CONTRIBUTION TO THE DATA WAREHOUSE AND PROSPECTS OF THE IRS PROGRAM

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ABSTRACT

Over the past two years, the IRS program has again significantly contributed to the GSC-DA Data Warehouse. From its suite of optical EO satellites which operate in the visible, near IR and shortwave IR domain, multispectral data from the HR LISS-III and MR AWiFS sensors have been provided. Both cameras are implemented on board of Resourcesat-1 and Resourcesat-2 respectively. Despite reduced capacities, the Resourcesat constellation of satellites so far acquired cloud-free images of a vast majority of the first HR coverage of CORE_001 and several monthly MR coverages for CORE_008 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]. In 1988, the Indian Remote Sensing (IRS) satellite system was commissioned with the launch of IRS-1A [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 1 m to 500 m [4].

Through several data reception agreements with Antrix Corporation Limited (Antrix), the commercial arm of ISRO, Euromap 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 Euromap the right to receive and exclusively distribute data from IRS-P6 Resourcesat-1 and IRS-P5 Cartosat-1 in Europe, including Turkey, and northern Africa. Currently, Antrix and Euromap are at the verge of signing the agreements for reception and distribution of Resourcesat-2 satellite data over Europe.

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

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

2. TECHNICAL SETUP OF COOPERATION

Shortly after the foundation of Euromap in 1996, DLR and Euromap 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, Euromap is responsible for the acquisition planning, reception, archiving, processing, marketing and distribution of IRS data. Resourcesat-2 data were acquired using the on-board solid state recorder and downlinked to Antrix's ground station network.

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 IRS-P6 Resourcesat-1 and IRS-P5 Cartosat-1 under a contract with Euromap.

DFD's multi-mission ground station employs three 7.3 m X-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), GAF AG and Euromap 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 [5].

The Indian L1 Data Product Generation System (DPGS) for system corrected products, the XDibias DSM processor, as well as manual editing and quality control processes are integrated into Euromap's Production Management System (PMS). The PMS controls the whole production workflow.

The main role of GAF AG was the representation of the user requirements during product definition as well as the accuracy assessment and control of the developed products.

A test using 22 single DSMs scattered across Europe, processed without block adjustment, confirmed a horizontal accuracy CE90 of 6.7 m and a vertical accuracy LE90 of 5.1 m relative to available GPS tracks [6]. Results of further tests are presented in [7].

2.3. IRS and GMES Space Component Data Access

In the frame of the Global Monitoring for Environment and Security (GMES) Space Component Data Access (GSC-DA) project, DLR and Euromap formed a consortium under the leadership of Euromap to integrate the IRS ground segment into the GSC-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 [8, p. 19] and later transferred to Euromap, was integrated into the Euromap 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).

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 Table 1 and further detailed in [9] and [10]. As a result of a systematic acquisition strategy, the Euromap archive contains multiple complete coverages of Europe from all sensors.

Table 1: IRS-1C and IRS-1D payload characteristics

Sensor	Bands	Resolution [m]	Swath [km]	Quantisation [bits]
PAN	pan	5.8	70	6
LISS-III	green red NIR SWIR	23 23 23 70	140	7
WiFS	red NIR	188	810	7

3.2. Data from Current IRS Missions

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 Euromap since 2004. The cameras main characteristics are provided in Table 2 and [11]. Most interesting is the fixed-track Advanced Wide Field Sensor (AWiFS) with its combination of 56 m resolution at nadir and a repetition rate of 5 days at the equator.

Table 2: 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

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 [12].

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

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 latter unfortunately leads to limited data availability as 70 km x 70 km products are not yet available to non-Indian users and the processing of 23.5 km x 23.5 km products from FMX acquisitions is not implemented [13]. The major payload characteristics are indicated in Table 4 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 4: 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

One of the latest additions to the fleet of IRS EO missions is the radar imaging satellite RISAT-1 launched in April 2012, which followed the launch of RISAT-2 in April 2009. RISAT-1 has a C-band multi-frequency synthetic aperture radar (SAR), capable of operating in Scansar Mode, Strip Map Mode and Interferometry Mode.

3.3. Upcoming IRS EO Missions

Resourcesat-2A, with the same specifications as Resourcesat-2, will be launched in 2015-16. 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.

A Resourcesat-3 mission with a multispectral camera with 20 m resolution and 740 km swath is in an early planning stage and has to be confirmed by the Indian government.

Cartosat-2C and Cartosat-2D, planned to be launched in 2014-15 and 2015-16 respectively, will simultaneously provide 0.64 m panchromatic data and 2.5 m multispectral data in 4 bands over a 10 km swath.

Cartosat-3, planned to be launched in 2016-17, will simultaneously provide data with a spatial resolution of 0.25 m in the panchromatic, 1 m in the multispectral and 5 m in the MIR bands with 10 bit radiometry over a swath of 16 km.

Cartosat-1A/1B/1C, with 1.25 m panchromatic in-flight stereo, 2.5 m resolution multispectral and 25 m hyper-spectral (VNIR & SWIR) imagers, as follow-ups for the Cartosat-1 in-flight stereo mission are currently in an early planning stage and have to be confirmed by the Indian government.

In an early planning stage and to be confirmed by the Indian government are also an Oceansat-3 series as well as RISAT-1A, RISAT-2A and RISAT-3 operating in the C, X and L band respectively.

The GEO-Imaging Satellite GISAT planned for 2016-17 will have two hyperspectral imagers, providing 60 bands in the VNIR with 320 m resolution and 150 bands in the SWIR with 192 m resolution respectively, as well as two multispectral sensors, with 4 bands in the VNIR and 50 m resolution and 3 thermal bands and 1.5 km resolution respectively.

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

After previous successful contributions to the European data requirements, e.g. 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, also

referred to as Image2009, through an GMES Space Component Data Access (GSC-DA) agreement with the European Space Agency (ESA), ESA and Euromap signed a GMES Space Component Data Access (GSC-DA) Data Warehouse (DWH) agreement in August 2011. 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, IRS-P6 Resourcesat-1 and IRS-P5 Cartosat-1 missions, as well as historical data from IRS-1C and IRS-1D, as contributions to the generic datasets, and Resourcesat-1 and Resourcesat-2 LISS-III and AWiFS data for two CORE data sets.

4.1. Optical High-Resolution Pan-European Coverages 2011/2012 (CORE_001)

Through the GSC-DA Data Warehouse agreement, ESA ordered one LISS-III coverage of 38 countries from the Resourcesat-1 or Resourcesat-2 satellites for the first coverage of the CORE_001 data set, the high-resolution pan-European Coverages 2011/2012, orthorectified in European and national projections. A second coverage without short wave infrared (SWIR) was contracted to RapidEye.

Despite the power constrains on board the aging Resourcesat-1, which exceeded its nominal mission life of five years [11, p. 15], approx. 60% of the contracted area was acquired cloud-free within the region-specific acquisition windows with Resourcesat-1 during 2011. The deliveries of system corrected and ortho products covering about 3 Mio km^2 cloud-free European territory during 2011 significantly exceeded the 2 Mio km^2 contractually due in 2011 and account for approx. 52% of the first coverage.

During 2012 and 2013, the direct downlinks from Resourcesat-1 were supplemented with Resourcesat-2 on-board solid state recorder acquisitions. In order to utilize the advantages of the direct downlink and local processing of system corrected products, and as far as permitted by the priorities of the acquisition windows and other criteria, during the data selection precedence was given to Resourcesat-1 data.

Finally approx. 18% of the delivered products stemmed from Resoucesat-2.

The quick look mosaic in Figure 1 shows the LISS-III data acquired in 2011 and 2012 as well as the gap fillers acquired up to 31-Aug-2013.

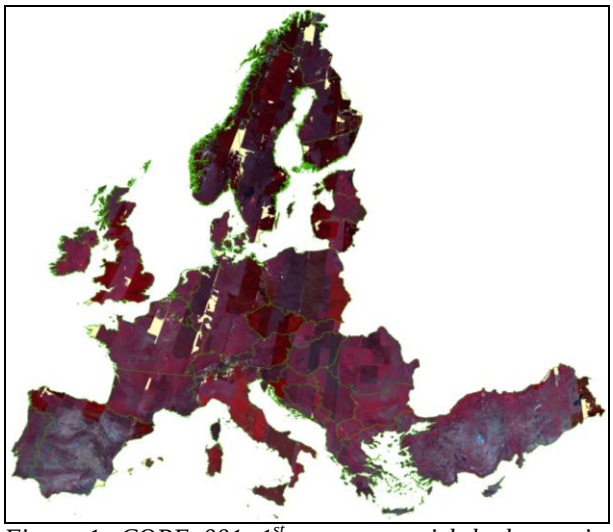

Figure 1: CORE_001, 1st coverage quick look mosaic, as of 31-Aug-2013

Figure 2 shows the achieved cloud-free coverages in percent per country and the contributions to the improvement of the coverages made by data acquired in 2011, 2012 and 2013 so far by 31-Aug-2013.

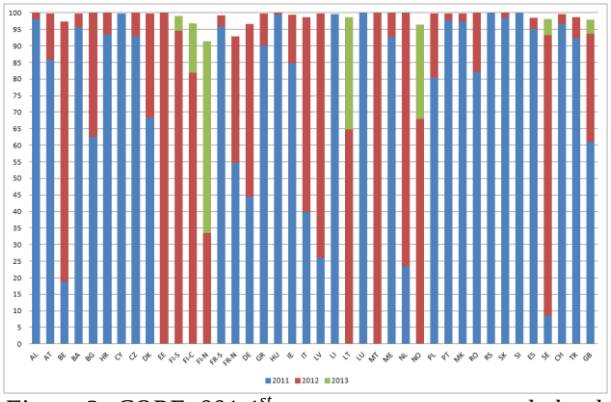

Figure 2: CORE_001 1st coverage, area covered cloud-free and contribution by data from 2011 - 2013 in %, as of 31-Aug-2013

Considering the area of all countries together, a cloud-free coverage of 94.2% for the first coverage was achieved with data from 2011 and 2012.

The aim to cover at least 95% of the area cloud-free with data from 2011 and 2012 was achieved for a majority of 80% of the countries or regions. The corresponding distribution is shown in Figure 3.

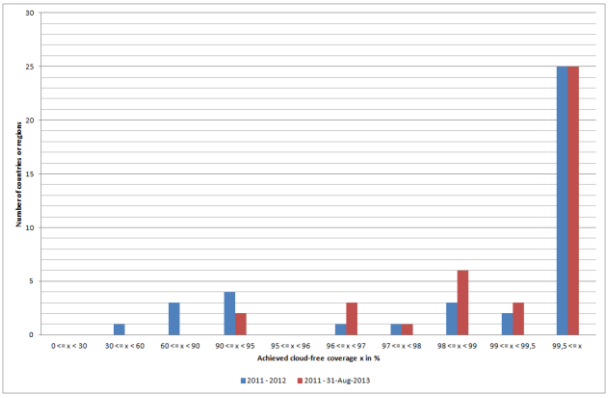

Figure 3: Distribution of achieved coverage per country or region with data from 2011 and 2012, and 2011 to 31-Aug-2013

A gap-filling exercise during 2013 aims at reducing the gaps in Scandinavia, Ireland and the UK as far as possible. The coverage achieved by 31-Aug-2013 is 98.2% of the total area, considering the area of all countries together, and the aim to cover at least 95% of the area cloud-free is achieved for 95% of the countries or regions. See also Figure 2 and Figure 3. The contribution made by acquisitions from different years is shown in Table 5.

Table 5: CORE_001 1st coverage, area covered cloud-free, as of 31-Aug-2013

Priority	Acquisition Year	Contribution from Acquisition Year [%]	Total cloud-free area [%]
1	2011	61.4	61.4
2	2012	32.8	94.2
3	2013	4.0	98.2

Due to the limited resources during 2011, the expressed wish to receive the 2 Mio km² in contiguous areas and the start of the respective acquisition windows, the focus for Resourcesat-1 acquisitions during 2011 had been on central Europe, southern Europe and Turkey, and the focus for Resourcesat-2 speculative acquisitions on northern Europe. Planning the Resourcesat-1 pass segments of limited length in the south during early summer, in the north during summer, and again in the south during late summer would at the end of 2011 most likely have led to very fragmented coverages everywhere. As the delays in the Resourcesat-2 commissioning, product release and ground segment deployment were only partially compensated by the on-board solid state recorder acquisitions, in retrospect an inclusion of Scandinavia in the 2011 Resourcesat-1 acquisition planning may have led to a better coverage of Scandinavia and slightly better overall results at the end of 2012.

4.1.1. Reprocessing over Malta

ESA's Coordinated Quality Control had identified an issue with the geolocation of the ortho images over Malta, where shifts of up to 150 m w.r.t. road vector layers were observed, and triggered a respective investigation by Euromap. With the experience stemming from the involvement in the provision of the previous Image2006 and Image2009 coverages, it was easy to demonstrate that the delivered ortho images fulfilled the accuracy requirements w.r.t. the prescribed reference, and that the root cause was the desire to produce an ortho layer as close as possible to the respective previous ortho layer in order to facilitate direct comparison of later derived land cover layers. For the production of Image2006 over Malta, Image2000 was used [15, p. 32], for which in turn 1:25,000 scale national topographic maps were used as reference [16, p. 39, p. 74].

To correct the issue, the Agency ordered the reprocessing of the IRS and SPOT data included in Image2006, Image2009 and CORE_001 Malta coverages employing the 2.5 m resolution ortho layer of Euro-Maps 3D, a digital surface model with 5 m post spacing and an absolute vertical accuracy LE90 of 5-10 m [17], as reference.

4.2. European Monthly Medium-Resolution Composites 2011-2013 (CORE_008)

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 through the GSC-DA Data Warehouse agreement by acquiring monthly pan-European coverages for the CORE_008 data set.

During 2011, eight monthly coverages from March to October were acquired over a fragmented AOI, determined by the intersection of the cloud-free area already delivered for CORE_001 and the area covered cloud-free by at least 3 monthly AWiFS coverages from the months March to June. Figure 4 shows a quick look mosaic of the August 2011 coverage over and outside the AOI, clipped to EEA-39.

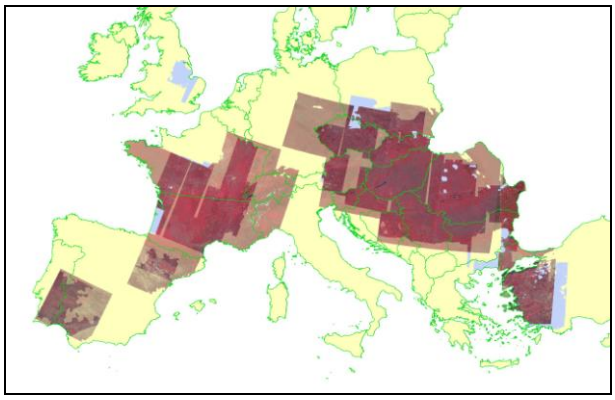

Figure 4: Aug 2011 (clear QL: data over AOI; opaque QL: data outside AOI; bluish: uncovered part of the AOI)

For 2012 the AOI consisted of 38 countries and six monthly coverages were acquired from March to August. The monthly coverages were mainly limited by snow cover and the prevailing weather situation. Compare Figure 5 and Figure 6 as well as Figure 7 and Figure 8.

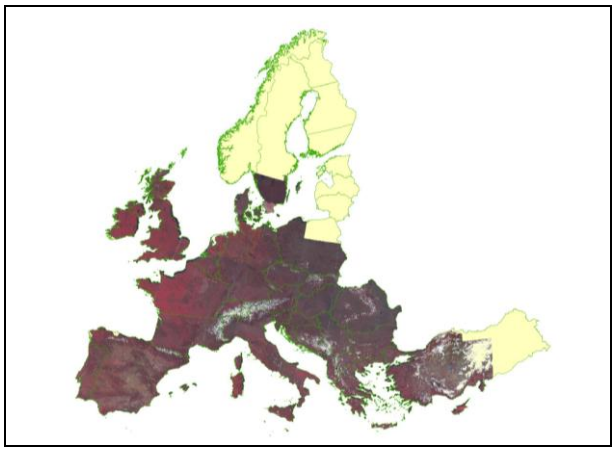

Figure 5: March 2012 coverage quick look mosaic

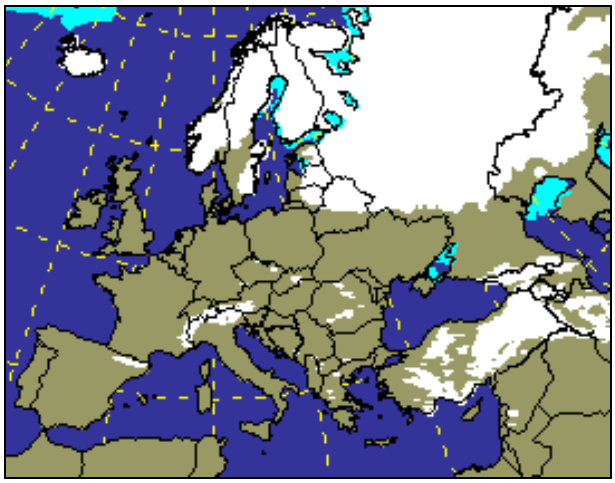

Figure 6: 31-Mar-2012 snow cover, NOAA-NESDIS

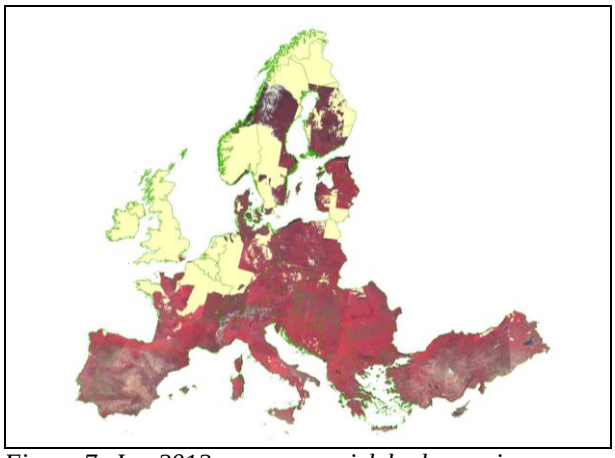

Figure 7: Jun 2012 coverage quick look mosaic

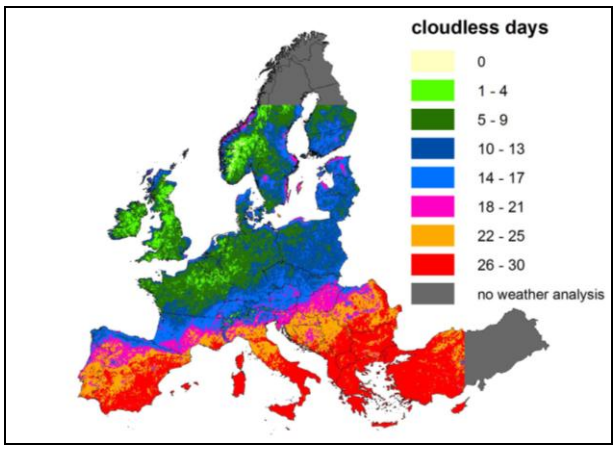

Figure 8: Jun 2012 Cloud-free days, processed from MSG 10:00 UTC data

As for CORE_001, the 2011 acquisitions were realized using the aging Resourcesat-1 alone. During 2012 the direct downlinks from Resourcesat-1 were supplemented with Resourcesat-2 on-board solid state recorder acquisitions.

5. CONCLUSIONS

With the IRS program, ISRO has established one of the world's leading EO programs. Through Euromap, the exclusive supplier of data from several IRS missions in Europe, the IRS program has significantly contributed to the GMES 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 GMES contributing mission data in the long run might be necessary to achieve the goals of Copernicus.

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