The Portuguese Land Cover Monitoring System (SMOS): from research and development (R&D) to operations

El Sistema de Monitoreo de Cobertura del Suelo de Portugal (SMOS): de la investigación y el desarrollo (I+D) a las operaciones

Hugo Costa, Pedro Benevides, Mário Caetano

REVISTA **MAPPING**
Vol.32, 210, 44-51
2023
ISSN: 1131-9100

Abstract

The Portuguese Land Cover Monitoring System SMOS (Sistema de Monitorização da Ocupação do Solo) is an initiative conceived and developed by Direção-Geral do Território (DGT) with the aim of continuously produce reference and thematic cartographic products on land use land cover for continental Portugal. SMOS is a collaborative and multifunctional system that involves the Public Administration, the national scientific and technological system, the private sector and the citizen, guided by user needs and open data policy. SMOS represents a paradigm shift in cartography production and uses the latest developments in space technologies and Artificial Intelligence to create maps with more detail, quality and promptness. Here, SMOS is presented, including the initial steps leading to the implementation of the system, its organization and governance, cartographic products and viewers, and foreseen developments.

Resumen

El Sistema de Monitoreo de Cobertura del Suelo de Portugal SMOS (Sistema de Monitorização da Ocupação do Solo) es una iniciativa concebida y desarrollada por la Direção-Geral do Território (DGT) con el objetivo de producir continuamente información cartográfica básica y temática sobre el uso y la cobertura del suelo para Portugal. SMOS es un sistema colaborativo y multifuncional con la intervención de la Administración Pública, el sistema científico y tecnológico nacional, el sector privado y el ciudadano, orientado por las necesidades del usuario y por una política de datos abiertos. SMOS representa un cambio de paradigma en la producción de cartografía y utiliza los últimos avances en tecnologías espaciales e Inteligencia Artificial para crear mapas con más detalle, calidad y velocidad. En este artículo se presenta SMOS, describiendo los pasos iniciales que permitieron la implementación del sistema, su organización y gobernanza, productos cartográficos y visualizadores de mapas, y desarrollos previstos para el futuro.

Keywords: *Satellite, Sentinel, Land cover, Land use, VGI, Design thinking*

Palabras clave: Satélite, Sentinel, Cobertura del suelo, Uso de la tierra, VGI, Pensamiento de diseño

Hugo Costa. Direção-Geral do Território
hcosta@dgterritorio.pt
Pedro Benevides. Direção-Geral do Território .
pbenevides@dgterritorio.pt
Mário Caetano. Direção-Geral do Território.
mario.caetano@dgterritorio.pt

DOI: https://doi.org/10.59192/mapping.387

Recepción 19/12/2022
Aprobación 23/01/2023

1. INTRODUCTION

Monitoring the status and change of land use land cover (LULC) is fundamental for a wide range of applications and the importance of LULC has crossed borders, spanning science, policy and business (Chaves et al., 2020). Therefore, the demand for reliable and updated information on LULC has grown and countries need to find the means to produce and disseminate LULC information regularly for a variety of end-users.

In Portugal, the National Mapping Agency, Direção-Geral do Território (DGT), produces and publishes since the 1990s a LULC map for the continental territory widely known as COS (Carta de Uso e Ocupação do Solo). This map is used for numerous purposes, such as landscape planning, decision-making, reporting obligations, research, education, and business, and its importance is widely recognized.

However, the technical specifications of COS unfits the needs of some users. COS has been produced through photo-interpretation of orthophotos and manual delimitation of polygons with a minimum mapping unit of 1 ha, considered too coarse for very detailed applications. Map updating occurs every 3-5 years and typically takes more than one year in production, making COS easily outdated. The map is mainly focused on land use, which is advantageous for long-term analysis such as landscape planning, but some aspects more related to land cover are omitted. For instance, forestry practices such as clear-cuts are not represented in COS because land use remains forest, although land cover changes temporarily. Moreover, COS is not suitable for users interested in seasonal variations such as vegetation greenness and yearly cycles associated to some classes such as annual agriculture.

The limitations of COS have been known for a long time, but some constraints such as costs associated to data acquisition hampered improvements to be put in place. The situation changed after witnessing key milestones in the field of Earth Observation, namely the launch of the Sentinel satellites of the Copernicus programme. This European programme led by the European Commission (EC) provides with an open policy high-resolution and multispectral data acquired every few days, making possible to observe the surface several times per month. This has triggered new science and applications worldwide (Phiri et al., 2020), including the development of new LULC products for Europe in the framework of Copernicus, such as High Resolution Layers (HRL) and the new generation of CORINE Land Cover (Probeck et al., 2021).

The benefits brought by recent and forthcoming LULC European products are evident, such as improved spatial resolution, thematic details and updating frequency for the whole Europe. However, at the national scales, European products, including the ones from Copernicus Land Monitoring Service, are seen as insufficient for particular applications. For example in Portugal, there is the need to harmonize the information produced by DGT and other institutions with regard to specific details with impact on the technical specifications of the cartography, which an European initiative cannot address.

Therefore, DGT started exploring the possibility of monitoring land cover of continental Portugal from space within an operational framework and able to accommodate the needs of a wide range of national users. The goal was to generate cartographic products and valuable information to assist decision-making at political and technical levels in a variety of domains, including forest, agriculture, water resources, nature conservation, wildfires management, landscape planning, urbanism, soil sealing, and cadaster. The favourable circumstances of data availability offered by the Copernicus programme and the DGT's experience in image classification made it possible to build the Portuguese land cover monitoring system SMOS (Sistema de Monitorização da Ocupação do Solo). This paper presents SMOS, including the initial steps leading to the implementation of the system, its organization and governance, cartographic products and viewers, and foreseen developments.

2. SETTING THE SYSTEM

SMOS relies upon years of experience in research and development (R&D) projects carried out at DGT related to land cover mapping and automatic image classification. Such experience was typically more academic than operational, but the availability of Sentinel data changed the situation. From 2019 onwards, DGT initiated the path leading to SMOS, here described in three stages.

Stage I – Proof of concept. Preliminary land cover maps produced from Sentinel-2 data were developed within R&D funded projects in partnership with several universities. The projects, generally dedicated to prevention of wildfires and firefighting, demonstrated the usefulness of the new maps in several ways such as for decision-making and fire spreading modelling. The idea of building SMOS gained strength and was shared with potential users in a series of events,

Figure 1. Key features of SMOS

including meetings and workshops, to show the R&D outcomes and discuss their potential interest. The ideas and preliminary maps were well received and DGT decided to move from R&D to operations.

Stage II – Development and implementation. SMOS began to take shape after funds were granted in the framework of Compete2020 (POCI-05-5762-FSE-000368), supported by the European Social Fund. Funding enabled DGT to undertake a series of initiatives based on design thinking to receive and process different opinions and needs from a variety of stakeholders. Dozens of national experts on land cover, and representatives of public and private organizations were involved in interviews and group sessions led by design thinking experts of NOVA Information Management School (NOVA IMS) to discuss the future system. Many ideas were generated and translated into the conceptual model of SMOS, its governance and cartographic products. Moreover, investments on the technological infrastructure of DGT reinforced its capacity to store and process large volumes of data, mostly satellite imagery. New land cover products were defined and produced, and on the 29th September 2022, SMOS was launched to the public, starting its operational functioning.

Stage III – Evolution and expansion. SMOS was born according to the outcomes of stages I and II, but DGT intends to keep the system open to the society and adapt it according to the feedback of the users and the progress of science and technology. This stage, in progress as of October 2022, is funded by the Portuguese Recovery and Resilience Plan (Investment RE-C08-i02.01) and several improvements are under consideration and development for the following years, such as acquiring and exploiting Light Detection And Ranging (LiDAR) data and releasing new cartographic products.

3. KEY FEATURES

SMOS can be described briefly by highlighting eight key features about the data used and the methods applied, the information produced and the way it is released, the internal organization of SMOS and how it interacts with the community, and the benefits gained (Figure 1).

4. ORGANIZATION AND GOVERNANCE

SMOS is a collaborative information system, coordinated and managed by DGT with the participation of entities of the central and local public administrations, national scientific and technological system, private sector and citizens, and it is oriented to the needs and interests of the different groups of users. Figure 2 presents SMOS in four main blocks that summarize the organization of the system.

SMOS is governed in partnership with other entities according to a governance model that includes the following bodies:

Figure 2. Organization of SMOS

- DGT – the entity responsible for coordinating the system, operating and managing the technological infrastructure and producing and releasing of cartographic products.
- Technical-Scientific Council – experts and technicians from the public administration and researchers from academia with the objective of collaborating in the strategic orientation of the system;
- SMOS Users Group (guSMOS) – representatives of central and local public administration entities, educational institutions, professional organizations and civil society, with the objective of promoting strategic alignment between public entities, dialogue between sectors and the strengthening of territorial culture.

SMOS also stablishes connections with other independent bodies already in place that act on matters related to the scope of SMOS, namely CNT (National Commission for Territory), FI PNPOT (Intersectoral Forum of the National Spatial Planning Policy Program1me), SGIFR (Integrated Wildland Fire Management System), CCC (National Cartography Coordination Committee), CO-SNIG (Committee for the strategic coordination of the Portuguese National Spatial Data Infrastructure), and GT SNIG Local (Working Group of CO-SNIG for the articulation of SNIG with the Local Public Administration).

A website hosted at smos.dgterritorio.gov.pt is the main interface between the system and the public, ensuring the interaction with the National

Cartography Database (BDNC) and the Portuguese National Spatial Data Infrastructure (SNIG) (Patrício et al., 2022b, 2022a) for accessing, viewing and downloading geographic data and cartographic products. Such products are based on R&D performed at DGT and in partnership with the national scientific and technological system to take advantage of the most recent advances in science and technology to develop cartographic products suitable for the users. The website concentrates all the information on the system, its products and a set of interactive cartographic viewers aimed at communicating with different user profiles.

5. CARTOGRAPHIC PRODUCTS

A variety of cartographic products composes the portfolio of SMOS. The products differ among them in terms of objectives and technical specifications, and are organized in three families, namely i) reference cartography, ii) LULC cartography, and iii) specific cartographic products.

Reference cartography includes traditional cartography such as image format cartography and topographic maps. They are valuable per se, although often are used as input data in the production of other types of cartography, such as thematic maps. The operational stage of SMOS started with two products included in this family, orthophotomaps and Sentinel-2 mosaics, produced from orthorectified imagery, either airborne or spaceborne imagery respectively (Figure 3).

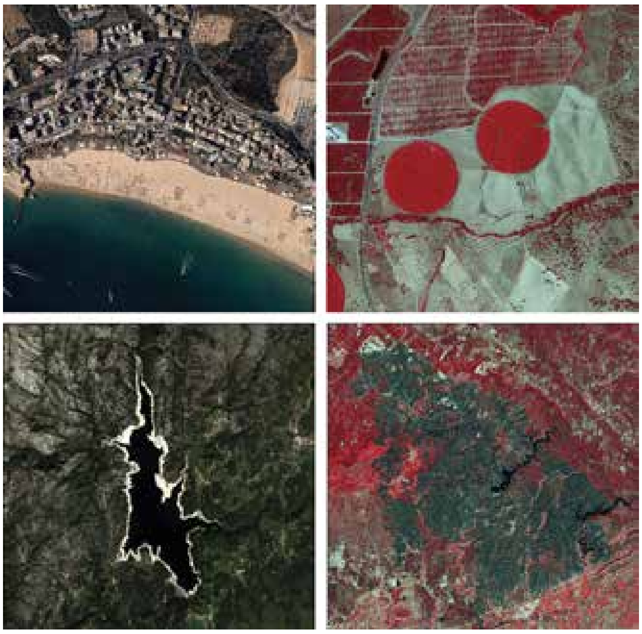

Figure 3. Image format cartography, namely multiannual orthophotomaps (top) and monthly Sentinel-2 mosaics (bottom) in true colour (left) and false colour (right)

LULC cartography includes two products. The first product is COS, the LULC cartography produced since the

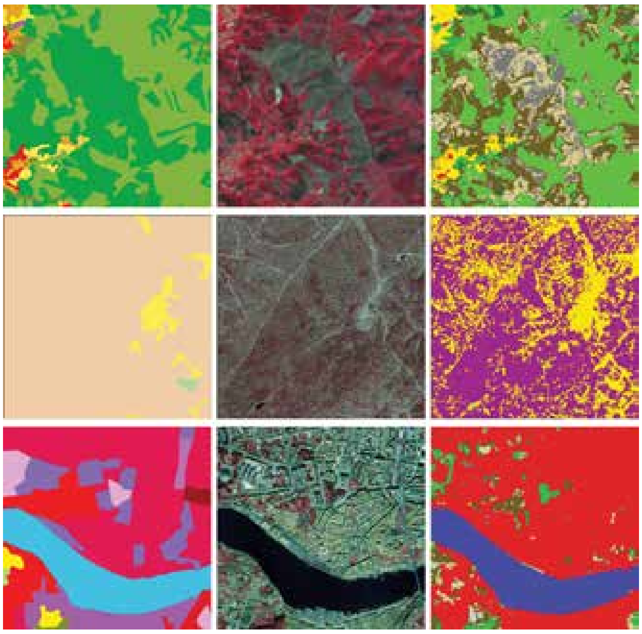

Figure 4. Some differences between COS (left) and COSc (right), with orthophotos in false colour (centre) to facilitate comparison. In forest (top), COS is mainly greenish as it represents forest use, even if land is temporarily treeless due to wildfires and clear-cuts, while COSc (less greenish then COS) reveals land covered by low vegetation. In agro-forestry (middle) represented in COS (beige), COSc is able to discriminate the spatial components of the landscape, namely trees (purple) and agriculture between trees (yellow). In urban areas (bottom), COS identifies several uses, such as residential and commercial (different tones of red), while COSc represents artificial land only.

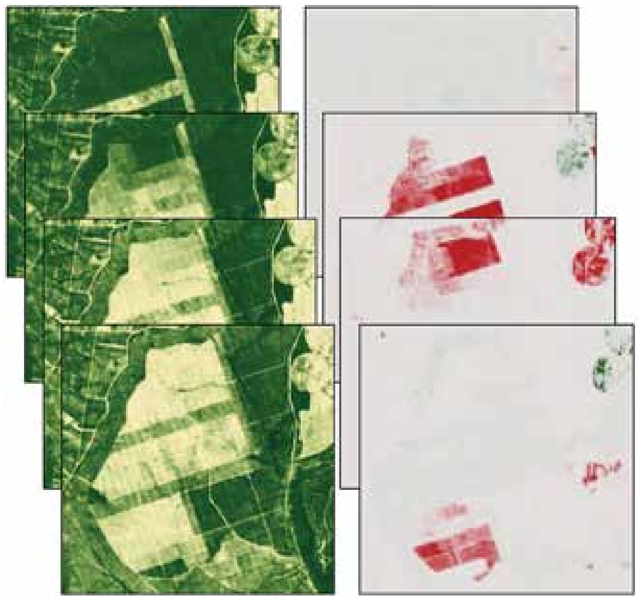

Figure 5. Some examples of MIAEV, namely VV (left) and DMVV (right) from January (top) to April (bottom) 2020

Figure 6. Annual crops represented in MACAT (coloured randomly). Sentinel-2 image shown is the background to provide context

1990s and now included in SMOS. The second product is COSc (Carta de Ocupação do Solo Conjuntural), an annual land cover map in raster format based on automatic classification of Sentinel-2 data with Artificial Intelligence. COS and COSc provide complementary information and can be used together or independently. COS is more focused on land use whereas COSc focuses on land cover, and both represent different spatial and thematic detail (Figure 4).

The third family gathers specific cartographic products developed to attend specific needs of some users. These products are developed for specific applications and some may be released as experimental products strongly related to R&D activities yet immature. The operational stage of SMOS started with four specific cartographic products. The first, MIAEV (Mapas Intra-Anuais do Estado da Vegetação), are raster maps produced every month from the Normalized Difference Vegetation Index (NDVI) to represent the vegetation greenness. There are three MIAEV, namely VV (Verdura da Vegetação), PHVV (Percentil Homólogo da Verdura da Vegetação), and DMVV (Diferença Mensal da Verdura da Vegetação). VV represents the vegetation greenness, PHVV compares the current vegetation greenness to that of the same month in previous years, and DMVV compares the vegetation greenness between the current and previous month (Figure 5).

The second product, MACAT (Mapa Anual de Culturas Agrícolas Temporárias), is a raster map identifying various annual crops, such as corn and wheat, in the agricultural areas of COS (Figure 6).

The remaining products take into account the built-up areas and how they relate to vegetation. CAE *(Carta de*

Figure 7. CAE (top) delimits the built-up areas and classifies them in three classes according to the present and type of buildings enclosed, while CIAE (bottom) classifies the interface between the built-up areas of CAE and the surroundings according to the proximity of vegetation; the differences between the structural CIAE (left) and conjunctural CIAE (right) are due to different methodologies and input data (COS and COSc respectively). Orthophotos in true colour shown is the background to provide context

Figure 8. Viewers of SMOS

Áreas Edificadas) is a vectorial map and delimits the areas with buildings, either residential or not. This product is used as input to produce CIAE *(Carta de Interfaces de Áreas Edificadas),* which is a vector map and classifies the wildland-urban interface. There are two CIAE, depending on the input data and methods used. First, the CIAE uses input information from COS, more focused on land use at the landscape level, hence producing a structural CIAE to be updated whenever COS is updated. Second, CIAE uses input information from COSc, more focused on land cover at the pixel level, hence producing a conjunctural CIAE to be updated annually.

6. VIEWERS

The easiest way to access and have contact with the cartographic products is to explore the viewers offered by SMOS. With a simple browser, all users, independently of their expertise on cartography, are able to visualize and interact with the maps.

Three viewers are available for different purposes (Figure 8). viSMOS is the viewer that gathers all cartographic products, and therefore is adequate for exploratory users to discover which products are relevant for them. With easy-to-use tools, such as zooming and search by coordinates, viSMOS makes it possible to visualize the products from a variety of perspectives, including simple and quick comparisons between products and their time series.

COScid is a viewer dedicated to the time series of COS and enables users to analyse the maps without having knowledge of specialized software such as Geographical Information Systems normally used for spatial analysis and data exploration. COScid empowers the user with a set of tools able to extract statistics and land change from the whole map or by administrative unit, covering a specific date or period, and exports the results as table and graphics.

COSvgi allows users to contribute with volunteered geographic information. This viewer includes tools for drawing points or polygons, or uploading them from a file, and associate them with LULC information relevant from the user's perspective. The contributions should address errors detected on COS and COSc or inform on recent land change that may influence the future editions of the cartography. Users may upload photos and other files to support the accuracy of their contributions. The volunteered geographic information received is analysed by experts at DGT and all contributions viable to comply with the technical specifications of COS and COSc are validated and incorporated in their following editions.

The cartographic products can be accessed beyond the viewers and users have the chance of exploring them on local computers. All products are available through WMS services and COS and COSc can be downloaded from SNIG.

7. FINAL REMARKS

SMOS, the Portuguese land cover monitoring system, is an initiative of DGT developed with contributions from the community with the purpose of producing and publishing new LULC products. Collaboration among DGT and stakeholders is fundamental as it guides the development of the system and its activities to meet the needs of the users. Institutional users such as entities of the public administration and private companies can find on SMOS a reliable partner capable to produce cartographic information with multiple applications in several fields, optimizing resources and increasing efficiency. Individual users, including non-experts such as journalists and land owners, can reach the cartographic products and answer to their questions easily and timely. Training courses offers the users new means to improve their background on remote sensing and LULC mapping, helping them in understanding the potential and limitations of the products. Users can repay with feedback on the quality and usefulness of the products and viewers, and contribute with volunteered geographic information.

Continuous R&D activities raise credibility of the system and permanently tries to improve the products and respond to the evolving needs of the users. This involves collaboration with the national scientific and technological system and new investments are underway to consolidate the regular production of cartographic products, improve the characteristics of reference cartography and expand the range of specific cartographic products. New developments include production of topographic cartography and high-accuracy imaging using technologies and methodologies for acquiring and processing LiDAR data and very high-resolution satellite images.

ACKNOWLEDGMENTS

SMOS relies upon R&D funded by Fundação para a Ciência e a Tecnologia (FCT) through projects such as IPSTERS (DSAIPA/AI/0100/2018), foRESTER (PCIF/SSI/0102/2017), and SCAPEFIRE (PCIF/MOS/0046/2017). The operationalization of SMOS was funded by Compete2020 (POCI-05-5762-FSE-000368), supported by the European Social Fund. The evolution and expansion of SMOS is funded by the Portuguese Recovery and Resilience Plan (investment RE-C08-i02.01).

REFERENCES

Chaves, M. E. D., Picoli, M. C. A., & Sanches, I. D. (2020). Recent applications of Landsat 8/OLI and Sentinel-2/MSI for land use and land cover mapping: A systematic review. In Remote Sensing (Vol. 12, Issue 18, p. 3062). https://doi.org/10.3390/rs12183062

Patrício, P., Furtado, D., Bica, V., Fonseca, A., Gomes, A. L., Serronha, A., Silva, H., Ferreira, S., & Caetano, M. (2022a). INSPIRE Directive implementation in Portugal. The state of play. Mapping, 28(198), 46–54.

Patrício, P., Furtado, D., Bica, V., Fonseca, A., Gomes, A. L., Serronha, A., Silva, H., Ferreira, S., & Caetano, M. (2022b). National register for geographic data and the new SNIG GeoPortal. Mapping, 29(199), 12–21.

Phiri, D., Simwanda, M., Salekin, S., Nyirenda, V., Murayama, Y., & Ranagalage, M. (2020). Sentinel-2 Data for Land Cover/Use Mapping: A Review. Remote Sensing, 12(14), 2291. https://doi.org/10.3390/rs12142291

Probeck, M., Ruiz, I., Ramminger, G., Fourie, C., Maier, P., Ickerott, M., Storch, C., Homolka, A., Muller, S. J., Tiwari, H., Stumpf, A., Chun, S., Mattos, C., Lindmayer, A., Jahangir, F., Endara, P., Berndt, F., Dohr, M., Kapferer, W., … Dufourmont, H. (2021). CLC+ Backbone: Set the Scene in Copernicus for the Coming Decade. 2021 IEEE International Geoscience and Remote Sensing Symposium IGARSS, 2076–2079. https://doi.org/10.1109/IGARSS47720.2021.9553252

About the authors

Hugo Costa

PhD in Geographical Information Science from the University of Nottingham and an MSc in Geographical Information Science and Systems from NOVA Information Management School (NOVA IMS). He has past experience in land cover mapping from satellite image classification, thematic accuracy assessment and ecological modelling. Currently he is working at DGT since 2018 developing satellite image processing methods to produce LCLU information at operational level. Hugo is also Professor of the Practice at NOVA IMS where he teaches remote sensing.

Pedro Benevides

PhD in Geophysical Sciences and Geoinformation and an MSc in Geographical Engineering both from the University of Lisbon. He has past experience in many satellite data processing (optical, radar, hyperspectral and GNSS). Currently he is working at DGT since 2018 developing satellite image processing methods to produce LCLU information at operational level.

Mario Caetano

Principal investigator of Directorate-General of Territorial Development (DGT) and Deputy Director-General of DGT since October 2014. Since 2000 he is an Associate Professor at Information Management School from the New University of Lisboa (NOVA IMS). Mário Caetano has a degree in Forest Engineering from the Lisboa University of Technology (1989), a MSc in Geography from the University of California, Santa Barbara (1995), a Ph.D. in Forestry (2000) from the Lisboa University of Technology, and a Habilitation in Information Management from NOVA-IMS (2013). Research interests include information systems and management, spatial analysis and the use of remote sensing data for land cover land use (LCLU) characterisation and environment monitoring. He is the author of more than 190 publications in books, journals and conference proceedings.