Detection of Areas Affected by Flooding River using SAR images.

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1. Abstract

This paper investigated the factors most significant impact on the response of a radar image for the detection of water bodies for flood affected areas, among which are: the electromagnetic spectrum, the angle of incidence, polarization, the dielectric constant and surface roughness of the object, among others.

Furthermore, in a general way indicated the techniques that are used for detection of flooded areas, as is the select of thresholds, thereby separating the water seeks other elements such as ground or vegetation, and detecting changes through the analysis of images of different dates.

Finally we give some examples of studies from around the world, considering some work in emergency situations within the framework of the International Charter Space and Major Disasters "Charter".
2. Introduction

The Earth Observation from remote sensing provides an important source of information territory, allowing the analysis and evaluation of different parameters and environmental phenomena through image processing. In addition, this set of techniques allow the monitoring of disasters such as forest fires, floods, earthquake. In this sense the availability of real-time information in the emergency phase is critical to support the adoption of measures for the disaster and also for later performances of responsible risk managers [Vales J.J., 2010].

Monitoring and evaluation of impacts in emergencies natural and human origin, has deepened in recent decades, due to the use of this technique, accessing valuable information for decision-making in areas of prevention and response to specific situations risk.

Applications of satellite images, optical and radar, are used in earthquakes, tsunamis, volcanic eruptions, landslides, floods, forest fires, marine pollution, among others.

In the present study, we investigated the techniques used in radar images for detection of flooded areas

3. Satellite Images

Satellite images can come from satellite sensors "passive" or "active" according they capture the electromagnetic energy reflected from the Earth's surface or produce their own energy beam and receive the backscattered signal energy. The first group corresponds multispectral sensors such as, for example: Landsat3 series, the series SPOT4, etc. Also active sensors radar technology. The second group includes technology sensors SAR (Synthetic Amplitude Radar) This group is processed satellite data from the sensors of the series: ERS 24, Radarsat5, Envisat4, Alos6 and others [CONAE., 2008].
3.1 Radar Images:

Radar is an acronym for detection and localization by radio.

A radar system has three primary functions:
- Transmit microwave signals (radio) to a scene.
- Receive portion of the transmitted energy, reflected to the sensor from the illuminated scene.
- Observing the reflected signal strength and the time required for return to the sensor signal.

3.1.1 Synthetic Aperture Radar (SAR)

A radar system side lighting, which produces a fine-resolution image of the area under observation.

Moving along its path, the radar illuminates one side of the flight direction, continuous strips parallel to each other, of the surface under study and accumulates information reflected microwaves. The signal is recorded on board, properly processed to form a digital image.

The distance between the radar and the target surface in the direction perpendicular to the flight is called range.

Is known as the azimuth distance along the path.

In a radar system, the resolution has two dimensions, one in the range direction and another in the azimuth (fig. 1).
Using a digital signal processing, the image can be focused and thus obtained a resolution better than of a conventional radar [CCRS].

4. Factors that determine the response of the radar

Parameters of the radar:
- Direction of observation (incidence angles of the pulses emitted)
- Observation mode (up / down)
- Frequency and wavelength
- Polarization

Parameters of the landscape:
- Heterogeneity and roughness
- Earrings, heights, features, geometric shape and orientation of the structures.
- Moisture content and dielectric properties.

Environmental parameters. climatic and anthropogenic:
- Temperature, rain and wind
- Dew and fog
- Height of water level in coastal areas
- Fire and forms of soil management
The following will detail some of them:

### 4.1 Electromagnetic Spectrum:

The electromagnetic spectrum is a representation of the energy, depending on the frequency (or wavenumber). The energy travels at the speed of light in the form of waves and can be detected through its interaction with the environment.

Some characteristics of electromagnetic energy are: frequency, polarization and wavelength (inversely proportional to frequency).

Remote sensing using radar employs portion of the electromagnetic spectrum where the microwaves are presented which have frequencies between 0.3 and 300 GHz and wavelengths between 1m and 1mm [CCRS]. (fig. 2).

Currently, the work systems SAR, consider the following microwave bands [ASAR Product Handbook, ESA 2007]:

- Band C, 5.3 GHz (ESA ERS and Envisat, the Canadian Radarsat, and U.S. shuttle missions)
- Band L, 1.2 GHz (the Japan J-ERS and ALOS)
- Band X, 10 GHz (The Germanic-Italian X-SAR shuttle missions)

The bands indicated previously can be seen in fig. 3, shown below.
4.2 Angle of incidence:

The incidence angle $\theta$ is defined as the angle between the radar beam and a line perpendicular to the surface (nadir). The interaction of microwaves with the surface are complex and different reflections can be generated in different angular regions. The return signal is normally stronger at low angles of incidence and decreases with increasing angle of incidence [Lanfr. S., 2011].

Below is a table of the different angles of incidence to the specifications of the swaths ASAR Image Mode:

<table>
<thead>
<tr>
<th>Image Swath</th>
<th>Swath Width (km)</th>
<th>Ground, position from nadir (km)</th>
<th>Incidence Angle Range</th>
<th>Worst Case Noise Equivalent Sigma Zero</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS1</td>
<td>105</td>
<td>187 - 292</td>
<td>15.0 - 22.9</td>
<td>-20.4</td>
</tr>
<tr>
<td>IS2</td>
<td>105</td>
<td>242 - 347</td>
<td>19.2 - 25.7</td>
<td>-20.6</td>
</tr>
<tr>
<td>IS3</td>
<td>82</td>
<td>337 - 419</td>
<td>26.0 - 31.4</td>
<td>-20.6</td>
</tr>
<tr>
<td>IS4</td>
<td>88</td>
<td>412 - 500</td>
<td>31.0 - 36.3</td>
<td>-19.4</td>
</tr>
<tr>
<td>IS5</td>
<td>64</td>
<td>490 - 555</td>
<td>35.8 - 39.4</td>
<td>-20.2</td>
</tr>
<tr>
<td>IS6</td>
<td>70</td>
<td>550 - 620</td>
<td>39.1 - 42.8</td>
<td>-22.0</td>
</tr>
<tr>
<td>IS7</td>
<td>56</td>
<td>615 - 671</td>
<td>42.5 - 45.2</td>
<td>-21.9</td>
</tr>
</tbody>
</table>

ASAR Product Handbook, ESA 2007
4.3 Polarization:

When an electromagnetic wave traveling in space, the electric field vector describes an ellipse in the plane of the wave. Characterising this ellipse define the state of polarization, this refers to the spatial orientation of the plane of oscillation of the electric field which can be oriented vertically, horizontally or at some other angle. They are described as plane waves or linear waves when it is horizontal or vertical polarization as shown in Fig. 4 [Karszenbaum H.].

(fig. 4)

The magnetic field at all times remains perpendicular to electric, it is important that according to the target characteristic, the result of the interaction between target and wave may be distinctly different depending on whether an incident wave of horizontal or vertical polarization.

A radar system that uses H and V can have the following channels:

HH - Horizontal transmission, reception horizontal (HH) (copol)
VV - Vertical transmission, reception vertical (VV) (copol)
HV - Horizontal transmission, reception vertical (HV), and (crosspol)
VH - Vertical transmission, reception horizontal (VH). (crosspol)

These systems may have several levels of complexity in the polarization characteristics:

- Simple Polarization: HH, VV, HV, VH (one of four)
- Dual Polarization: HH and HV, VV and VH, or HH and VV (two of three)
- Four polarizations: HH, VV, HV, and VH

A quadruple polarization radar (polarimétrico) uses these four polarizations and measures the difference in phase between channels well as intensities.
Interaction of Electromagnetic Radiation with

To explain the electromagnetic wave propagation in a material in need introduce some properties of the medium. In particular, the electromagnetic wave interaction with the soil depends on the electrical properties (dielectric constant) and surface roughness [Karszenbaum H].

4.4 Dielectric Constant (degree of humidity):

In the microwave region of the dielectric properties of the material determine the characteristics of the electric field, and depends on the water content. The moisture content of the surface, significantly modifies the response of the radar.

The dielectric constant is a parameter that measures the electrical properties of a medium surface and consists of two terms: the permittivity and conductivity. The values of dielectric constant of the soil in an almost linear increase with increasing water content, thus increasing the radar reflectivity of the surface [Karszenbaum H].

In the microwave region, the dielectric constant of most natural materials varies between 3 and 8. Water has a dielectric constant of 80. This makes the radar response has variations due to the presence of water in soil and vegetation.

The increased moisture in the medium, reduces the signal penetration below the surface and / or through the canopy. A high dielectric constant, implies high moisture content, high reflectivity, and potentially high response.

4.5 Roughness of the surface of the object

The degree of roughness of a surface depends on the dimension of the roughness present in relation to the wavelength of the incident electromagnetic energy and angle of incidence. The average roughness of an object is determined by the dimension of the roughness (measured in cm) present on the surface, measured in the vertical (height of the roughness) or horizontally (spacing between roughness).

As in reality for many surfaces that definition hardly characterizable in quantitative terms. The objective criteria to establish the degree of surface roughness is defined by Rayleigh [Elachi, 1988], taking into account the wavelength value, the
angle of incidence of the emission, and is expressed as follows. The object surface is considered smooth (not rough) if:

\[ h < \frac{\lambda}{8 \cdot \cos(\theta)} \]

Where \( h \) is the average height of the surface roughness (measured in cm), \( \lambda \) represents the wavelength of the incident radar energy (measured in cm), and \( \theta \) represents the value of the angle of incidence of the wave on the object surface.

In terms of radar reflectivity, it should be noted that a smooth surface will reflect all the incident energy at an angle of reflection similar but opposite to the angle of incidence, while a rough surface the diffuse in all directions even in the sensor, which will register a certain percentage of energy (fig. 5).

Increased surface roughness leads to an increase of the diffusion and in the percentage of energy reflected toward the antenna causing higher brightness of the corresponding pixel on the image.

In radar observation of the Earth's surface, one can observe that the elements of the territory that have smooth surfaces (Fig. 6) will be represented on the image with darker shades of gray (streets, water surfaces, airport runways, etc.) tending
to black. This means that such elements behave as optimal lighting reflectors radar and therefore retrodispersan very little energy to the antenna.

![Radar Reflection Diagram](fig. 6)

### 4.6 Backscattering Coefficient

The backscatter coefficient ($\sigma$) represents the effect of the earth’s surface on the radar signal, i.e., the percentage of the electromagnetic energy is reflected back to the radar from a ‘cell or resolution unit’. This is calculated as:

$$\sigma^b = \frac{\sigma}{\text{Area}}$$
The value of $\sigma$ for a particular surface depends on various parameters of the field (such as geometry, roughness, the moisture content) and radar parameters (wavelength, angle of incidence, polarization). The backscatter coefficient is proportional to the intensity ($I$) incident [Lanfri. S., 2011].

The values of the backscattering of radar images can be expressed in different ways:

<table>
<thead>
<tr>
<th>Potency</th>
<th>Amplitude</th>
<th>Decibels</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma$</td>
<td>$\sqrt{\sigma}$</td>
<td>$10 \cdot \log \sigma$</td>
</tr>
</tbody>
</table>

The potency ($P$) is the average flux per unit time received by the antenna and is a representation of $\sigma$ in potency of backscatter coefficient. In turn, the potency ($P$) is proportional to the square of the amplitude of the wave ($A$) and therefore the square root $\sigma$ in potency is $\sigma$ in amplitude. Finally, $\sigma$ may also be expressed in logarithmic form, for example in decibels (dB $\sigma$). The latter representation is useful because the intensity of the response of the radar has a dynamic range which can be several orders of magnitude in potencies of ten.

5. Radar Imaging Applications for Detection of Water Bodies and Flooded Areas.

One of the major advantages of using SAR images corresponds to the ease of distinguishing between water and other classes, given by the high contrast that exists. Water bodies act as a mirror reflecting surface, their response is low (low backscatter coefficient in SAR images) and then looks like a dark area. The earth, for its part, gives a much greater amount of radar energy due for example to the surface roughness and this generates the high contrast between surfaces: soil and water [Lanfri. S., 2011].

For the particular case of water, wind, waves, or runoff, can cause changes, because the wavelengths in the radar images are usually sensitive to these changes in water bodies. These changes result in enhanced backscattering and hence lowers the contrast between surfaces of water compared to the other cover. This is directly related to the size of the body of water where these surface changes are imperceptible in water with small surfaces.

Through change detection is possible to know the status of some phenomenon visualizing it in two different times. In practice, the phenomenon in question may be for example, an overflow stream, and as a result, the flooding of the surrounding areas [Lamperein., 1999].
SAR appears to be an ideal sensor for detecting flooding in extensive areas, since the backscattering signature is so distinctive water compared to the vegetation [Lewis et al., 1998]

Backscatter intensity and coherence InSAR can be used successfully together for mapping the regions affected by the floods [Joyce K. et al., 2009]

In the study by Oberstadler et al. (1997), shows that the flood areas appear darker in SAR (ERS) in the image intensity and, therefore, the comparison of two images before and during flooding, it is possible to assign the flooded areas with a high degree of precision.

In coherence maps a pair of SAR images acquired before and during floods, the flood-affected areas have significantly lower coherence than in dry areas, making it possible to clearly identify these areas. [Joyce K. et al., 2009]

In the case of wetlands, the water, is of great importance in the application of SAR data, because it affects the dielectric constant of the surface, and therefore its backscatter coefficient. The behavior of the earth backscattering is regulated by the geometric features of the surface and the dielectric properties of the soil, which depends on the water content (humidity). The dielectric constant increases with soil moisture content also influences the wavelength. The longer the wavelength, the greater the sensitivity of the dielectric constant moisture content in soil. [Elachi, C. 1987]. This means that in the L band SAR images tend to be more sensitive to moisture in the soil than the bands of shorter wavelength [Leão de Moraes E. 2006].

Should be considered to wetlands rarely presented without cover vegetal. Even in flood phases become aquatic systems, aquatic vegetation present. Therefore, the microwave radiation interacts first with vegetation, before interacting with the substrate.

Therefore for these cases should consider some factors that affect the behavior of backscatter: the dielectric constant, height, density and biomass, the size, shape and orientation of the individual components [Leão de Moraes E. 2006]

5.1 Methods Used

Various image processing techniques are used to delimit areas covered with water from SAR images. Traditionally, the detection of water bodies in SAR has been carried out by selecting the thresholds in intensity image [Brivio et al., 2002].
However, the selection thresholds have problems in land and water separation, for example, at different angles of incidence.

In relation to the detection of water bodies in SAR radar images, there is no single method that can be considered appropriate for all images, not all methods are equally good for different types of images [Pal & Pal, 1993 in Lanfri. S., 2011].

A body of water whose roughness is determined by the Rayleigh criterion can be modeled as specular scattering (low backscatter values) and is dominated by dark tones in the SAR image [Horritt et al., 2003]. Due to the horizontal nature of water, images acquired with HH polarization mode are preferred before the VV polarization.

Similarly, it is assumed that the greater the angle of incidence is a greater contrast between the water and the rest of the land surfaces. On the other hand, to detect any type of flood low plant canopy, sensors measuring both C-band and L-band are suitable, and HH polarization is better than the VV [Bourgeau-Chavez et al., 2001]. If there vegetation, in the body of water analyzed, is commonly observed an increase in radar backscatter that dependent on the wavelength [Giacomelli et al., 1997]. For example, X-band and C-band signal is scattered by the leaves, small stems within the canopy of trees. P or L-band signal penetration gets higher in the canopy but strongly interacts with trunks and large branches.

Through change detection is possible to know the status of some phenomenon visualizing it in two different times. In practice, the phenomenon in question could be an overflow of a watercourse, and as a result, the flooding of the surrounding areas. By taking a picture of the river in its course, plus another at the time of maximum flood, you can know the magnitude of the event, the mere fact of knowing the differences between the two images.
6. Application Studies

6.1 "Study of Flood Affected Areas in the watersheds Guadalquivir and Guadalete Radar using images of the TerraSAR-X. REDIAM" [J.J. Vales et al]

This work was performed in the Guadalquivir River basin, in the areas of Jerez de la Frontera, Lora del Rio, Sevilla, Córdoba and Andújar, Spain. with satellite radar images Retrasar-X, acquired between 27 February and 8 March 2010.

The cloud cover that was presented in the region during the rainy season (fig. 7) difficult to study with optical sensors. Therefore, it was necessary to use radar images.

(fig. 7) Imagen METEOSAT
We performed automatically calculating flood mask, considering that water surfaces have a particular spectral signature that allows a fully automatic detection of areas due to the characteristics of the signal in X-band radar that uses satellite sensor Retrasar-X.

To determine the boundaries of the sheet of water was employed segmentation technique, which assumes that the images are formed by homogeneous regions separated by edges, where the radar reflectivity of the signal is constant.

Respect to the segmentation technique is necessary to indicate that they are a group of algorithms aimed at segmenting a raster, i.e., to separate objects of an image that we are interested in of the rest. With the aid of threshold methods in simple situations can decide which pixels correspond to the object of interest, and which pixels do not correspond to that object.

With the methods of segmentation is to assign each pixel to a certain group, commonly called "segment." The image to be segmented, as any rasterized graphic is composed of values. Of a pixel belonging to a certain segment is decided by comparing the level with a threshold value.

In general, automatic segmentation is one of the most difficult tasks in image processing [Belmonte and Caamaño. 2009]. Segmentation algorithms are based practically in two corresponding properties of the gray levels of the image: discontinuity and similarity. Within the first category are trying to divide the image based on abrupt changes in the gray level. The tasks of interest in this category are the detection of points, lines and edges in the image. Within the second category, interest focuses on the study of thresholds techniques, region growing, and, splitting and merging techniques.

Results:
Following the automatic segmentation process, there is a process of generalization of the polygons obtained. To decide which polygons are candidates for being water surface, using other information in that introduce additional constraints that allow limit the results, such as the MDT to detect depressions (pits) that collect water, or the analysis of the connection of polygons with the drainage network showing continuity.
6.2 "Using TerraSAR-X Technology for determination of flooded areas in emergency phase" [Tomás Fernández de Sevilla]

The purpose of this work was to determine the extent of the water surface caused by intense precipitation during the winter and spring period 2009-2010 in the region Andaluza, Spain. Through a flood mapping.

Worked with TerraSAR-X orthoimages called ORI-SAR, to obtain that product, geometrically corrected and georeferenced in ETRS89 reference system and projection UTM zone 30 was necessary to the application of a Digital Terrain Model (DTM), in this case with a resolution of 10 m. Geometric accuracy ORI-SAR, depends directly accuracy altimetric the "MDT", the precision in the determination of the orbit, and acquisition angle

In orthorectified images (ORI-SAR) was performed an automatic detection of areas covered by water, based on the signal at X-band radar, using the segmentation technique. About the vectorized result (polygon layer) apply a series of treatments to debug the geometry of the mask (sheet flooding). The geometric accuracy of the water level will never be better than that of the starting ORI-SAR, on which we must also consider the possibility of errors of omission / commission flooded areas.

Classification of areas covered by water:

On the sheet of water obtained, were classified soil types covered. Not all of the surface that is covered by water, may be considered as flooded, since there rivers and reservoirs. In addition, verification of current land use, through the interpretation of orthophotos.
6.3 "Radarsat satellite images for Emergency Monitoring and obtaining information for Disaster Prevention" [Lamperein P., 1999]

Below is a job which used three RADARSAT images to analyze the effect caused by the overflowing of the River Ohio in USA. Each image corresponds to a specific date of the event and to interpret, is assigned to each one a color (red, green, blue). Thus it can be seen the vector of change between the three dates. The product itself is very easy to get and in turn is very useful to evaluate the change vector.

This study considered a methodology for characterizing space/time for floods. Images were used RADARSAT-1 and 2, altimetry and rainfall data. The study area includes the area of the city of Villahermosa, Mexico. The algorithm USTC (Unsupervised semivariogram Textural Classifier) was used to identify the different cover classes representing: water, dry forest and flooded forest or buildings.

Three classes were individualized, considering the type of scattering predominant in the interaction white-pulse of radar: 1. Bodies of Water (specular reflection), 2. dry forest (diffuse scattering) and 3. buildings and flooded vegetation (lateral reflection).

The USTC classification identified three types of hedges tentatively associated to different types of interaction radar pulse, with surface targets.
6.5 "Mapping wetlands using multi-temporal RADARSAT-1 data and a decision-based classifier" [Parmuchi M. et al]

The study area corresponded to the Lower Delta Islands of the Paraná River, Argentina. For this study we used five RADARSAT-1 SAR images, corresponding to the C-band and HH polarization, three of them in 1997 (normal year) and two in 1998 (El Niño year). The images are presented in modes S1 and S6, corresponding to degrees of angle of incidence at which the images were taken.

Detail of the images used:

<table>
<thead>
<tr>
<th>Date</th>
<th>Band</th>
<th>Polarization</th>
<th>Mode</th>
<th>Incidence angle (°)</th>
<th>Season</th>
<th>Flood condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 Feb. 1997</td>
<td>C</td>
<td>HH</td>
<td>S6</td>
<td>41–46</td>
<td>Summer</td>
<td>Normal</td>
</tr>
<tr>
<td>16 Mar. 1997</td>
<td>C</td>
<td>HH</td>
<td>S1</td>
<td>20–27</td>
<td>Summer</td>
<td>Normal</td>
</tr>
<tr>
<td>7 Aug. 1997</td>
<td>C</td>
<td>HH</td>
<td>S1</td>
<td>20–27</td>
<td>Winter</td>
<td>Normal</td>
</tr>
<tr>
<td>18 May 1998</td>
<td>C</td>
<td>HH</td>
<td>S6</td>
<td>41–46</td>
<td>Winter</td>
<td>El Niño flood</td>
</tr>
<tr>
<td>22 May 1998</td>
<td>C</td>
<td>HH</td>
<td>S1</td>
<td>20–27</td>
<td>Winter</td>
<td>El Niño flood</td>
</tr>
</tbody>
</table>

The method used in this study to classify different coverage considered as prior knowledge basis of the dependence of microwave scattering in the system and, the geometrical properties of soil and vegetation.
The results obtained for the graph S6 February 16, 1997, under normal water level, shows a very uniform response between land cover types, except for the low values of water (no wind and average value of -24 dB) though correspond to different seasons of the year, graphics S1-16 March 1997, and S1-August 7, 1997 the responses are similar in all categories, except rushes. Such land cover shows a greater response than the other categories and with a difference of about 4 dB between summer and winter. Figure S6 of the May 18, 1998 (winter, the Niño phenomenon) and S1 of the May 22, 1998 (winter, the Niño phenomenon), a clear difference between the graphs can be observed. The changes in the contributions of scattering of the main types of land cover, due to strong variations in the water surface, are responsible for this behavior.

The image S6 Feb. 16 (Summer), 1997, is used to separate water from the types of coverage that are still lands.
7. Application in CHARTER

7.1 Floods in southern Manitoba, Canada and northern Minnesota, USA, June 2002.

7.2 Flooding in Santa Fe, Argentina. April 2003.

Multitemporal satellite image showing the receding flood waters during the 1-6 May period. Source: Landsat and Radarsat.

7.4 Flood in Nigeria. August 2011.

7.5 Flooding in Manila, Philippines. August 2012.

7.6 Flood Sindh Province, Pakistan. September 2012.


7.7 Flooding in Nigeria. September 2012.

7.8 Flooding south-east of England and Wales. December 2012.

Flooding in area 26/12/2012 - River Severn and the River Thames, Source: TerraSAR-X, Acquired: 26/12/2012, Copyright: TerraSAR-X/TanDEM-X © 2012 German Aerospace Center (DLR), 2012 Astrium Services / Infoterra GmbH
7.9 Floods in Mozambique, January 2013.

Floods in Chokwe, Guika, Bilene and Xai-Xai district, Gaza province, Mozambique. Source: TerraSAR-X, Acquired: 24/01/2013, Copyright: DLR Map produced by UNITAR / UNOSAT
8. Conclusions

Understanding the magnitude of the event, such as a river overflow, simply capturing an image of the river in its course, plus another at the time of maximum flood, and thus know the differences between the two images. However, that may present problems associated corresponds to the assumption that the flood water remains visible for a time period enough to allow acquisition of images.

Particularly in emergency situations, it is deemed necessary, in addition to the delineation of the flooded area, incorporating useful geographic information as populated areas, hydric and road network, land use, critical infrastructure, among other layers of information, thus can concretely evaluate the real impact and the effect caused by the flood.

Importantly ideally SAR image processing, must be combined with optical imaging, if weather conditions permit, just as this technique can be used with other geospatial data, such as a Digital Elevation Model "DEM", to estimate the depth of the flooded areas.
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