CONTRIBUTION TO THE DATA WAREHOUSE 2 AND PROSPECTS OF THE IRS PROGRAM

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ABSTRACT

During 2015 and 2016, the IRS program has significantly contributed to the CSC-DA Data Warehouse. From its suite of optical EO satellites which operate in the visible, near IR and shortwave IR domain, data from the HR LISS-III and MR AWiFS sensors on board of Resourcesat-2 have been provided. Resourcesat-2 so far acquired cloud-free images of a vast majority of the first and second coverage of HR_IMAGE_2015 and several monthly MR coverages for MR_IMAGE_2015 over the EEA-39. The results regarding the above mentioned data sets will be discussed including an appraisal of the possible future role of upcoming IRS EO satellites for European data requirements.

1. INTRODUCTION

India's space activities started during the early 1960's with investigations of the upper atmosphere and ionosphere [1]. In 1969, the Indian Space Research Organisation (ISRO) was formed, and the first indigenous Indian satellite Aryabhata was launched from the Volgograd launch station in 1975 [2], [3]. In 1988, the Indian Remote Sensing (IRS) satellite system was commissioned with the launch of IRS-1A [4], [3]. ISRO has successfully operationalised the Polar Satellite Launch Vehicle (PSLV), the Geostationary Satellite Launch Vehicle (GSLV), the Indian National Satellites (INSAT) for communication services, and the Indian Remote Sensing (IRS) satellites for management of natural resources [1].

Today, the IRS satellite system is worldwide one of the largest constellations of remote sensing satellites in operation. The IRS programme, commissioned with the launch of IRS-1A in 1988, presently includes eleven satellites that continue to provide imagery in a variety of spatial resolutions from less than 1 m to 500 m [5]. There are government-approved plans to augment the constellation by more than 10 further missions within the next five years, which will provide continuity and add capabilities, such as e.g. 0.25 m spatial resolution optical, hyperspectral and geo-stationary imaging, to the IRS programme [6].

Through several data reception agreements with Antrix Corporation Limited (Antrix), the commercial arm of ISRO, Euromap, a former subsidiary of GAF, became the first and only actor in Europe to successfully receive, archive and market Earth observation data from IRS satellites. Current agreements with Antrix grant GAF the right to receive and exclusively distribute data from Resourcesat-2 and IRS-P5 Cartosat-1 in Europe, including Turkey, and northern Africa. Further, the agreements permit the reception and distribution of Oceansat-2 OCM data as well as the distribution of data from the historical missions IRS-1C, IRS-1D and IRS-P6 Resourcesat-1.

Through agreements with the European Space Agency (ESA), historical (Resourcesat-1) and recent (Resourcesat-2, Cartosat-1) worldwide IRS data and related services are made available to the Copernicus user community. Through Euromap and GAF, the IRS program significantly contributed to activities like Image2006, Image2009, CORE_001, CORE_008, HR_IMAGE_2015, MR_IMAGE_2015 and Monitoring Agriculture with Remote Sensing (MARS).

The German Aerospace Center (DLR) is GAF's long-term partner regarding reception and archiving activities, as well as the development and operation of interfaces towards ESA.

2. TECHNICAL SETUP OF COOPERATION

Shortly after the foundation of former Euromap in 1996, DLR and GAF entered into a cooperation agreement. This cooperation agreement was amended to cover mission specifics regarding the reception of raw data from the Indian remote sensing missions IRS-1C, IRS-1D, IRS-P6 Resourcesat-1 and IRS-P5 Cartosat-1, to facilitate the joint development of a DSM processing chain, and to integrate the Neustrelitz IRS ground segment into ESA's Coordinated Data access System (CDS) infrastructure.

2.1. Data Reception

As Antrix's partner in Europe, GAF is responsible for the acquisition planning, reception, archiving, processing, marketing and distribution of IRS data.

The data reception is performed through DLR's German Remote Sensing Data Center (DFD) at its multi-mission ground station in Neustrelitz, approximately 100 km north of Berlin. Besides data from several other missions received for other clients, DFD currently receives data from Resourcesat-2, IRS-P5 Cartosat-1 and Oceansat-2 under contracts with GAF.

DFD's multi-mission ground station employs three 7.3 m S/X-band, one 11.5 m S/X/Ka-band and several smaller antennas. The highly flexible ground station permits the fast allocation of antennas, demodulators, bit synchronisers and direct archive systems in several combinations through a programmable high-frequency matrix.

2.2. Development of DSM Products

The DLR Institute for Remote Sensing Methodology (IMF) and GAF cooperate regarding the development of Digital Surface Model (DSM) products based on IRS-P5 Cartosat-1 in flight stereo data.

The core of the DSM generation process is implemented as part of the DLR XDibias image processing system. The main processing steps are discussed in [6].

A test using 22 single DSMs scattered across Europe, processed without block adjustment, confirmed an absolute horizontal accuracy CE90 of 6.7 m and an absolute vertical accuracy LE90 of 5.1 m in comparison to available kinematic GPS measurements [7]. The relative horizontal and vertical accuracies are about 2.5 m. Results of further tests are presented in [8].

In the last years, processing times were reduced through workflow optimizations, like further automation of water body delineation, water level determination, and detection and removal of artefacts.

Euro-Maps 3D 5 m DSMs are a cost-efficient solution that combines a very detailed representation of the surface (e.g. larger single buildings, settlements structures, forest areas and geomorphological features) and large trans-national coverages.

In the meantime, over 2.5 million km² have been pre-processed over Europe, North Africa and the Middle East, and 1 million km² are already available as completely edited Euro-Maps 3D 5 m DSMs. Cartosat-1 has provided a huge stereo data archive for many areas in the world. A complete set of multi-coverages covering EEA-39 is ready to be processed and could be delivered as 5 m DSM within a short time.

2.3. IRS and Copernicus Space Component Data Access

In the frame of the Copernicus Space Component Data Access (CSC-DA) project, DLR and GAF formed a consortium under the leadership of GAF to integrate the IRS ground segment into the CSC-DA infrastructure and to make IRS data therewith accessible to the Copernicus user community.

The development of interfaces towards the ESA Coordinated Data access System (CDS) was performed in cooperation with the DFD. One of DFD's major tasks was the migration of the IRS catalogue service and its interfacing with the CDS Core Infrastructure (CDS-CI).

The IMF in Oberpfaffenhofen is partner with respect to the orthorectification of IRS data. An XDibias-based ortho processing system, established in the frame of the Image2006 project [9, p. 19] and later transferred to GAF, was integrated into the GAF Production Management System (PMS). The PMS and ortho processing system were successfully used to orthorectify large amounts of Resourcesat-1 and Resourcesat-2 LISS-III data for the Optical High-Resolution Pan-European Coverages 2011/2012 (CORE_001) and AWiFS data of the same missions for the European Monthly Medium-Resolution Composites 2011-2013 (CORE_008) and the European Optical Monthly Medium-Resolution Composites (MR_IMAGE_2015).

3. IRS PROGAM'S SUITE OF OPTICAL EO SATELLITES

3.1. Historical Data

Optical remote sensing data from the missions IRS-1C and IRS-1D were acquired through the Neustrelitz ground station between June 1996 and September 2005. Both missions were identical and carried the payload indicated in [3] and further detailed in [10] and [11]. As a result of a systematic acquisition strategy, GAF's archive contains multiple complete coverages of Europe from all sensors. Even though not available through the Data Warehouse, IRS-1C and IRS-1D data are likely to be made available to scientific users through ESA's Third Party Mission program and are available directly from GAF.

The series of optical EO missions within the IRS program was continued with the launch of IRS-P6 Resourcesat-1 in October 2003. Data from its improved payloads were acquired by GAF between 2004 and 2013. The cameras main characteristics are provided in Table 1 and [12]. Again, as a result of a systematic acquisition strategy, GAF's archive contains multiple complete coverages of Europe from the sensors LISS-III, AWiFS and LISS-IV Mono mode. The archive therefore is a unique basis, e.g. because of the included SWIR data, for change detection analysis within the land domain.

Table 1: IRS-P6 Resourcesat-1 payload characteristics

Sensor	Bands	Resolution [m]	Swath [km]	Quantisation [bits]
LISS-IV Mono mode	red	5.8	70	7
LISS-IV MX mode	green red NIR	5.8	23.9	7
LISS-III	green red NIR SWIR	23	140	7
AWiFS	green red NIR SWIR	56 (nadir) … 70 (edge)	740	10

3.2. Data from Current IRS Missions

Resourcesat-2 was launched on April 20, 2011 from Satish Dhawan Space Centre by the Indian PSLV-C16. Compared to its predecessor Resourcesat-1, Resourcesat-2 has two major improvements. The LISS-IV and LISS-III cameras work with 10 bit, and the swath of the LISS-IV camera in the multispectral FMX mode is 70 km. The major payload characteristics are indicated in Table 2 and [14]. LISS-IV has an off-nadir viewing capability of ±26°, leading to a revisit capability of 5 d at the equator. The repetition rate of LISS-III is 24 d and that of AWiFS is 5 d at the equator.

Table 2: Resourcesat-2 payload characteristics

Sensor	Bands	Resolution [m]	Swath [km]	Quantisation [bits]
LISS-IV Mono mode	red	5.8	70	10
LISS-IV SMX mode	green red NIR	5.8	23.5	10
LISS-IV FMX mode	green red NIR	5.8	70	10
LISS-III	green red NIR SWIR	23	141	10
AWiFS	green red NIR SWIR	56 (nadir) … 70 (edge)	740	12

With IRS-P5 Cartosat-1, launched in May 2005, an in-flight stereo mission was added to the fleet. The cameras are mounted with a fixed stereo angle of 31°. Through different pitch biases of the spacecraft, the cameras can be operated with different combinations of canting or tilts along track. The main characteristics for the initially used combination of canting are provided in Table 3 and [13].

Table 3: IRS-P5 Cartosat-1 payload characteristics

Sensor	Tilt along track [°]	Resolution [m]	Swath [km]	Quantisation [bits]
PAN-Fore	+26	2.5	30	10
PAN-Aft	-5	2.2	27	10

3.3. Upcoming IRS EO Missions

In common understanding and building on the fruitful and successful co-operation of the last 20 years, GAF is foreseen to continue to be the commercial partner of Antrix in Europe to bring the elaborated Indian spaceborne Earth observation capacities to the European market.

Resourcesat-2A, with the same specifications as Resourcesat-2, is approved and will be launched in the third quarter of 2016. With its combination of three multispectral cameras of different spatial and timely resolutions, Resourcesat-2A will be a valuable tool for all kinds of monitoring applications and assure data continuity until 2020 and beyond [6, p. 5].

A Resourcesat-3 mission is approved for 2020. Through three cameras (ALISS-III A, C, B) it will acquire multispectral data in five bands (blue, green, red, NIR, SWIR) with 20 m resolution and ATCOR data (256 bands a 2.5 nm) with 240 m resolution over a swath of 740 km. The nadir looking ALISS-III C will provide 10 m resolution over a swath of 240 km. The not yet approved Resourcesat-3A and Resourcesat-3B are planned for 2021 and 2022 [6, pp. 15-16].

Resourcesat-3S and Resourcesat-3SA are two approved missions planned for 2019 and 2020. They are in-flight stereo missions that each provide panchromatic data with an instantaneous geometric field of view (IGFOV) of 2.5 m and a ground sampling distance (GSD) of 1.25 m over a swath of 60 km through two cameras mounted with a fixed stereo angle of 31°. In addition, both cameras will simultaneously acquire multispectral data with three bands (green, red, NIR), 2.5 m spatial resolution, and a swath of 60 km. [6, pp. 13-14].

Cartosat-2C and Cartosat-2D, approved and planned to be launched in 2016 and 2017 respectively [6, p. 2], will simultaneously provide 0.64 m panchromatic data and 2.5 m multispectral data in 4 bands over a 10 km swath [6, p. 4], [3]. Cartosat-2E, approved and planned for end of 2017, will have the same payloads plus a video camera for event monitoring [6, p. 4].

Cartosat-3, approved and planned to be launched in 2018, will simultaneously acquire panchromatic data with 0.25 m spatial resolution and multispectral data in four bands with 1 m spatial resolution over a swath of 15 km.

For the identical Cartosat-3A/3B missions, planned to be launched in 2019/20, government approval is pending. [6, pp. 2, 6].

Oceansat-3 and Oceansat-3A are both approved and planned for 2018 and 2019 with identical payloads. The improved Ocean Colour Monitor (OCM-3) will deliver data in 13 spectral bands with 360 m spatial resolution. In comparison with OCM-2, there will be more and narrower bands with a better signal to noise ratio. Further, there will be a Ku band scatterometer and a sea surface temperature monitor (SSTM) [6, p. 7].

The approved geostationary GEO-Imaging Satellite GISAT-1 planned for 2017 will have two hyperspectral imagers, providing 60 bands in the VNIR with 500 m resolution and 150 bands in the SWIR with 500 m resolution respectively, as well as two multispectral sensors, with 6 bands in the VNIR and 50 m resolution and 6 thermal bands and 1.5 km resolution respectively. [15, pp. 31, 46].

Information regarding further missions can be found in [6].

4. CONTRIBUTION TO THE CSC-DA DWH DURING THE LAST TWO YEARS

ESA and GAF signed a Copernicus Space Component Data Access (CSC-DA) Data Warehouse 2014-2020 (DWH2) agreement in April 2015.

Through this agreement, European and world-wide IRS data are accessible to the Copernicus user community. The agreement covers optical remote sensing data from the current Resourcesat-2 and IRS-P5 Cartosat-1 missions, as well as historical data from IRS-P6 Resourcesat-1, as contributions to the generic datasets, and Resourcesat-2 LISS-III and AWiFS data for two CORE data sets.

The agreement was signed after previous successful contributions to fulfil European data requirements, e.g. the provision of LISS-III data to the GMES Fast Track Land Service Image2006 through a consortium with Spot Image as the prime contractor, and to the European wall-to-wall Coverage 2009 and to CORE_001 through the GMES Space Component Data Access (GSC-DA) Data Warehouse (DWH) agreement. Through the latter also AWiFS data for CORE_008 were provided.

4.1. Optical High-Resolution Pan-European Coverages (HR_IMAGE_2015)

Through the CSC-DA Data Warehouse agreement, ESA ordered the systematic acquisition of Resourcesat-2 LISS-III data in 2015 over 38 countries.

Together with data from 2014, which were speculatively acquired during the tendering phase, over 92% could be achieved cloud-free within the narrow window.

Table 4: HR_IMAGE_2015, area covered cloud-free within narrow and extended window

Acquisition Year	Narrow window cloud-free achievement [%]	Extended window cloud-free achievement [%]
2014	75.3	83.5
2015	76.5	81.9
2014, 2015	92.4	95.0

The quick look mosaics in Figure 1 and Figure 2 show the cloud-free LISS-III data acquired in 2014 and 2015 within the narrow window respectively extended window.

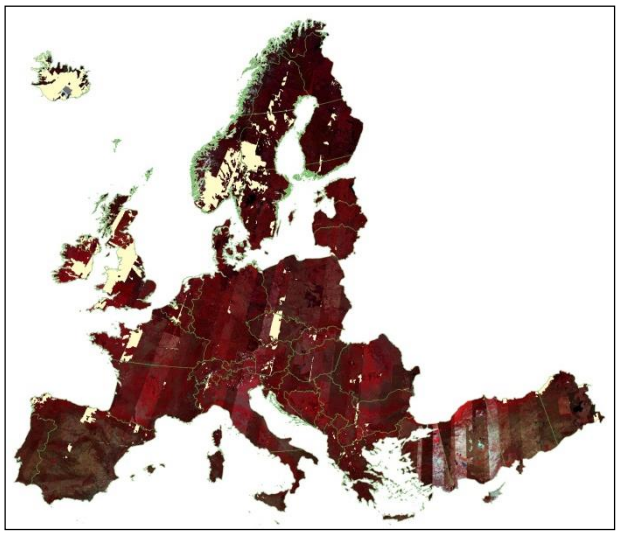

Figure 1: HR_IMAGE_2015, achievement within narrow window

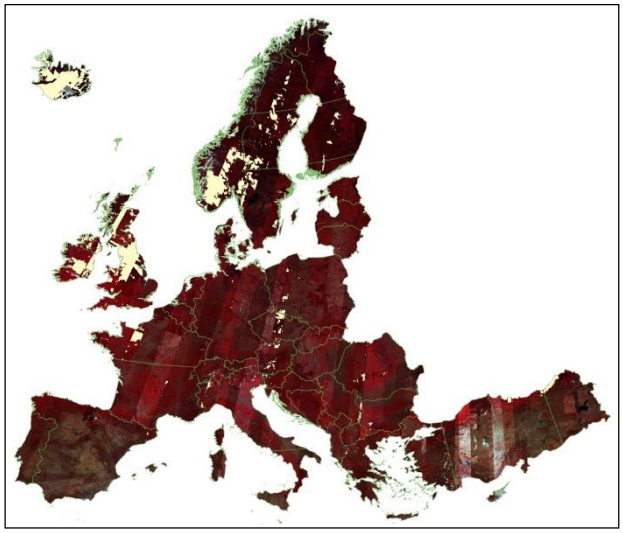

Figure 2: HR_IMAGE_2015, achievement within extended window

For a majority of 71% of the countries or regions, at least 95% of the area was covered cloud-free with LISS-III

data from the narrow windows 2014 and 2015. The corresponding distribution is shown in Figure 3.

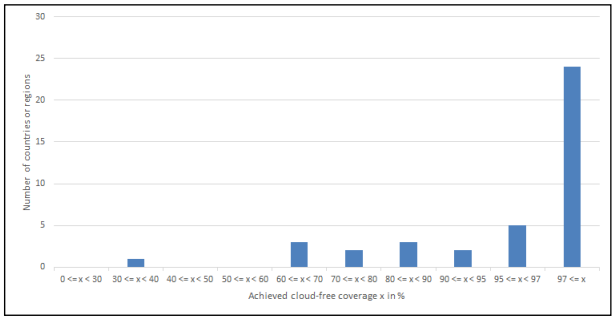

Figure 3: Distribution of achievement per country or region with data from the narrow window 2014 and 2015

According to a preliminary assignment of acquired scenes to the two coverages, considering only the narrow window for Coverage 1, this could lead to 87% achieved cloud-free for Coverage 1 and 50% achieved cloud-free for Coverage 2 with Resourcesat-2 LISS-III alone.

GAF has been approached by EEA and ESA to perform a coverage composition exercise taking into account SPOT-5 data from 2014, Resourcesat-2 data from 2014 and 2015, as well as Sentinel-2 data from 2015.

Data products will be delivered as system-corrected ortho kits and as top of atmosphere (TOA) reflectance products orthorectified in European and national projections.

4.2. European Optical Monthly Medium-Resolution Composites (MR_IMAGE_2015)

The potential of the AWiFS sensor with its enormous swath and its 5 d repetition rate at the equator to provide multispectral MR, multi-temporal coverages was utilized to acquire eight monthly pan-European coverages per year in 2014 and 2015. Through the CSC-DA Data Warehouse agreement, eight monthly pan-European coverages acquired from March to October 2014 were made available for the MR_IMAGE_2015 dataset.

The monthly coverages were mainly limited by snow cover and the prevailing weather situation. All monthly coverages are partial coverages. Table 5 shows that for the monthly coverages of 2014, between 75% and 94% of the area were achieved cloud-free. Considering the area of the months March to October 2014 together, the total achievement in 2014 is 85.7%. Figure 4 shows the number of cloud-free days during July 2014, Figure 5 the acquisition attempts made during that month, and Figure 6 a quick look mosaic of the therewith achieved partial coverage of July 2014.

As a comparison between the July coverages of 2014 and 2015 in Figure 6 and Figure 7 shows, the two coverages complement each other. See also the last column of Table 5.

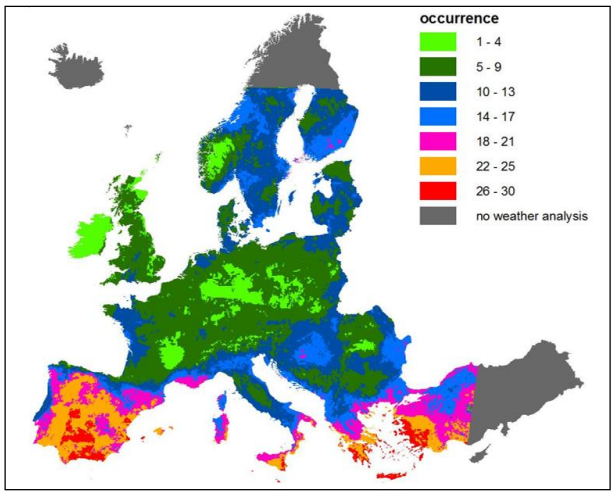

Figure 4: Jul 2014 cloud-free days

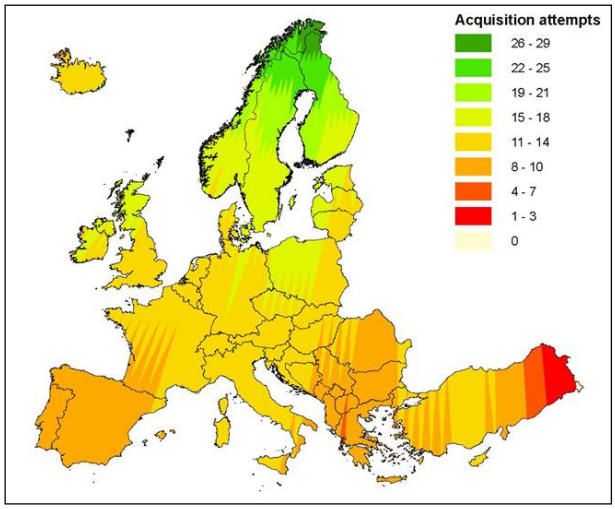

Figure 5: Jul 2014 acquisition attempts

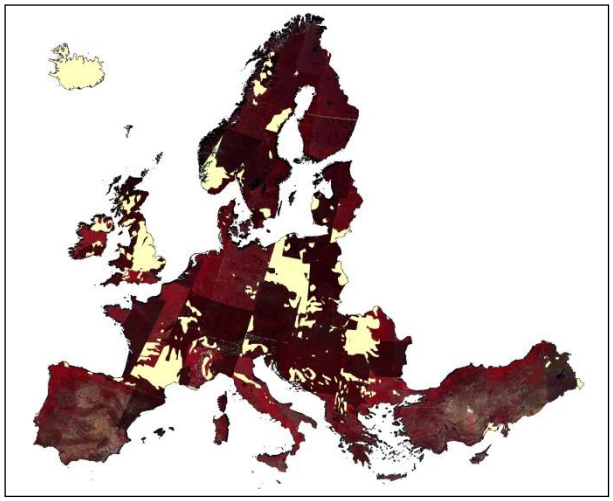

Figure 6: Jul 2014 coverage quick look mosaic

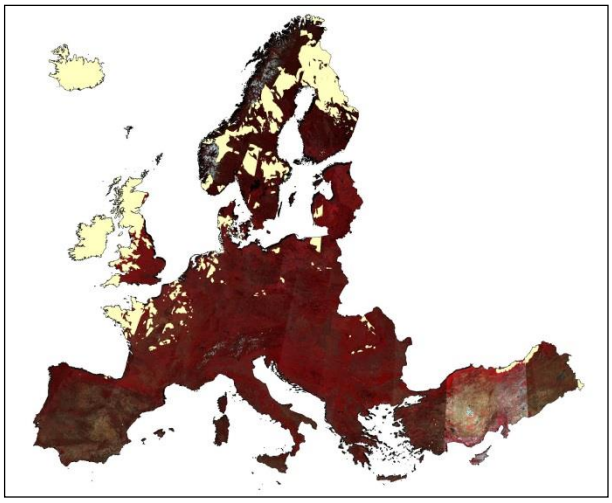

Figure 7: Jul 2015 coverage quick look mosaic

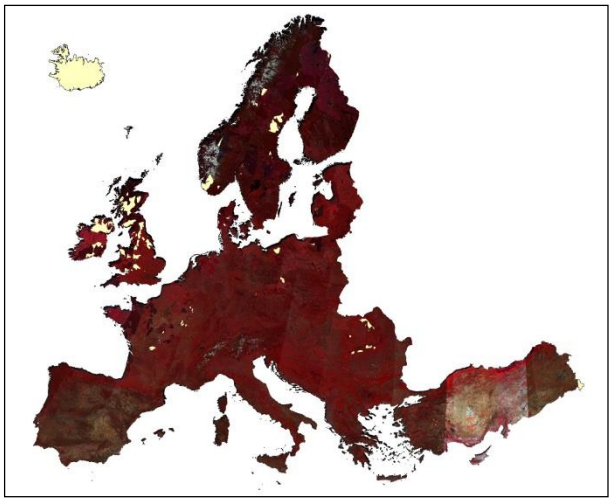

Figure 8: Jul 2014 and 2015 combined coverage quick look mosaic

Table 5: MR_IMAGE_2015, area covered cloud-free

Month	Area covered cloud-free in 2014 [%]	Estimated area covered cloud-free in 2015 [%]	Estimated area covered cloud-free in 2014 and 2015 [%]
03	74.6	75	82
04	81.1	86	85
05	86.5	73	91
06	91.8	81	95
07	94.4	86	97
08	83.0	89	92
09	92.2	91	97
10	81.7	83	92
03 to 10	85.7	83	91

The priority was to achieve at least three cloud-free coverages out of the months April to July, which as indicated in Table 6 was only achieved for 83.2% of the area in 2014, but could be increased by approx. 11% by also using data from 2015.

Table 6: MR_IMAGE_2015, estimated area for which 3 or 4 cloud-free coverages were achieved

2014 [%]	2015 [%]	2014 and 2015 [%]
83	78	94

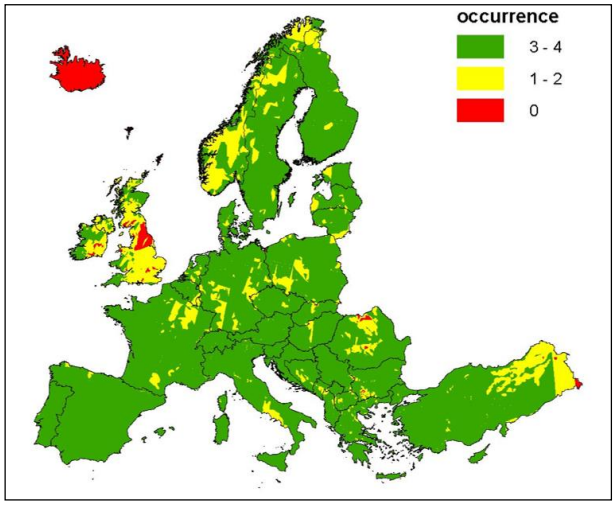

Figure 9: Number of coverages achieved, Apr-Jul 2014

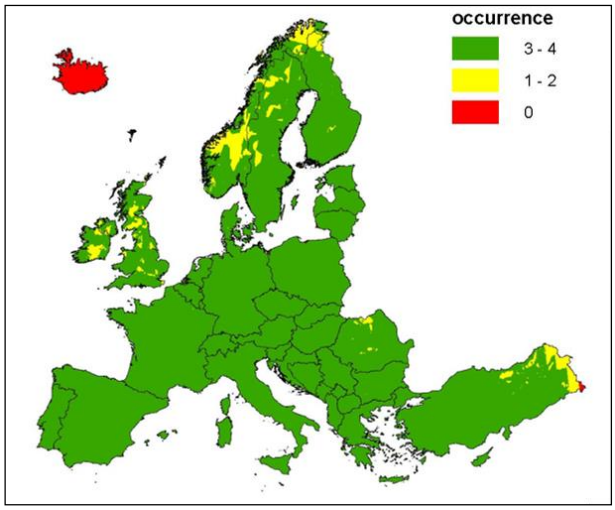

Figure 10: Number of coverages achieved, Apr-Jul 2014 and 2015

It has to be noticed that the estimates provided in Table 5 and Table 6 as well as the figures Figure 6 to Figure 10 in this section are based on relatively coarse cloud masks derived from quick looks. The coarse cloud masks tend to mark too large areas as cloudy and the difference to the much more precise cloud masks derived from ortho-corrected products is significant, e.g. more than 8% for July 2014. This explains differences between the visual impression provided by Figure 6 and the actual achievement stated for 2014 in Table 5, and means that the estimates in Table 5 and Table 6 are underestimates.

5. CONCLUSIONS

With the IRS program, ISRO has established one of the world's leading EO programs. Through GAF, the exclusive supplier of data from several IRS missions in Europe, the IRS program has significantly contributed to the Copernicus Data Warehouse and other European activities. Considering the upcoming IRS EO missions, the IRS program has the potential to continue being a significant data source to support the fulfilment of European data needs.

In the light of free and open data policies for Sentinel-2 and Landsat-8 data, the availability of IRS EO data as a data source provided under commercial terms so far to European users is however at risk. A respective procurement policy to ensure the availability of Copernicus contributing mission data in the long run might be necessary to achieve the goals of Copernicus.

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