GlobWetland: ESA Earth Observation Project Series to Support Ramsar Convention

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Abstract

Achieving the objectives of the Ramsar Convention requires access to global, up-to-date, and reliable information to complete national wetland inventories and to undertake adequate assessment and monitoring, and establish appropriate management and restoration plans. The use of satellite Earth Observations (EO) with innovative geo-spatial analyses has become a key tool and source of information for such purposes. Remote sensing observations acquired over short- to long-time frames by airborne and more particularly by spaceborne missions are increasingly used to support the implementation of the convention by supporting the efficient management of wetlands through the provision of local to global, up-to-date information. These data also enhance the reporting mechanisms of the convention by facilitating better decision-making through the generation of common datasets and information systems, as well as the harmonization of formats, methods, and procedures for gathering and analyzing information. A number of projects are

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aimed at supporting the Ramsar Convention through the characterization, mapping, and monitoring of wetlands at regional to global levels. Among these are the ESA GlobWetlands Project, the Japan Aerospace Exploration Agency's (JAXA) Kyoto and Carbon (K&C) Initiative, and the NASAMeasures program.

Keywords
Earth observation · Assessment · Monitoring · Mapping · GlobWetlands · Kyoto and carbon initiative · NASA measures

Introduction

The Ramsar Convention addresses the importance of developing and intensifying internationally coordinated actions for the conservation and wise use of wetlands. Achieving the main objectives of the Ramsar convention, which is to maintain the ecological character of wetlands and the ecosystem services they provide, requires having access to global, up-to-date and reliable information to complete national inventories and the ability to perform adequate monitoring activities, carry out assessments and put appropriate management and restoration plans in practice. In recent years, the use of satellite earth observations (EO) with innovative geo-spatial analyses has turned out to be a key tool and unique source of information for the Ramsar Convention (Mackay et al. 2009).

Remote sensing observations acquired over short to long-time frames by airborne and more particularly by spaceborne missions are increasingly used to support the implementation of the Convention by:

- Increasing scientific knowledge and understanding of the physical, biological and chemical components of wetlands (e.g., soil, water, plants and nutrients) and the interactions between these, as well as the changing role of wetlands in the global environment.
- Supporting the efficient management of wetland areas, through provision of local to global, up-to-date and useful information that allows more efficient inventory, assessment and monitoring of wetland sites and catchments, and the development and implementation of restoration or rehabilitation plans.
- Enhancing reporting mechanisms of the Convention, strengthening the ability of the contracting parties to monitor efficiently treaty-relevant behavior, and facilitating better decision-making through the generation of common datasets and information systems, and through harmonization of formats, methods and procedures for gathering and analyzing information.

A number of projects are aimed at supporting the Ramsar Convention through characterization, mapping and monitoring of wetlands at regional to global levels. Amongst these are the ESA GlobWetlands Project, the Japanese Space Exploration Agency (JAXA) Kyoto and Carbon (K&C) Initiative and the NASA Measures program.

Table 1 EO technologies tested during the GlobWetland project

	GlobWetland I (2003–08)	GlobWetland II (2009–13)
Land use/land cover	Development & demonstration	Pre-operational deployment
Change detection	Development & demonstration	Pre-operational deployment
Water cycle regime	Development & demonstration	Pre-operational deployment
Wetland identification and delineation	Feasibility study	Demonstration
Water quality	Feasibility study	Not covered

The ESA GlobWetland Projects

The European Space Agency's (ESA) GlobWetland projects (Fernandez-Prieto et al. 2006; Jones et al. 2009) were designed to demonstrate, across large areas, the unique capabilities offered by EO assets to wetland mapping and monitoring. The GlobWetland projects aimed to facilitate the use of EO technologies by all communities engaged in wetlands conservation, restoration and management in support of the Ramsar Convention. During the GlobWetland projects, different EO applications were studied, from feasibility assessments to research and demonstration and up to pre-operational deployment (Table 1).

GlobWetland I (2003–2008) was launched in collaboration with the Ramsar Secretariat and was aimed at developing and demonstrating products and services based on remote sensing data that could be used to support wetland managers and national authorities in responding to the requirements of the Ramsar Convention and allowing more efficient monitoring of wetlands globally. This initial project involved 52 different wetlands that were distributed in 21 countries worldwide and relied on the direct collaboration of several local, national and regional conservation authorities and wetland managers.

The core products represented the basic set of common geo-information needed for all wetlands and included information on land use and land cover, long-term change analysis and mapping of the water cycle regime. A number of site-specific products were also generated in response to precise requests to better monitor and assess different conditions at the local scale, including water quality parameters (e.g., turbidity, suspended sediments and chlorophyll concentration), coastal wetlands dynamics (erosion and sedimentation), and topography for the delineation of wetlands and catchment areas and location of points of discharge. The GlobWetland I project organized the "GlobWetland Symposium: Looking at wetlands from space" in Frascati, Italy, in 2006, to stimulate discussions between the remote sensing and the wetland communities, review the current and emerging earth observation developments relevant for the inventory, assessment and monitoring of wetlands, and

identify key scientific technical and policy-relevant challenges that remained at local to global levels.

Building on the findings of the GlobWetland I project and on the recommendations from the GlobWetland symposium, GlobWetland II (2009–2013; Paganini et al. 2010) aimed to further demonstrate the operational capacity of Earth Observation and geo-information technologies to provide wetland practitioners with effective decision support tools for wetland management and conservation activities. The overarching objective was to contribute to the establishment of a Global Wetlands Observing System (GWOS) in accordance with the Ramsar Strategic Plan and represented a pilot effort by the Ramsar Convention to put in place a regional observation system over the Mediterranean Basin in partnership with the MedWet initiative, the Mediterranean Wetlands Observatory (MWO) and ten countries from the Southern Mediterranean Basin (from Morocco to Jordan). The majority of wetlands were coastal and distributed equally along the southern Mediterranean coast. Time-series of Landsat MSS, TM and ETM+ data were used to produce the base geospatial products for three points in time (1975, 1990 and 2005), and then to derive wetland indicators. The project also developed the GlobWetland toolbox for end-to-end processing of satellite images, and installed the software toolbox at the premises of all partner organisations, with adequate training and capacity building.

The first objective of the GlobWetland II mapping activities was to build on the knowledge gained through its predecessor and produce 1,800 thematic maps, at 1:50,000 to 1:100,000 scale, of land use and land cover (including wetland typologies), change detection (for long term trend analysis) and water cycle regimes (including the estimation of annual variations in water tables) for a total of 200 wetlands.

The Land Use/Land Cover (LULC) maps (Fig. 1) provided a detailed classification of all land parcels within the area of interest, which typically included the wetland site, and the surrounding areas. The Corine Land Cover system (EC 1993) was used for classification, although was adapted to incorporate the Ramsar wetlands classification system. The thematic information provided followed a 5 level nomenclature, with the first distinguishing between water, natural areas and artificial surfaces and the most detailed levels include wetland typologies defined by the Ramsar Convention. Maps were georeferenced to the corresponding national systems and overall thematic accuracies ranged typically from 85% to 95%.

The Change Detection (CD) maps (Fig. 2) provided a historical comparison of land use and cover in the wetland site and its surroundings between two reference dates, thereby providing a synoptic view of the main changes occurring in the catchment areas, whether natural or anthropogenic. From these maps, the evolution of many wetlands could be observed and threats affecting the wetlands and their impacts over time could also be assessed.

The Water Cycle Regime (WCR) maps (Fig. 3) provided an overview of the annual variations of water extent (minimum and maximum) and differentiated permanent and seasonally inundated water bodies and associated vegetation. The

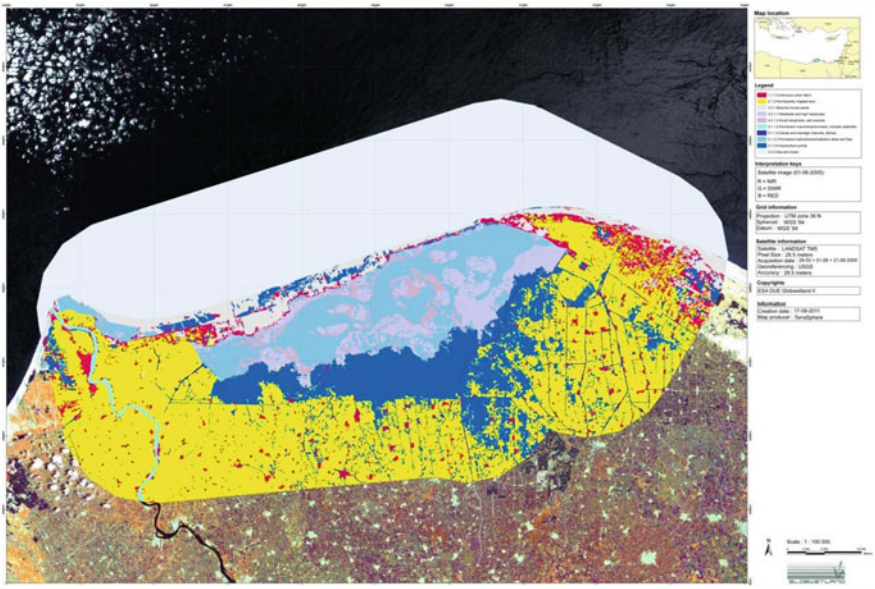

Fig. 1 Land Use Land Cover, Lake Burullus, Egypt, 2005. GlobWetland II project

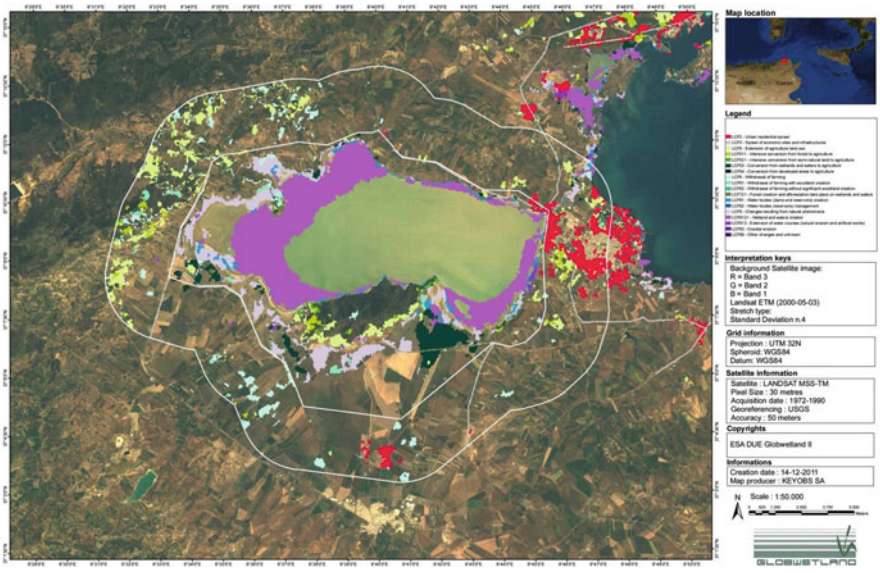

Fig. 2 Land cover evolution, Lake Ichkheul, Tunisia, 1972–90, GlobWetland II project (Source of information: Landsat TM/ETM, USGS)

Fig. 3 Water cycle regimes (WCR), Merja Zerga, Morocco, 2005, GlobWetland II project (Source of information: Landsat TM/ETM, USGS)

WCR maps provided wetland managers with a unique capacity to monitor and characterize the dynamics of water retention and flow and how these affected the overall ecosystems.

The base maps of LULC, CD and WCR were then further elaborated with geospatial information technologies to derive indicators on wetland status and trends. This served the needs of the Ramsar Convention and of the Mediterranean Wetlands Observatory, in that they provided, for the 200 sites studied, four GlobWetland Indicators relating to the status and trends in wetland ecosystem extent, in wetland threats and in water quantity and extent with these being:

- Changes in wetland area (% wetland loss or gain between two epochs);
- Area of wetland ecosystem inundated (% of seasonally and permanently flooded area);
- Causes of wetland changes (areas lost to agriculture or urban/artificial surfaces between two epochs);
- Status and trends of wetland threats.

These indicators were generated for each wetland site and for each point in time, and also aggregated at an administrative level to derive maps for individual countries and regions.

In addition to the above core products (LULC, CD and WCR), the GlobWetland projects have experimented with EO techniques with promising applications that still need some further developments in order to become operational:

- Maps of wetland ecosystem extent to identify and delineate wetlands as a support to wetland inventories. Such a product serves the needs of national agencies interested in exploring the options to reduce costs associated with large wetland inventory exercises. The production of such maps requires long and dense time series of satellite images to cope with the high spatial and temporal variability;
- Maps of water quality indicators (chlorophyll concentration, total suspended matters, yellow matters). The extraction of water quality parameters in inland waters is still a complex process in particular for shallow waters where the bio-optical properties of the water constituents are contaminated by the reflection of the bottom of the water body. In spite of the still experimental stage of the retrieval methods available, EO satellites can provide today and under certain conditions, accurate information on water quality (Fig. 4).

The GlobWetland Toolbox

To assist the wetland community at large with the processing of satellite images, GlobWetland II developed an easy to use and cost effective toolkit for end-to-end processing of satellite images (Fig. 5), including pre-processing, segmentation and classification, computation of wetland indicators and a Web-GIS system for map distribution (Fig. 6). The toolkit was installed within each of the different organisations of the ten participating countries and user handbooks, targeted training and capacity building, and technical assistance were provided by the project team. These toolboxes have subsequently been integrated within the geographical information systems (GIS) of the national bodies. The Mediterranean Wetlands Observatory decided to continue the mapping undertaken within GlobWetland II and used the GlobWetland Toolbox to produce wetland maps and indicators over the remaining 17 Mediterranean countries of the MedWet initiative, with the objective to publish, in 2014, a special report on the status and trends of wetlands in the Mediterranean basin.

The JAXA K&C Initiative

The Kyoto and Carbon ("K&C") Initiative (Lowry et al. 2009) is a project led by the Japan Aerospace Exploration Agency (JAXA) and supported by an international Science Team consisting of approximately 25 research groups from some 14 countries. The project builds on the experience gained from the JERS-1 Global Rainforest and Boreal Forest Mapping (GRFM/GBFM) projects, which demonstrated the utility

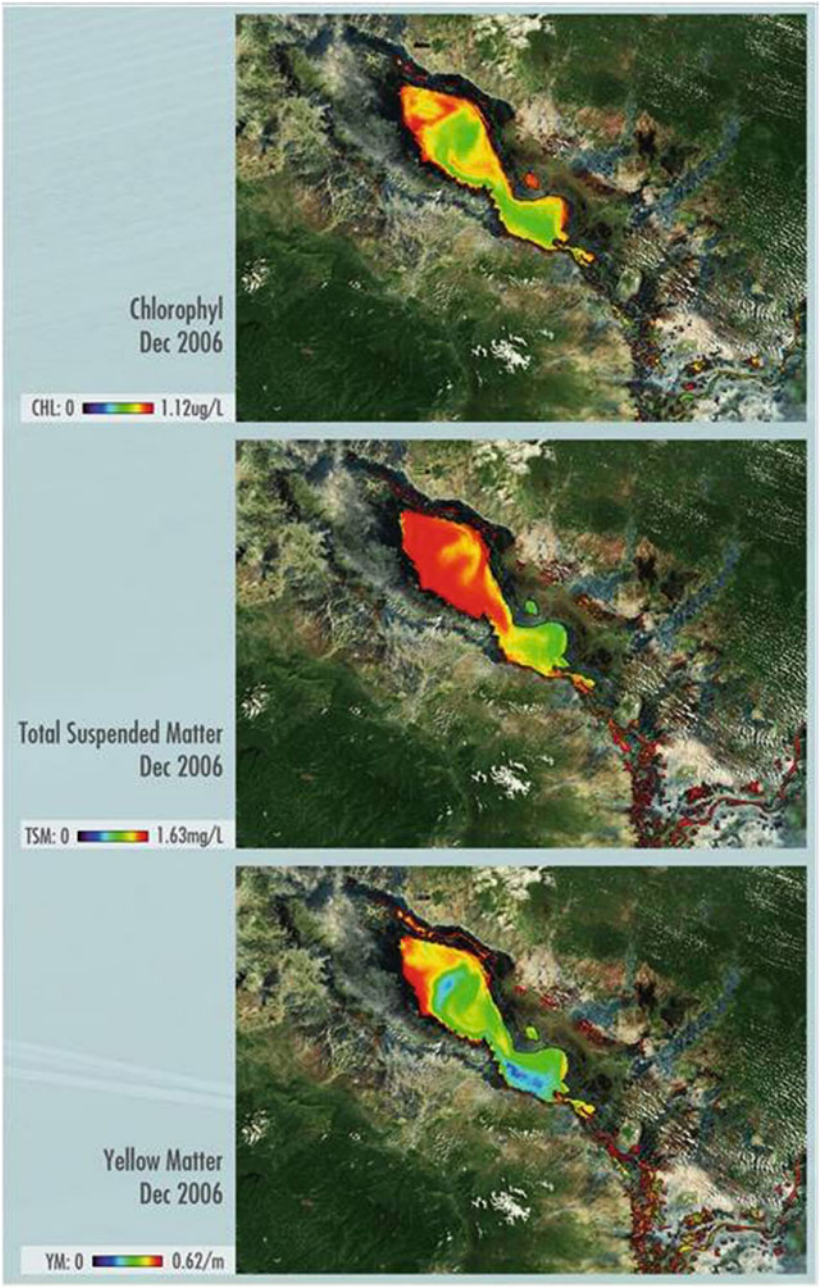

Fig. 4 Water quality parameters (*Chlorophyll concentration, Total Suspended Matters, Yellow matters*) Mekong River Basin, 2006, GlobWetland I project (Source of information: ENVISAT MERIS, ESA)

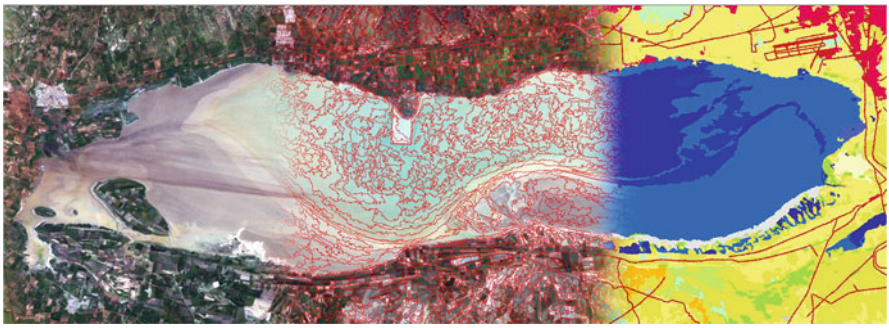

Fig. 5 End to end processing from satellite image geometric and radiometric corrections, to image segmentation and land cover classification, as undertaken within the GlobWetland II project

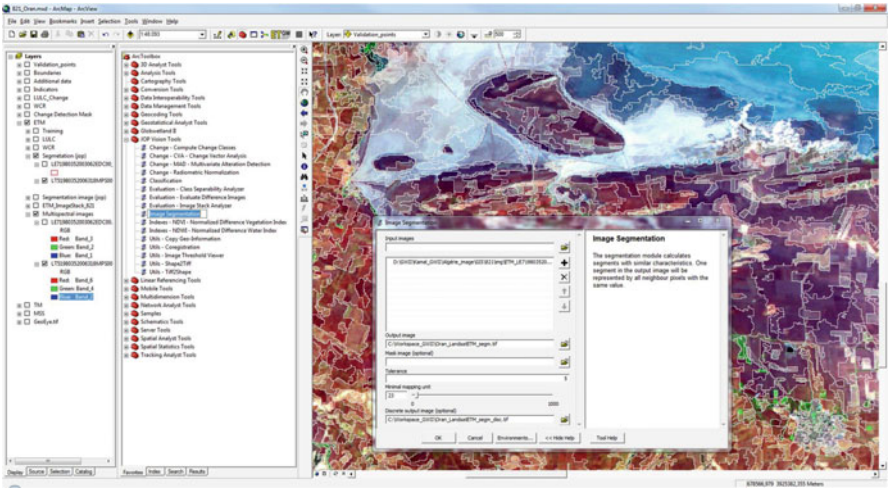

Fig. 6 Snapshot of the GlobWetland II toolbox

of L-band SAR data for mapping and monitoring forest and wetland areas, as well as the importance of providing spatially and temporally consistent satellite acquisitions for regional scale monitoring and surveillance.

The objective of the initiative is to develop regional scale applications and thematic products, derived primarily from data acquired by the Phased Array L-band Synthetic Aperture Radar (PALSAR) instrument on board the Advance Land Observing Satellite (ALOS) satellite, that support the data and information needs raised by international environmental conventions (such as the Ramsar Convention on Wetlands of International Importance), carbon cycle science, and conservation of the environment. The initiative is undertaken within the context of three themes which relate to global biomes: forest, desert and wetlands. Within the

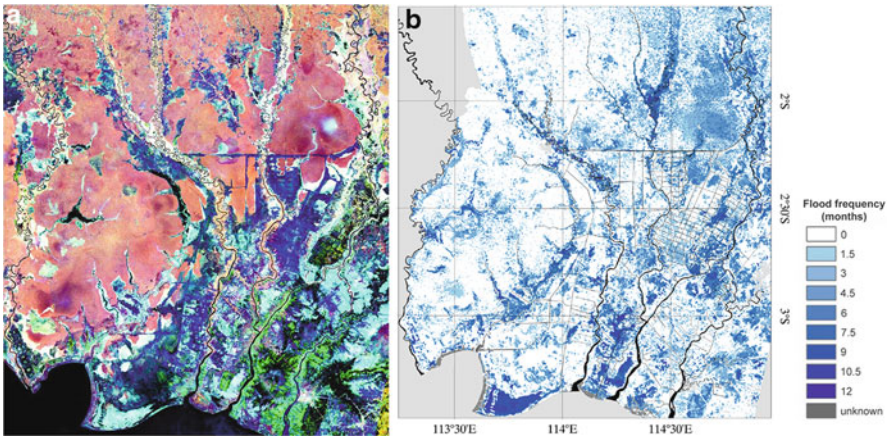

Fig. 7 (**a**) 2007 ALOS PALSAR colour composite image of South Kalimantan, Indonesia, where major conversion of peat swamp forest to rice cultivation is occurring. Canals built to drain water from the swamps are visible as *blue* linear features. (**b**) Map derived from PALSAR ScanSAR time-series showing flooding frequency in 2007 (Hoekman et al. 2010. © JAXA METI)

wetlands theme, the key products that have been identified and are generated from the PALSAR data aim to support global wetland inventory and change analysis. Key outcomes from the K&C Initiative have included mapping of wetlands and flood levels in Indonesia (Fig. 7a, b), with these supporting sustainable peatland management strategies. Flood dynamics have also been quantified in the Pantanal with the resulting maps used to define strategic areas that should be protected for wildlife and help answer questions about how changes in climate and human activities over time affect the biodiversity and people who are dependent upon the wetlands. In Africa, multi-temporal L-band Synthetic Aperture Radar (SAR) datasets have been combined with Landsat Thematic Mapper (TM) and ASTER images, digital elevation models, and vegetation species data to provide information on wetland ecology and hydrology (Fig. 8; Rebelo 2010). The Global Mangrove Watch (GMW) has also been developed with this aimed at monitoring the changing extent of mangroves globally using combinations of JERS-1 SAR, ALOS PALSAR and ALOS-2 PALSAR-2. The K&C research phases leading to the GMW have focused specifically on establishing methods for revising baselines of mangrove extent for the mid 1990s, 2007, 2008, 2009 and 2010 based on JERS-1 SAR and ALOS PALSAR data respectively. Following observation by the ALOS-2 PALSAR-2, revised baselines of mangrove extent are being generated for 2015 and 2016.

The NASA Measures Project

A component of the NASA Measures project is to construct an Inundated Wetlands Earth System Data Record (IW-ESDR). This involves the use of SAR for continental scale mapping of wetland extent, seasonal inundation dynamics and vegetation

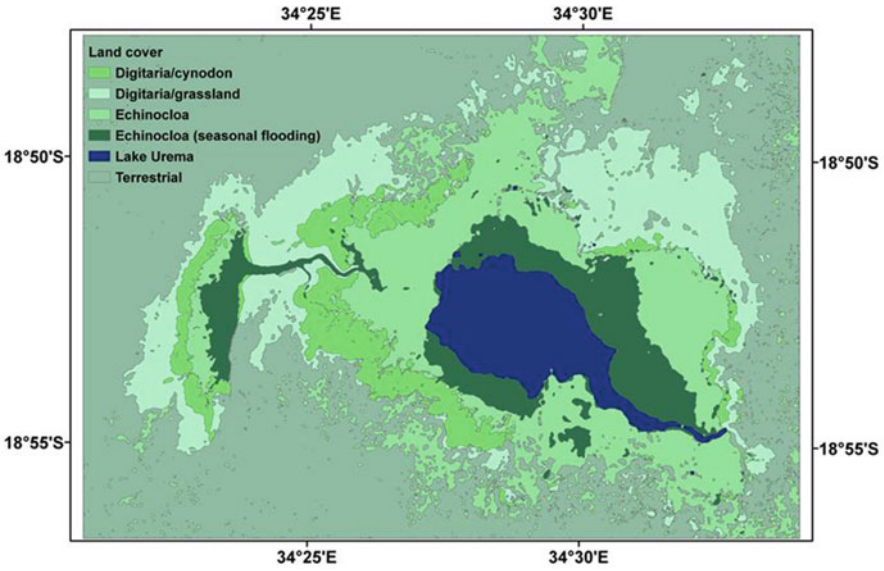

Fig. 8 Dominant vegetation types and flooding regime, Lake Urema, Mozambique, derived from multi-temporal ALOS PALSAR data (© JAXA METI)

(100 m spatial resolution) and multiple satellite observations to generate global monthly maps of inundation extent at ~25 m resolution. The intention is to generate the first global scale dataset of wetland inundation and vegetation, within this then providing a new understanding of how wetlands are functioning at regional to global scales. Such information can be used to quantify, for example, greenhouse gas emissions (primarily methane and CO_2), climate feedbacks and water exchanges.

Conclusion

A number of key projects, including those outlined above, have led to significant advances in the observation, characterization, mapping and monitoring of wetlands. Within these projects, a wide range of remote sensing data have been used over varying time frames, with these ranging from very high resolution (VHR) optical data for localized studies to SAR data acquired consistently and over large regions.

The GlobWetland projects fulfilled their objectives of facilitating the integration of EO data and analysis techniques into the conservation and management of wetlands, serving the needs of wetland conservation practitioners from wetland site managers to stakeholders of the Ramsar Convention. The projects have also led to the use of these data being considered essential tools for the inventory, mapping and monitoring of wetland ecosystems worldwide. As such, the GlobWetland projects have highlighted the cost effectiveness and efficiency of EO

data for fulfilling the requirements of the Ramsar Convention, in prioritizing management measures and in policy making, reporting and planning. Indeed, the Scientific and Technical Review Panel (STRP) of the Ramsar Convention has strongly recommended the use of these data at all scales.

Whilst a number of the methods developed for mapping land use and cover, detecting change and quantifying water cycle regimes are sufficiently mature for uptake by the wetland community at large, further development is needed for the production of water quality parameters or wetlands inventory. This is likely to be fulfilled through the third GlobWetland project, GlobWetland Africa (2014–2017), which has the principal objective of addressing wetland conservation and management from a water basin perspective with a focus on the African continent and the use of satellite data from the Sentinel constellations of the Copernicus initiative.

The JAXA K&C Initiative provided L-band SAR data at a regional level, which could be used to support characterization, mapping and monitoring of a range of wetland types, including peat swamps and mangroves. With the launch of the ALOS-2 PALSAR, considerable scope exists for ongoing observations of wetlands at a global scale. Such data can also be used to support the objectives of the NASA IW-ESDR, which is advancing the integration of remote sensing data from a diversity of sources.

The Sentinel 1 and Sentinel 2 satellite missions of the European Copernicus initiative will also provide long-term access to enhanced radar observations and high resolution super-spectral data opening a new scenario for mapping, assessment and monitoring of wetlands worldwide. The C-band imaging radar of the Sentinel 1 mission is providing all-weather day-and-night imagery which will be extremely useful for monitoring wetlands in cloudy conditions. The Sentinel-2 mission will provide systematic optical observations of all terrestrial and coastal zones, at 10 m spatial resolution, with a swath width of 290 km. Together with its twin satellite, it will cover the Earth's surface with a repeat cycle of 5 days at the equator. The impressive footprint of Sentinel 2 along with the short revisit time and its systematic acquisition policy will allows rapid changes in ecosystems to be precisely monitored and is ideally suited to monitor sensitive habitats such as wetlands. It will allow for seasonal and permanent changes in wetlands to be monitored with higher accuracy. The Copernicus Sentinel data policy, with its full and open access for all users worldwide, is an important initiative that will largely facilitate the uptake of these new technologies by the wetland community.

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