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Assessing Nighttime DMSP/OLS Data for Detection of Human Settlements in the Brazilian Amazonia.

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Abstract. This paper describes an initial assessment of the DMSP/OLS night-light data as an instrument to investigate the human presence and activity over the Brazilian Amazonia. The work explores the potential of the sensor for detecting and monitoring urban area extensions and human presence and activity at a regional scale. Using DMSP/OLS night-lights imagery, the authors detected 248 towns from a total of 749 *municípios* presented in the Legal Amazonia. All the night-lights foci detected were related to human activities, including urban settlements and mining. A strong linear relation (R^2= 0.8) was obtained between urban area extensions, detected by TM/Landsat, and DMSP night-lights foci. Our conclusion is that DMSP/OLS imagery can be used as an indication of human presence and activity in the Amazon region.

Keywords: DMSP/OLS night-lights, human settlements, urban area, human activities, Urban Amazon, Spatial Analysis, Regional Scale.

1 Introduction

The Brazilian Amazonia supports the World's largest contiguous area of still untouched tropical forest. Land cover changes in the Amazon region contributes significantly to carbon budgets, and it is taken as a disturbance agent to the biodiversity conservation, to the hydrological cycle having serious impacts over the global climate change (Gash et al., 1996).

During the last three decades, the region has experienced the biggest urban growth rates in Brazil. In 1970, urban population comprised 35.5% of the total population. This proportion increased to 44.6% in 1980, to 58% in 1991 and to 61% in the 1996[1]. An increasing diversity in

[1] Population data for this paper was obtained from IBGE (Brazil's Census Bureau) surveys.

economic activities and the resulting population changes have restructured and reorganised the network of human settlements all over the region. As a result, the picture over the early 21st century shows patterns and spatial arrangements that reveals a different Amazonia. This new Amazonia emerges instead is a tropical forest with a complex urban tissue in the making, a perspective that has taken some researchers to put forward the claim for an “urbanized forest” (Becker, 1996).

Currently, the mainstream research agenda for the Amazonia is focused on the physical geography aspects (such as land use and land cover change) and on global change issue. By contrast, a relatively small number of researchers are concentrating on the human aspects of the Amazonian occupation. These studies are showing that the growth in urban population has not came with an improvement on quality of life of local populations, as demonstrated by the low indices of health, education and income wages (Becker, (1996 and 1998), Browder and Godfrey (1997), Monte-Mór (1998)).

The fragile ecological equilibrium of the Amazon forest, the population growth and its movements, the lack of basic infrastructure, and the conflicting driving forces around the region, make a project for sustainable development of the region the real issue to be dealt with and the actual challenge for world science.

The objective of this study was to assess nighttime DMSP/OLS data to detect human settlements in the Brazilian Amazonia. To reach this goal, we developed a procedure to detect human activity on DMSP/OLS image composition and to integrate and analyse the data set in a spatial database. We investigated the correlation between DMSP/OLS night-lights and the human activity information obtained from ancillary data sources.

2 A Review of DMSP/OLS data for Detection of Urban Settlements

The U.S. Air Force Defense Meteorological Satellite Program (DMSP) operates since 1970s the Operational Linescan System (OLS), an oscillating scan radiometer capable of detecting the visible and thermal-infrared emissions, with nominal resolution of 2.7 km and ~3000 km of swath. The OLS sensor's primary mission was the observation of nighttime moonlit cloud cover for global meteorological forecasting for the Air Force. For this reason, the visible spectral band (VIS: 0,4-1,1 μm) signal, that includes the visible near infrared portion of the spectrum (VNIR: 0.5 to 0.9 μm), is intensified at night using a photomultiplier tube. This makes the sensor four orders of magnitude more sensitive, enabling to detect faint VNIR emission sources. With sunlight eliminated, the light intensification results in a unique data set in which city lights, gas flares, lightning illuminated clouds and fires can be observed (Elvidge et al., 1997).

There are two spatial resolution modes in which data can be acquired. The full resolution data has a nominal spatial resolution of 0.56 km and it is referred to as "fine". The "smooth" resolution mode is generated towards averaging of five by five blocks of fine data onboard, with nominal spatial resolution of 2.8km.

DMSP/OLS image was first presented as a potential urban mapping tool by Croft (1973, 1978). The author argued that high contrast between lighted and unlighted areas and the sensor's spatial resolution made it a useful tool to identify regions of significant human activity. Welch (1980), Foster (1983) and Welch and Zupko (1980) attempted to use DMSP/OLS imagery to map the distribution of human settlements and inventory the spatial distribution of human activities, such as energy consumption. These works showed promising results, but also exposed problems in the use of single data acquisition, pixel saturation and blooming, cloud cover and presence of ephemeral light sources as lightning and fires.

Sullivan (1989) produced a VNIR emission sources global map (10km resolution). Despite it was derived from single dates of DMSP/OLS film data imagery and mosaicked into a global product, many of the features presented, in some areas like Africa, were ephemeral VNIR emission from fires.

The problem with ephemeral lights and cloud cover was eliminated with the methodology developed to generate a stable light data set by the NOAA/NGDC (National Oceanic and Atmospheric Administration's National Geoscience Data Center). This method includes the collection, rectification and aggregation of a large number of nighttime OLS image (Elvidge et al., 1997). The image time series analysis distinguishes stable lights produces by cities, towns and industrial facilities from ephemeral lights. This analysis is additionally used for cloud screening and ensures sufficient cloud-free observations for determining the location of all VNIR emissions.

To convert this stable light data set into a map of "urban areas" in the United States mosaic, Imhoff et al. (1997) proposed a thresholding technique. The values reported in the original data set represent a percentage of lighted pixel, for each pixel extracted from 231 images of nighttime cloud screen orbits. Each pixel has a digital number ranging from 0 to 100, representing the ratio of lighted observations to total cloud free observation x 100. A digital number of 30 means that this pixel was lighted 30% of the times that it was observed under could-free conditions. A threshold of >89% removed ephemeral light sources and blooming of light onto water when adjacent to cities, while still leaving the dense urban core intact. Comparing with the urban areas from 1990 U.S. Census, the urban area from DMSP night-lights was only 5% smaller. Although this technique worked well in the United States, the authors emphasised the need to verify these relations in less-developed countries where the type of infrastructure development and its associated nighttime lighting may be different.

Based on a series of DSMP/OLS images, Miranda (1999) generated a map of cities and urban settlements in the Amazon that identified 1300 urban sites comprising small towns, medium size towns and cities in the region. Using ancillary data from federal institutes (IBGE, FUNAI, DNPM) and non-governmental organisations, this number raised to up to 1500 sites of *vila*s and cities in the Amazon. Unfortunately, a scientific assessment of his work is not possible, since the author did not publish a description of his methodology.

3 Data Integration and Analysis

3.1 General Description

The methodology for data integration and analysis used in this work included the following steps, as outlined in **Figure 1**: Fig. 01

1. Building a spatial database consisting of DMSP/OLS data, TM/Landsat images and IBGE-derived geographic limits of *municípios*, urban centres and *vilas*. All the 749 *municípios* of the Legal Amazon had their boundary and urban centres spatialized from the IBGE (Instituto Brasileiro de Geografia e Estatística) data available for 1997. The geographical positions of the 256 *vila*s, computed from IBGE-1998 data, were also spatialized. Both, cities and *vila*s, were defined as objects in the database in order to enable the spatial query over these features.

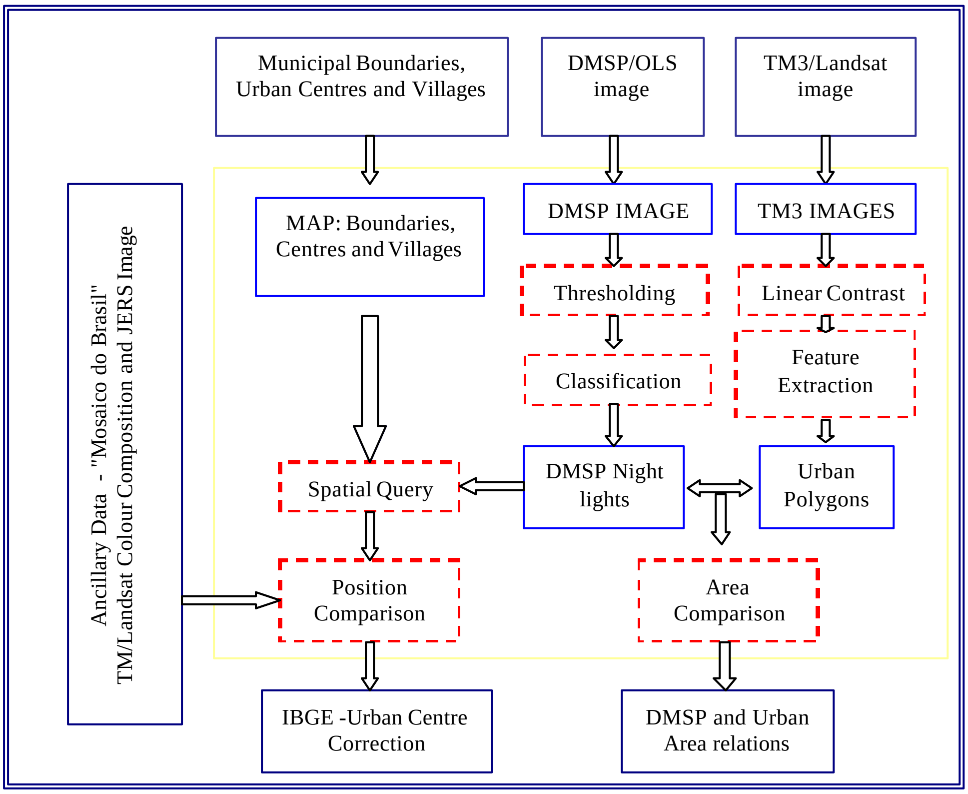


Figure 1 - The data integration and analysis flow chart.

2. Correction of the urban centre location of the original IBGE data set based on DMSP/OLS night-lights and urban polygons derived from TM/LANDSAT imagery.
3. Comparison of DMSP/OLS night-lights and urban polygons derived from TM/LANDSAT imagery to assess the potential of DMSP/OLS for detection of urban settlement extension.

The spatial database and the analytical procedure used the SPRING GIS system, version 3.5 (SPRING, 2000).

3.2 DMSP/OLS Data Processing

An image from DMSP/OLS covering the Amazon region was used. This image was generated by NOAA- National Geophysical Data Center, from 16 single DMSP/OLS orbit, from September 2nd to 18th, 1999. In order to have only stable light sources in the final image, ephemeral night-lights like clouds and fires were removed during the mosaic process, using the procedure described by Elvidge et al. (1997).

The original image data were available in a "geographical" projection with cells that are 0.008333 degrees square, 1 km^2 approximately. The conversion from "geographical" to Policonic projection was the unique geometrical correction applied over the image.

Although the DMSP/OLS image used an 8-bits quantization (255 values), its histogram had frequencies only from 7 to 100, due to the fact that the digital numbers in the image represent the cumulative percentage of lighted pixels considering the nighttime cloud screen orbits available.

The next processing step was to select a threshold for the pixel values that could detect urban areas, without overestimating larger cities. To preserve the city boundaries and to detect small towns for the continental US, Imhoff et al., (1997) used a threshold value of 89%. However, their methodology was developed for a series of 236 images, whereas only 16 images were available for this work for a region with frequent cloud cover. By interactive visual analysis, we compared different threshold values at DMSP images with the location of small towns and big cities in the TM/Landsat image. We found that a threshold of 7% over estimated the city boundaries, and a threshold of 89% did not detect most of the small towns. As a compromise, a threshold of 30% was defined to generate a DMSP binary image.

The DMSP binary image was then classified into night-light and background classes, so polygons of night-light were defined. These night-lights foci were used to compare with the spatial location of the cities and *vila*s available, and the extension of the urban areas.

3.3 Integration of TM/Landsat Data with DMSP/OLS

TM/Landsat images were used to verify the relations between DMSP night-light focus and the urban area of the cities. The spatial resolution of 30 m and the spectral bands of TM/Landsat sensor enable the detection of urban areas. Urban structures as houses, buildings, parking, civil constructions, roads, asphalt, etc., are easily distinguished in the TM3 band because of the intense spectral response of these targets at the red visible wavelength (0.63 μm a 0.69 μm).

The intense cloud cover in the Amazon region and the large dimension of the area restricted the number of the TM/Landsat scenes available, so this analysis was limited to Mato Grosso State. To that end, we included 32 TM/Landsat band 3, from 1999 dry season, to our spatial database. A linear contrast was applied over these images to enhance the urban areas.

For every *município* in the Mato Grosso state, the urban area was defined as polygons that had their total area calculated by the GIS. These urban area values were introduced in the database as an attribute in the table, to be further comparable with the night-light foci.

3.4 Use of Ancillary Data

The image data available in the "Mosaico do Brasil" (www.dpi.inpe.br/mosaico) were used to locate urban sites and to identify the features pointed out by the night-light focus. Basically, TM/Landsat colour compositions (TM3-B, TM4-G, TM5-R) available for 1998 and 1999, and the JERS-1 SAR mosaic image of 1995 were used.

4 Results

4.1 Detecting Human Presence and Activity

By visualising the DMSP night-lights foci with the city centres and *vila*s overlaid, it was possible to assess the ability in the DMSP night-lights to detect human activity. Some IBGE urban centres had their geographical position corrected, based on the DMSP night-lights, with confirmation obtained from TM/Landsat data.

Considering the DMSP image threshold adopted (ND>30), 261 night-light foci were detected, while with ND>7, it was possible to identify 560 foci. Even without any specific geometrical correction, the visual analysis verified a general good spatial correspondence between the night-lights foci and the IBGE urban centres, as presented at **Figure 2**.

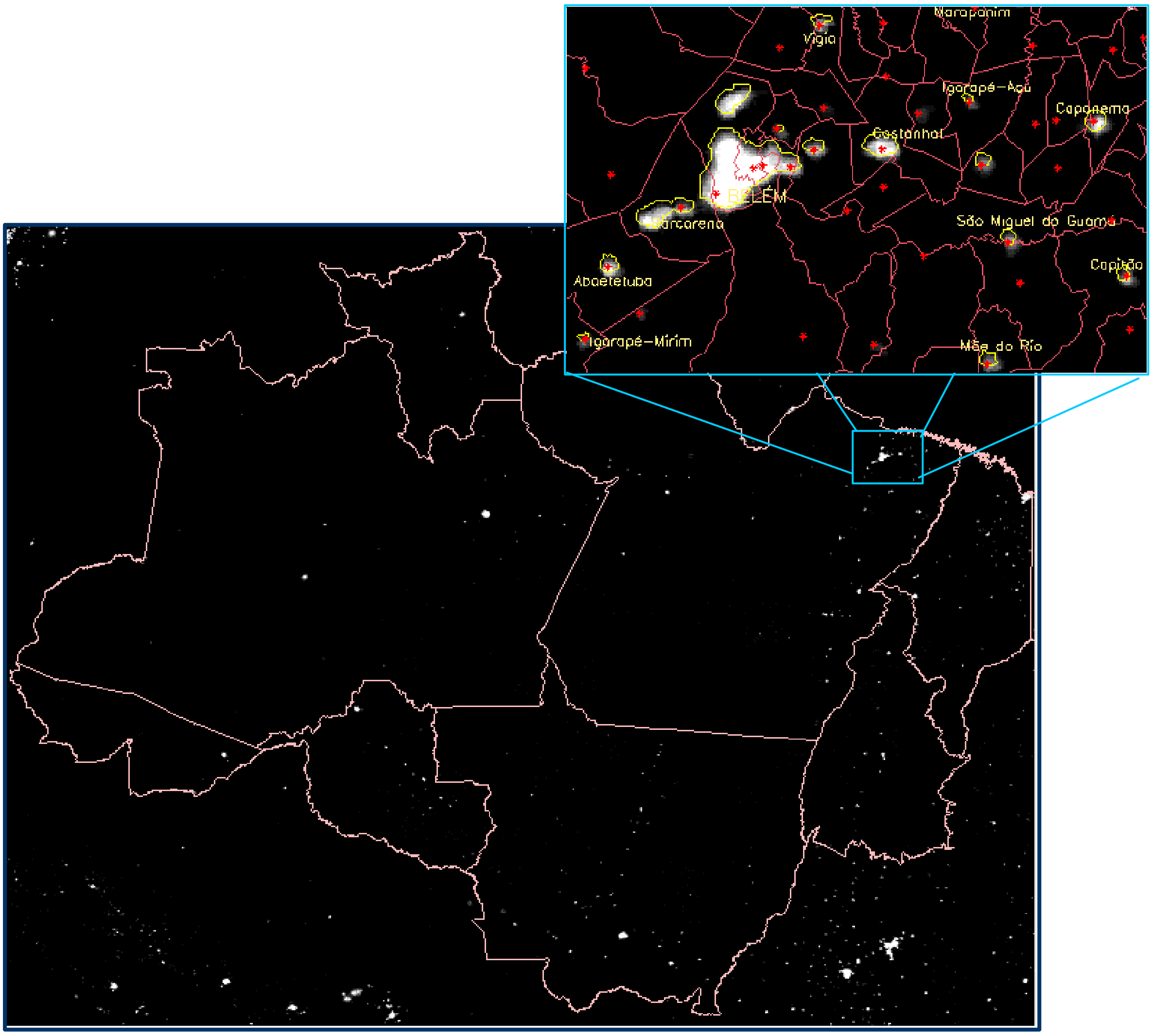


Figure 2 - DMSP/OLS image over the Amazonia with a detail of Belém-PA region.

From the total of 261 night-light foci, 149 contained IBGE urban centres and 64 were less than 5 km from IBGE urban centres. 48 night-light foci were not related to any urban centre. Using the ancillary data from "Mosaico do Brasil" these 48 foci were analysed.

The results, summarised in the **Table 1**, indicate that the DMSP night-lights detection is always related to human activity. Even in places without resident population, the lights point out human presence that requires some type of infrastructure, such as mining or oil production. **Tab. 01**

Analysing the 749 *municípios* from the Legal Amazon, 186 are inside the night-light foci and 62 are less than 5 km from the foci, a total of 248 cities detected by the DMSP/OLS data. Considering the total resident population **(Table 2)**, DMSP/OLS imagery could, in some cases, detect the night-lights from *municípios* with 1.000-2.000 people. **Tab. 02**

However, DMSP/OLS night-lights only detected all *municípios* in the population class of more than 500.000 residents. *Municípios* with population between 5.000 and 500.000 were partially detected.

Table 1 - DMSP night-light foci not associated with urban centres.

Description - targets observed at "Mosaico do Brasil"	Nº Focus
Urban settlements - small towns and *vila*s - missing at IBGE census	9
IBGE *Vila*s	3
Urban nuclei near to big cities	4
*Vila*s near to reservoirs	2
Mining	3
Oil and Gas production (URUCU-AM)	1
IBGE urban centres - inaccurate coordinates	16
Unable to check - TM/Landsat or JERS images not available	7
Out of Amazon Legal limits	3

From this result, 501 towns were not detected with DMSP night-lights. Santa Luzia do Maranhão was the *município* with the highest population (53.287 people, 19.450 at urban area); in this case the lack of TM/Landsat image for this area suggests frequent cloud cover. Alta Floresta (MT) had the biggest urban population (35.053 people), and only was detected with the DMSP image threshold of DN=7, probably the fires and smokes, very intense in this region at that time of the year, attenuated the night-light signal. Only 25 of these 501 towns not detected by DMSP had urban population greater than 10.000 people. With exception of Alta Floresta and Rosário do Oeste, situated at Mato Grosso state, all of then are at north part of the region, at Acre, Amapá, Pará and Maranhão states where the cloud cover is very frequent.

Table 2 - Municipal population and *municípios* in the Legal Amazon.

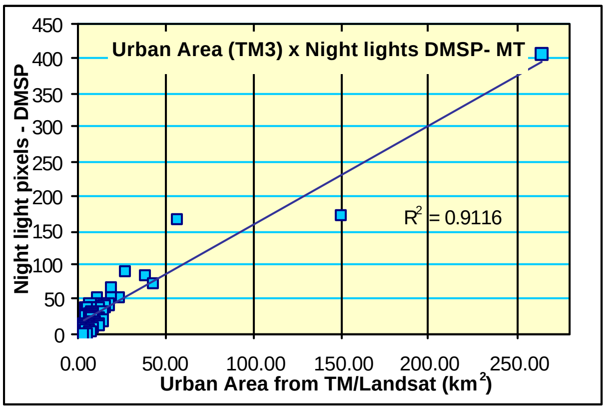
Population (IBGE-1996)	Number of *Municípios*	
	Total	DMSP light
0 - 1000	1	0
1.000 - 2.000	31	1
2.000 - 5.000	135	5
5.000 -10.000	190	28
10.000 -20.000	219	67
20.000 -50.000	159	96
50.000 - 100.000	37	34
100.000 - 200.000	10	7
200.000 -500.000	7	7
500.000 - 1.000.000	1	1
> 1.000.000	2	2
Total	**792**	**248**

Among the 248 towns detected by DMSP night-lights, Paço do Lumiar (MA) presented the smaller urban population (1095), but it is adjacent to São José do Ribamar and São Luís, the capital of Maranhão state, configuring a metropolitan region. The city detected by DMSP night-lights with the smallest urban population was Alto Alegre (RR), with 3.292 people.

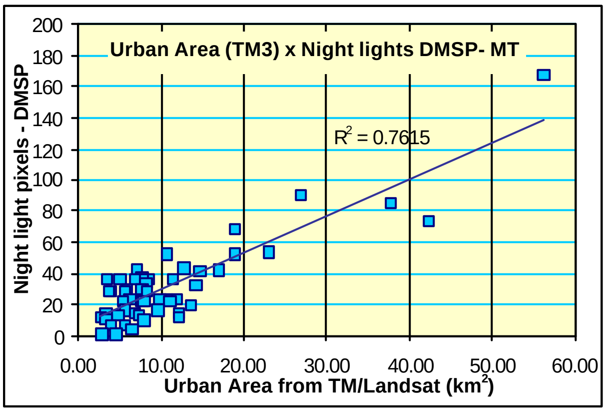
4.2 Locating and Measuring Urban Areas

To correlate DMSP night-light area with the urban area extracted from the TM/Landsat images, the total of DMSP night-lights pixels was calculated for every *município* having the municipal boundary as a spatial restriction. This area value was stored in the table of *municípios* in the database.

From the urban area analysis, performed to Mato Grosso state, 56 towns from 118 *municípios* had its night-light detected by DMSP imagery. The **Figure 2** presents the linear relation that can be obtained between urban area, identified from TM-3 Landsat and night-light foci.



(a)



(b)

Figure 2 - Relation between urban area detected by TM/Landsat and DMSP night-lights: (a) considering all *municípios*, (b) without Cuiabá and Várzea Grande - metropolitan region.

The urban area identified from TM/Landsat image was linearly related to the area defined from DMSP night-lights, with a R^2=0.91, if we consider the capital and the metropolitan region, and R^2=0.76, if we exclude this extreme values. The DMSP night-lights, corresponding to towns, are then a reference of urban infrastructure area, like streets, houses and civil constructions that requires night illumination.

5 Conclusion

This work presented the first results from the analysis of DMSP/OLS nighttime image to detect human settlements in the Amazon region. With the data available, it was observed that the detection of cities and towns is limited by several factors like cloud cover, smoke, and the threshold definition to the DMSP image. Even with these limitations, DMSP night-light image is a potential data to identify human presence, not only urban regions, but also any human activity that requires illumination, as mining and others civil constructions.

From 749 *municípios*, only 248 were directly associated to urban centres. Therefore, our results do not support the claims made by Miranda (1999) of the detection of 1300 towns and cities from DMPS/OLS. Further comparison with results from Miranda (1999) is hindered, since this author did not publish detailed information about his data sets and analysis procedures.

A strong linear relation was obtained for the urban area identified from TM/Landsat image and from DMSP night-light. It was expected since the urban area is usually illuminated in a continuous extension.

Better results could be obtained with a DMSP image mosaicked from at least 6 months of single orbits with fine resolution (0.56 km). Additionally, the radiance image and not only relative frequency of night-light image would provide better estimates of area and population.

The results presented here are just part of the data obtained from the analysis of DMSP/OLS imagery. To continue this work, the relations between DMSP/OLS data with other variables like population and electrical energy will be explored.

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