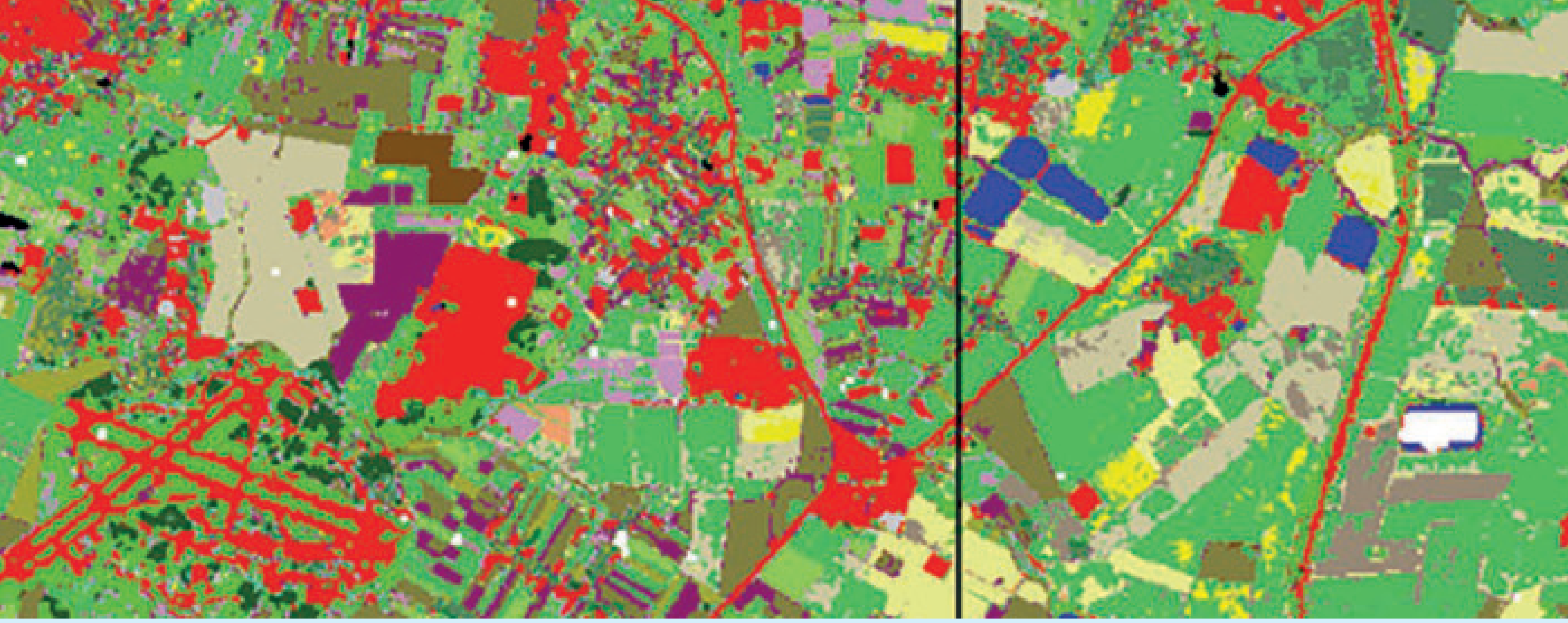
mundialis GmbH & Co. KG, Hinrich Paulsen

BMBF Atlas of Water Innovations:
https://www.innovationsatlas-wasser.de/de/produkte/webbasierte-satellitenbildanalyse-und-geodatenmanagement-weomerge

WEOMerge is accessible here:
https://wandel.mundialis.de



THE GRoW FUNDING MEASURE

With the funding measure "Water as a Global Resource (GRoW)" as part of the framework programme "Research for Sustainable Development (FONA)", the Federal Ministry of Education and Research (BMBF) is contributing to the achievement of SDG 6. GRoW comprises 12 international cooperation projects with 90 partner institutions from Germany and more than 40 case studies worldwide, involving approximately 300 experts from research, policy and practice over more than 3 years.

GRoW is characterised by a close link between local and global action. On the one hand, the projects develop new methods for the improved monitoring and forecasting of global water resources and global water demand. On the other hand, they develop decision support systems and practical solutions for sustainable water resource management at local and regional levels. In order to ensure the long-term implementation of project results, particular attention is paid to social framework conditions and relevant actors are involved in the development at an early stage.

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