# Geotechnological Tools for Monitoring Disturbing Phenomena; Experiences from the National Laboratory of Earth Observation, UAEMéx

# Outils Géotechnologiques pour le Suivi des Phénomènes Perturbateurs; Expériences du Laboratoire National d'Observation de la Terre, UAEMéx

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**ABSTRACT:** Mexico is a country with physical-geographical and socioeconomic particularities that favor the occurrence of various disturbing phenomena, potentially dangerous for the population and infrastructure. The risks for the General Law of Civil Protection are established according to their origin in: geological, hydrometeorological, chemical-technological, sanitary-ecological and socio-organizational. This work will be focused on the use of geotechnological tools for the monitoring of geological and hydrometeorological phenomena, in particular phenomena monitored at the National Laboratory of Earth Observation. Through satellite images and geospatial data we will analyze phenomena that have occurred recently in the Mexican Republic. The objective of our work, using examples of the practical application of monitoring tools, is to make potential users aware of them, particularly in the areas of municipal civil protection, since some of these technologies are available online for use and allow an active response to natural hazards. Various products are presented that show monitoring of hazardous phenomena with geotechnological support.
**KEY WORDS:** geotechnologies, satellite images, geospatial data.

**RÉSUMÉ:** Le Mexique est un pays présentant des particularités physico-géographiques et socio-économiques qui favorisent l'apparition de divers phénomènes inquiétants, potentiellement dangereux pour la population et les infrastructures. Les risques pour la Loi Générale de la Protection Civile sont établis selon leur origine : géologique, hydrométéorologique, chimique-technologique, sanitaire-écologique et socio-organisationnelle. Ces travaux porteront sur l'utilisation d'instruments géotechnologiques pour le suivi des phénomènes géologiques et hydrométéorologiques, notamment les phénomènes suivis au Laboratoire National d'Observation de la Terre. Grâce à des images satellite et des données géospatiales, nous allons analyser les phénomènes survenus récemment dans la République mexicaine. L'objectif de notre travail est qu'à partir d'exemples d'application pratique des outils de surveillance, les utilisateurs potentiels en apprennent davantage, notamment dans les domaines de la protection civile municipale, puisque certaines de ces technologies sont disponibles en ligne pour leur utilisation et permettent une réponse active. aux risques naturels. Différents produits sont présentés qui montrent la surveillance des phénomènes dangereux avec un support géotechnologique.

**MOTS CLÉS:** géotechniques, images satellites, données géospatiales.

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## 1. Introduction

The National Earth Observation Laboratory (LANOT) officially began operations in 2017, when it received recognition as a national laboratory from the National Council of Humanities, Science and Technology (CONAHCyT). This laboratory has its main headquarters at the Institute of Geography of the National Autonomous University of Mexico (UNAM).

In general terms, LANOT performs tasks of receiving, processing and distributing Earth Observation (EO) data that receives data from various special platforms, with two main sources currently. The first of these are the Moderate Resolution Imaging Spectroradiometer (MODIS) and Visible Infrared Imaging Radiometer (VIIRS) sensors; which are transported aboard polar orbiting satellites, Terra, Aqua and SUOMI-NPP, respectively. The second source is the laboratory's flagship satellite, GOES-16, which is a meteorological platform with a geostationary orbit and one of its main sensors is the Advanced Baseline Imager (ABI). The data and products derived from these sources are distributed to the laboratory's partners and users. According to the last update about who are the members of the consortium, published in the laboratory website, currently, various federal government agencies of significant importance to the country use data generated by this laboratory. To mention a few, the Secretariat of the Navy, the National Meteorological Service, the Federal Electricity Commission, the National Center for Disaster Prevention, the National Institute of Statistics and Geography, among others (LANOT, 2024).

It is important to be clear that LANOT is a consortium made up of several academic and government institutions, and that the Autonomous University of the State of Mexico (UAEMéx) is among the main partners, through its Faculty of Geography (FG). This institution joined the consortium in 2018 and since then, actions aimed at strengthening it have been outlined; thus, in 2019, a space was enabled in the FG, as well as the acquisition of specialized equipment, to house the functions and activities inherent to it. With these actions, in that year what was called the National Earth Observation Laboratory - Faculty of Geography Unit (LANOT-UFG) was established.

Since Earth Observation through remote sensing is the laboratory's main capability, it is possible to direct actions dedicated to the continuous monitoring of the planet with the purpose of generating geospatial data that support research and decisions on hydrometeorological and geological phenomena that may represent a risk for the population and infrastructure, mainly in Mexico. This approach is framed in a global context in which, according to the Centre for Research on the Epidemiology of Disasters (2023), between the years 2003 and 2022, an average of 369 disasters have occurred. Of which, the highest annual averages are associated with events of hydrometeorological origin, such as floods (170) and tropical storms (104), whose death toll, in terms of annual average, amounts to 5,518 and 10,017 people deceased, respectively. For its part, economic losses on an annual average during the aforementioned period amounted to 196.3 (US$ Billion) with 41.1 (US$ Billion) for disasters associated with floods and 95.6 (US$ Billion) for those associated with tropical storms. It should be noted that, according to the same source, the year 2023 will exceed the annual averages reported between 2003 and 2022, both in terms of the number of disasters, deaths, and economic losses. In fact, for 2023, the disaster associated with Hurricane Otis in Mexico, with US$12 billion in economic losses, ranked fourth worldwide in this category.

Likewise, the National Center for Disaster Prevention (2024) reports that, in the period 2000-2023, the years 2010 and 2023 have been the costliest for the country in terms of disasters. Even Hurricane Otis, which occurred in 2023, exceeded the economic losses caused by the 2017 earthquake. It is worth noting that according to what was reported by this federal center, between the years 2000 and 2023, there is an increasing trend in the number of human lives lost due to disasters; going from 70 at the beginning of the period to 984 at the end of it.

That is why, with this work, we seek to make known in a main way the potential of the ABI sensor of the GOES-16 satellite, through the presentation of some examples of the use of some of its spectral bands in the monitoring of tropical cyclones during the current 2024 season in Mexico. Likewise, to show the use of other geotechnological tools specialized in disaster risk issues, which add to the generation of scientific dissemination information on the subject. Likewise, it is intended that potential users of this information, especially those who perform professional tasks in civil protection at the municipal level, know and ideally use these freely accessible tools, thus strengthening their capacities to act effectively in the fulfillment of their responsibilities and, at the same time, improve the capabilities of the laboratory by disseminating its products and its scientific work.

## 2. Study area

The observations carried out from the laboratory focus on the continental and maritime territory of the Mexican Republic, since some of the hydrometeorological phenomena that occur can become dangerous. However, due to the genesis, dynamics, evolution, as well as the extension and spatial distribution of these phenomena, it is necessary that monitoring be carried out in larger spaces and on a planetary regional scale.

In this sense, the observation of Region IV: North America, Central America and the Caribbean, defined by the World Meteorological Organization (WMO), which includes Mexico, becomes relevant. It should be noted that this region is fully observable in the Continental United States (CONUS) and Full Disk acquisition modes of the GOES-16 satellite.


**Figure 1** World Meteorology Organization Regions. Source: World Meteorology Organization (2024).

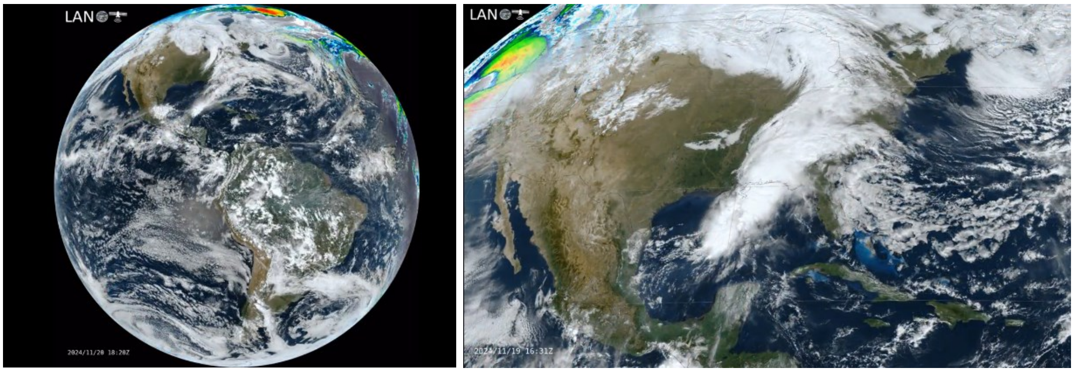


**Figure 2** Adquisition modes of GOES-16: left is Full Disk mode and right is CONUS mode. Source: LANOT (2024).

## 3. Methods

The observation of a hydrometeorological phenomenon, for example a tropical cyclone, begins with the review of two main sources: the first is the National Meteorological Service of Mexico, which offers information on cyclones from the time they are in the tropical disturbance stage, up to the maximum evolution they reach. The second source is the portal of the National Hurricane Center of the United States of America, which, in addition to providing information about the probability of evolution of cyclones, also provides data about the probable trajectory and its cone of uncertainty. This initial information is essential to have an idea of how dangerous the hydrometeorological phenomenon in question could be. The following figure shows, as an example, information published at the time by the aforementioned entities for the case of Hurricane John, which affected the Pacific coastal area in Mexico.

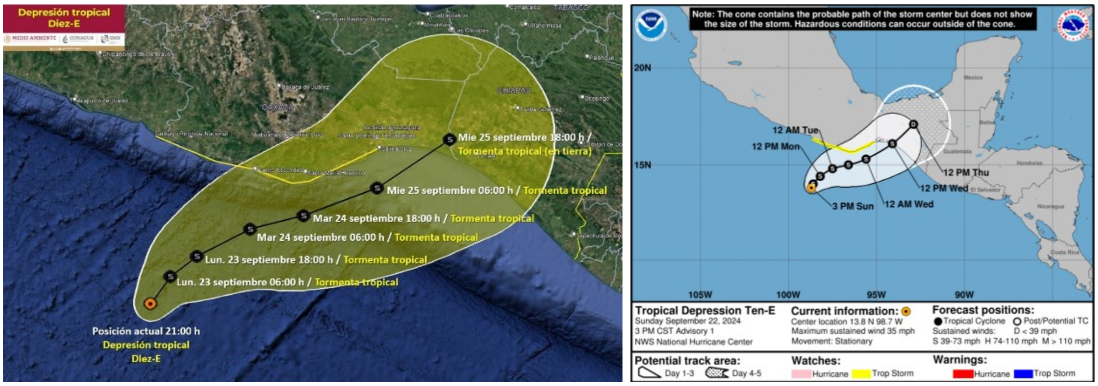


**Figure 3** Trajectory and evolution forecast of Tropical Depression Ten (after Hurricane John) emmited by National Weather Service (left) and by te National Hurricane Center (right). Sources: Mexico National Weather Service (2024) and U. S. National Hurricane Center (2024) respectivily.

Subsequently, the processing of geospatial data in the laboratory begins with the acquisition of images from the ABI sensor of the GOES-16 Satellite, through access to the receiving station; this is achieved through a File Transfer Protocol (FTP) type software which provides access to the complete LANOT data catalog. At this point, emphasis is placed on images that are at a processing level 1B. This level provides data in radiance values and brightness temperatures, for the bands of the visible region and the infrared region of the electromagnetic spectrum, respectively.

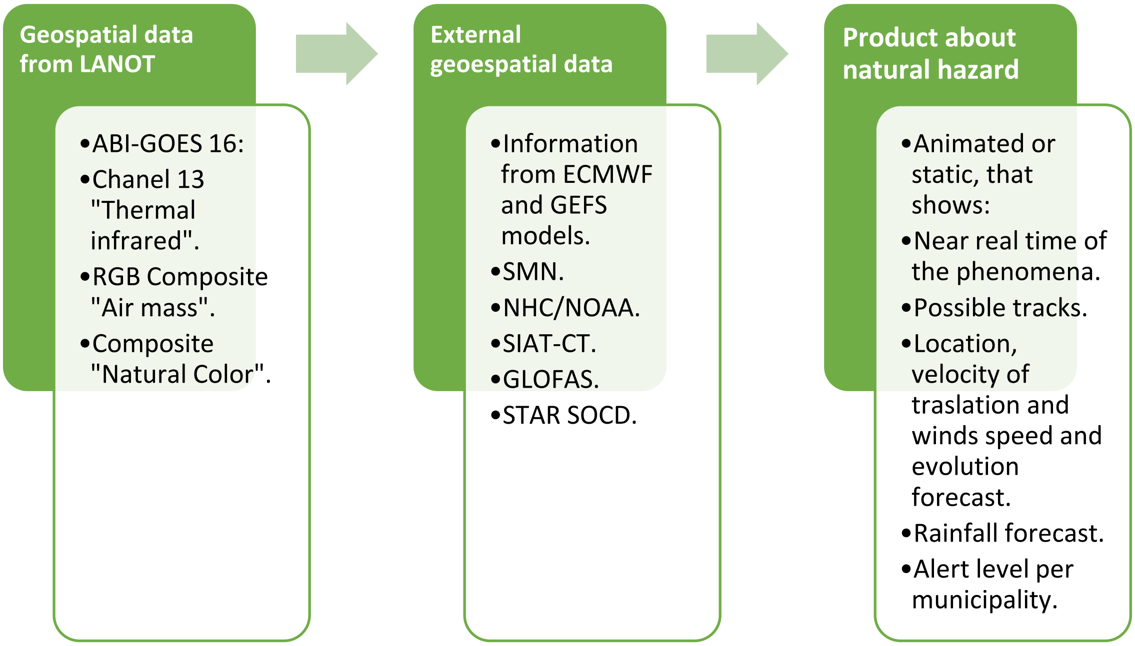


**Figure 4** The scheme represents the workflow, as well as the inputs and outputs of information and products, that are derived from the implementation of the data described in the following paragraphs. Source: own elaboration.

The following figure shows the nomenclature of the 16 ABI-GOES-16 bands, as well as their central wavelength and spatial resolution. The field called Nickname allows to know in a general way what is the primary application of each band.

| **Table 1** GOES-ABI Bands. Source: Schmit et al. (2018).**ABI Band** | **Central Wavelength (ɥm)** | **Type** | **Nickname** | **Spatial resolution (km)** |
|---|---|---|---|---|
| 1 | 0.47 | Visible | Blue | 1 |
| 2 | 0.64 | Visible | Red | 0.5 |
| 3 | 0.86 | Near Infrared | Veggie | 1 |
| 4 | 1.37 | Near Infrared | Cirrus | 2 |
| 5 | 1.6 | Near Infrared | Snow/Ice | 1 |
| 6 | 2.2 | Near Infrared | Cloud Particle Size | 2 |
| 7 | 3.9 | Infrared | Shortwave window | 2 |
| 8 | 6.2 | Infrared | Upper-level water vapor | 2 |
| 9 | 6.9 | Infrared | Midlevel water vapor | 2 |
| 10 | 7.3 | Infrared | Lower-level water vapor | 2 |
| 11 | 8.4 | Infrared | Cloud-top phase | 2 |
| 12 | 9.6 | Infrared | Ozone | 2 |
| 13 | 10.3 | Infrared | “Clean” longwave window | 2 |
| 14 | 11.2 | Infrared | Longwave window | 2 |
| 15 | 12.3 | Infrared | “Dirty” longwave window | 2 |
| 16 | 13.3 | Infrared | $CO_2$ longwave | 2 |

As can be seen in the list of bands, the ABI sensor offers a wide range of possibilities for observing the atmosphere; in the present study, bands 6, 10, 12 and 13 are highlighted, since they are the ones most frequently used for observing cyclones, either individually or through color composites. In this sense, band 13, with a wavelength of 10.3 um, allows us to know the brightness temperature and is essential for tracking hurricanes. For the visualization and analysis of these types of bands, the Satellite Information Familiarization Tool (SIFT) developed by Gerth et al. (2020) of the Space Science and Engineering Center (SSEC) of the University of Wisconsin is used. Through SIFT, it is also possible to perform algebraic operations applicable to spectral bands, as well as color compositions. A particular case is the compound called Air Mass, whose logic is explained in the following table.

**Table 2** Composición RGB para el producto "Air Mass".

| Color | Bands (μm) | Min - Max | It is related to: |
|---|---|---|---|
| Red | 6.2 - 7.3 | -26.6 to 0.6 | Vertical water vapor diffference |
| Green | 9.6 - 10.3 | -43.2 to 6.7 | Tropopause heihgt based on ozone |
| Blue | 6.2 (Inverted) | -29.25 to -64.65 | Water vapor ~200-500 mb |

Source: NASA SPoRT (2018).

As can be seen in the table above, the difference between wavelengths of the selected bands is used to highlight specific characteristics of the terrain. This process is based on the spectral response of each band, which allows to identify variations in the properties of the surface. The selected bands are assigned to the RGB components (red, green and blue) to form a composite image. Finally, the necessary parameters are adjusted to obtain the final product, in this case the "Air mass" composite. This product is used to diagnose the environment surrounding synoptic systems by enhancing temperature and humidity characteristics of air masses and has as primary applications inferring cyclogenesis and the identification of polar and tropical air masses.

A next source of information, which has to do with the possible trajectories of cyclones, since there are various global forecast models and sometimes they can present differences in this regard. In this regard, the Weathernerds meteorology portal offers information on this subject based on models such as the European Centre for Medium-Range Weather Forecasts (ECMWF), the Global Ensemble Forecast System (GEFS), the Global Forecast System (GFS), the Icosahedral Nonhydrostatic model (ICON), among others.

Satellite images at processing level 1 do not offer all the information that a civil protection actor should have for better risk management; In this regard, the Global Flood Awareness System (GLOFAS) of the Copernicus Programme of the European Space Agency represents a very useful geotechnological tool, since, based on meteorological models and other sources of hydrological data, it allows to know the probability of rainfall of certain intensities and this in turn, links it with reporting points located in the context of hydrographic basins, to estimate the possible hydrological response of the causes and thus, predict extreme events that could generate overflows, when the return period of two, five, ten and even twenty years is exceeded. This system also allows to identify potentially flooded areas based on simulations and after the event, as soon as there is an image from the Sentinel 1 satellite available, which has a Synthetic Aperture Radar sensor, it allows to identify the areas that were actually flooded.

The data generated by SAR sensors are also useful for monitoring cyclones; In this case, The NOAA STAR Water Surface Conditions (WSC) provides images with estimates of maximum winds at the time of acquisition by the Sentinel 1 satellite. On the other hand, in the powerful Google Earth Engine tool, rapid mapping algorithms can be run to detect flooded areas from SAR images and overlay other layers of information related to the exposure of people and material assets. In this work, the code developed by the United Nations Office for Outer Space Affairs (2019) and published in the UN-SPIDER Knowledge Portal was used and adapted to a strip on the coasts of Guerrero and Michocán, Mexico, to assess the possible damage caused by flooding after the passage of Hurricane John between September 23 and 29, 2024.

## 4. Results and discussion

As already mentioned, in addition to the products generated from GOES-16 data, other geotechnological resources are used, since it is essential that these tools are known and used. In addition, it is important to remember that one of the main objectives of the laboratory is the scientific dissemination of the products produced there. Such as infographics that describe the main characteristics of disturbing hydrometeorological phenomena, while these affect some part of the Mexican Republic, which at that moment represent a threat, as shown in the following figure.

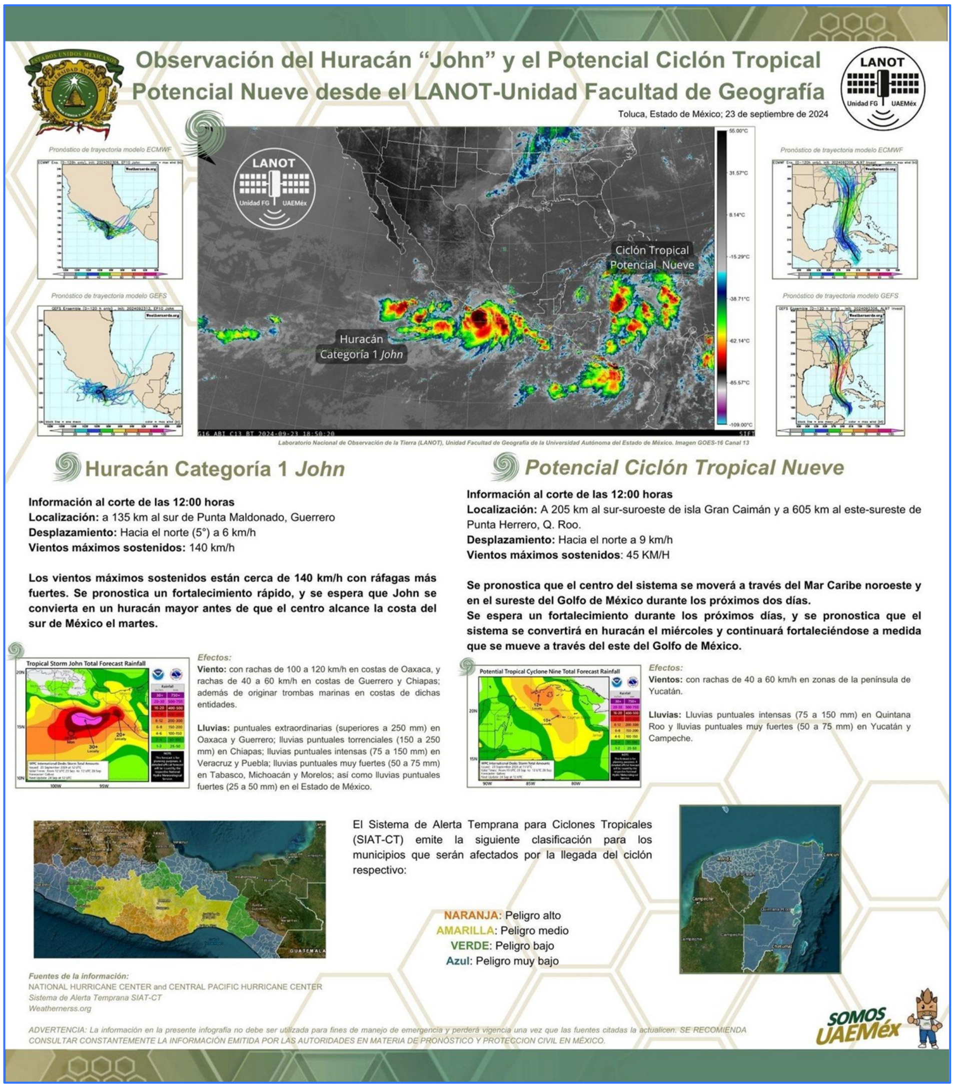


**Figure 5** Infographic from September 23, 2024. Source: Own elaboration.

The infographic in Figure 5, issued on September 23, 2024, shows cyclonic activity in the Pacific (left) and Atlantic (right) oceans. At that time, what was then Hurricane John was developing in the Pacific, while Potential Tropical Cyclone number 9 was being observed in the Atlantic. The infographic is made up of various products, from top to bottom the following are shown: observation of hydrometeors through channel 13 of ABI-GOES 16; trajectory forecasts according to the ECWMF and GEFS models; rainfall forecast issued by the National Hurricane Center and finally, danger level by municipality, issued by the Early Warning System for Tropical Cyclones of Mexico.

Another of the infographics prepared in the laboratory was made with the purpose of helping the community understand how different atmospheric phenomena work. Figure 6 illustrates and explains, for example, the influence that dust from the Sahara Desert has on the atmosphere in the possible formation of hurricanes. This infographic clearly and visually shows the presence of dust particles suspended in the air, which can inhibit the development of tropical cyclones by reducing humidity in the atmosphere or altering the dynamics of cloud formation. In this way, the laboratory contributes to environmental education and this type of educational material seeks to foster interest and understanding of atmospheric processes and their impact on the planet, as well as interest in geosciences.


**Figure 6** Infographic made at the National Earth Observation Laboratory - Faculty of Geography Unit of the UAEMéx on July 12, 2024.

### 4.1. Tropical cyclones image with data from ABI-GOES 16

Band 13 of the GOES-16 satellite's ABI sensor is essential for monitoring and analyzing hurricanes because it captures emissions in the infrared range (10.3 µm). The image, generated on September 24, 2024, allows the observation of the temperature of the Earth's surface and clouds, even in the absence of sunlight. In the context of the hurricanes present at that time, it facilitated the identification of key structures, such as the eye and cloud bands, as well as the monitoring of their intensity and trajectory. Its high temporal resolution significantly improves the ability to predict and respond to these phenomena, since depending on the acquisition mode, this channel can be reviewed every 10, 5, and 2 minutes.

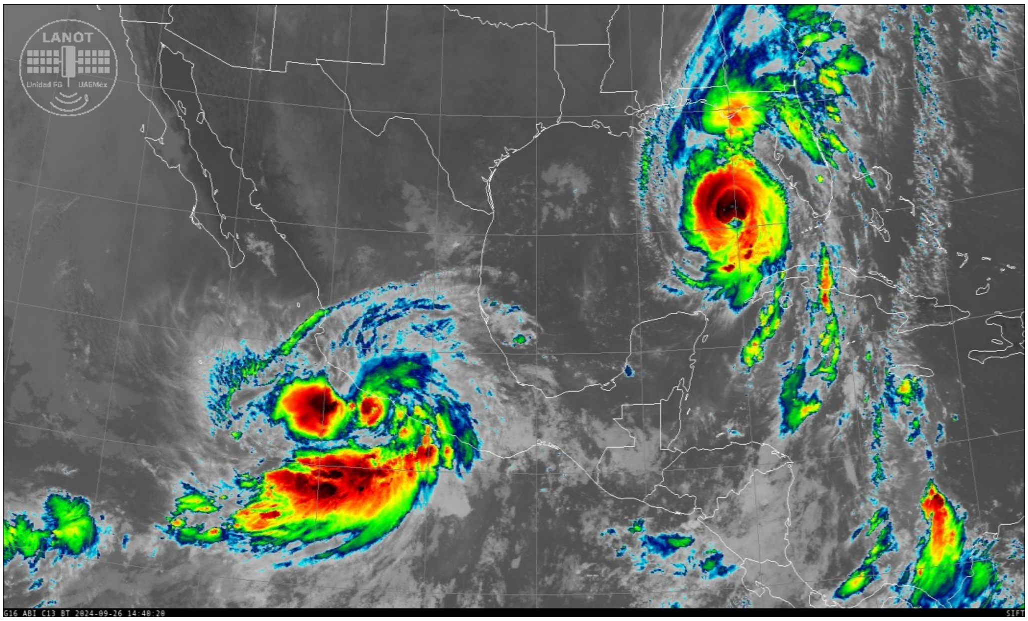


**Figure 7** Product generated from GOES-16 Satellite Band 13 (ABI). Hurricane "John" to the west and Hurricane "Helen" to the east.

### 4.2. "Air Mass" false color composite

The Air Mass RGB product enables us to diagnose temperature and humidity characteristics in air masses. This approach is essential for analyzing synoptic systems and their environment, as it facilitates the identification of polar and tropical air masses, potential vorticity (PV) anomalies associated with jet streams and stratospheric air intrusions, and clouds at different levels of the atmosphere.

Air Mass RGB combines data from multiple spectral channels to highlight differences in water vapor, ozone content, and tropopause height. The generated colors indicate specific atmospheric conditions, such as dry or moist levels in the upper atmosphere, and the presence of PV anomalies. Its main applications include the inference of cyclogenesis processes, the monitoring of mid- and low-level cloud evolution, and the identification of turbulence. It also helps distinguish between warm and cold air masses, as well as between high and mid-level clouds.

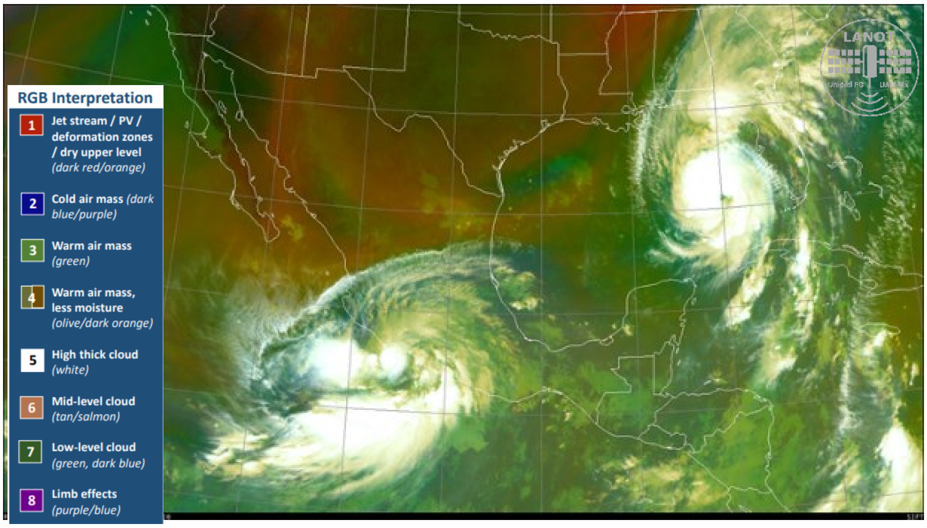


**Figure 8** RGB “Air Mass” product generated from GOES-16 Satellite (ABI) bands 8, 10, 12, and 13. Hurricane “John” to the west and Hurricane “Helen” to the east.

As indicated by the RGB rendition on the left side of the image, the color cues are of great importance, as we can see different atmospheric elements and features. Dark red/orange indicates jet streams, deformation zones, and dry upper levels. Dark blue/purple colors identify cold air masses, while green represents warm air masses. Dark olive/orange shows warm air with less moisture. Thick high clouds appear white, mid-level clouds are pink/salmon, and low clouds appear green or dark blue. Finally, edge effects are displayed in purple/blue.

## 4.3. Global Flood Awareness System (Reporting Points)

Reporting points show areas where flooding is expected to exceed the 20-year (purple), 5-year (red), or 2-year (yellow) return period by at least 30%. Shapes represent flood trends: ascending triangle (increasing), descending triangle (decreasing), and circle (no change). Colored borders show the timing of peak flooding. Numbers show specific exceedance probabilities but are hidden at low zoom levels or for gray points. Pop-ups provide additional information, including location details, forecast summaries, flood hydrographs, meteorological data, and consistency diagrams.

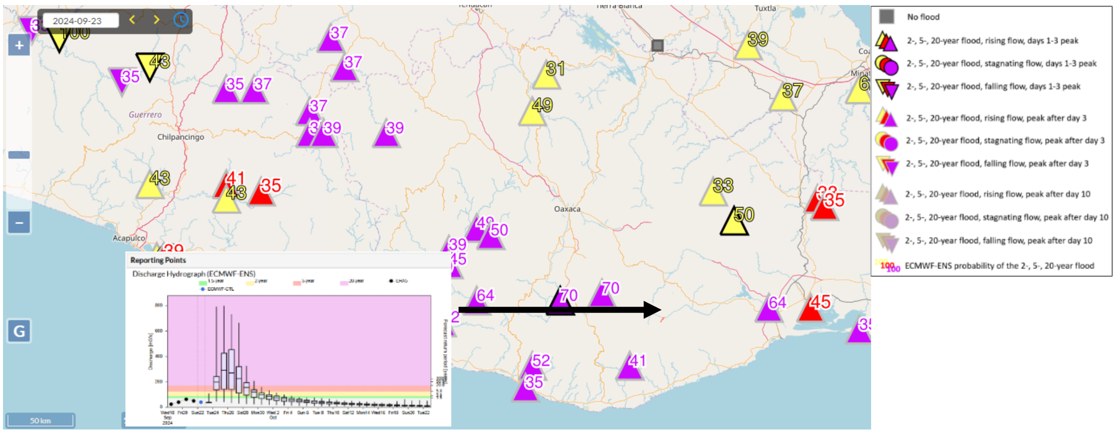


**Figure 9** Reporting Points and example of flood forescast in a portion of Guerreo, Mexico. Source: COPERNICUS-Global Flood Awareness System (2024).

The figure above was generated on September 23, 2024, and was limited to a portion of the coast of Guerrero, Mexico, when Hurricane John was generating extraordinary rainfall. This tool is essential for calculating the return time after a flood, allowing to evaluate how long it takes an area to recover after the event. The period necessary for conditions to return to normal is identified, including the lowering of the water level, the recovery of soil, and the restoration of infrastructure. This is important for improving water risk management and the resilience of affected communities.

## 4.4. Synthetic Aperture Radar (SAR) images

Images obtained by Synthetic Aperture Radar (SAR) sensors also allow hurricanes to be observed regardless of weather or lighting conditions. This type of sensor uses radar waves to measure the ocean surface, detecting wind intensity, wave height and storm characteristics. These images are useful for improving trajectory and intensity predictions, assessing damage after impact and planning disaster responses.

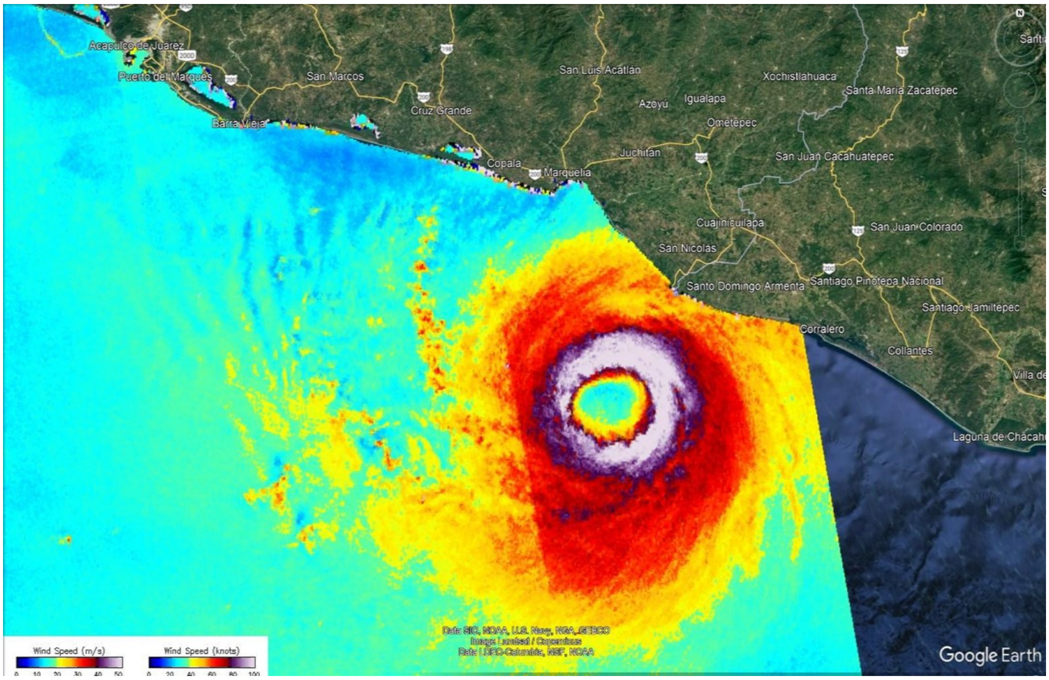


**Figure 10** SAR image of Hurricane John. Obtained from NOAA STAR Water Surface Conditions Team (2024).

The image, generated by NOAA's STAR service, was acquired on 09-24-2024 at 00:48:10 UTC, which in Central Mexico local time corresponds to 09-23-2024 at 18:48:10 UTC. The maximum wind measurements recorded at that time were as follows: Quadrant 1 NE: 104.37 kts (193.2 km/h); Quadrant 2 SE: 104.08 kts (192.7 km/h); Quadrant 3 SW: 94.23 kts (174.5 km/h) and Quadrant 4 NW: 103.09 kts (190.9 km/h).

## 4.6. Google Earth Engine platform

The Google Earth Engine tool has an extensive catalog of geospatial data that has been generated primarily through Earth Observation techniques. In addition, it incorporates powerful capabilities for analyzing and processing satellite images in the cloud. After Hurricane John and based on the algorithm "Flood Mapping and Damage Assessment Using Sentinel-1 SAR Data in Google Earth Engine" published on the UN-SPIDER portal, an analysis of potentially flooded areas and the possible effects on exposed elements was carried out, mainly in the Acapulco area and surrounding areas.

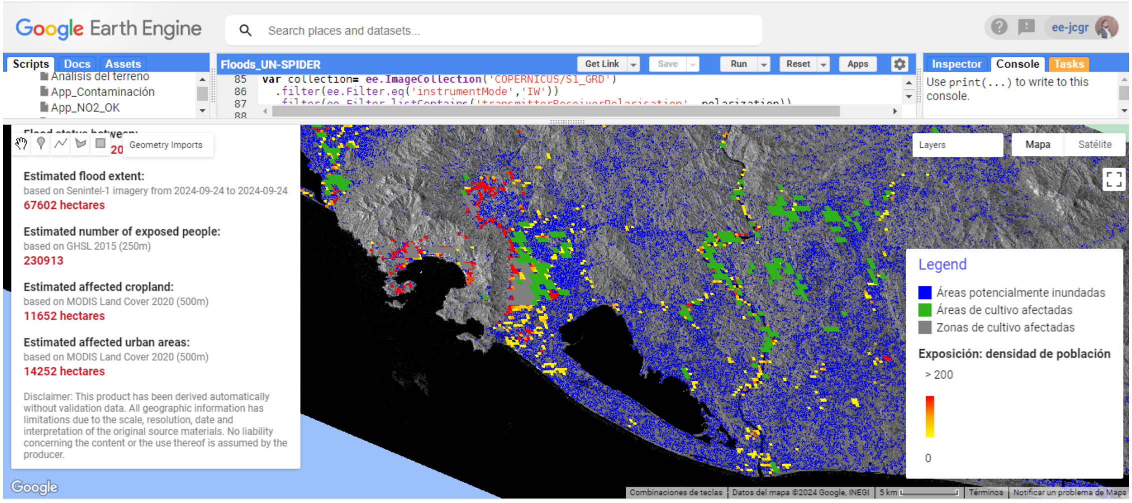


**Figure 11** Example of flooded areas analysis focused un Acapulco City. Source: own elaborated based on UN-SPIDER and Google Earth Engine.

As shown in the image, this tool allowed two key actions to be carried out in flood risk management. On the one hand, it allowed the diagnosis of potentially flooded areas, in this case, in a period between 23-09-2024 and 29-09-204. And on the other hand, it allowed the identification of the degree of exposure, both in urban and agricultural contexts. With both elements, the detection of disaster areas was achieved. This facilitates a rapid and effective response to emergencies, helping to prioritize rescue operations, efficiently distribute resources and evaluate the impact to plan recovery.

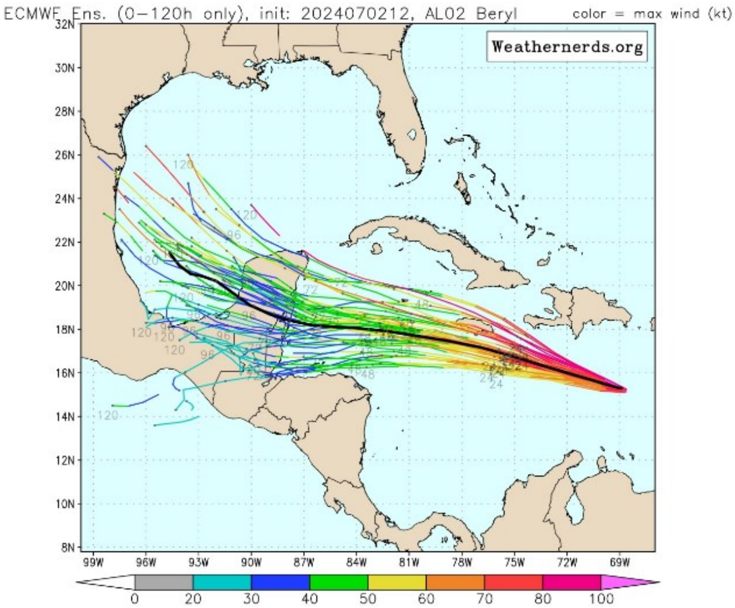


**Figure 12** Possible wind paths and intensity of Hurricane Beryl. Retrieved from Weathernerds.org (2024).

## 4.7. Weathernerds.org site

Weathernerds is a website that provides weather data. The site includes weather models such as ECMWF, GEM, GFS, HRRR, ICON, NAM, HWRF, HMON, HAFS-A/B and RAP. Also during hurricane season, the "TC Forecast Guidance" section provides forecasts thanks to the GFS and ECMWF models, useful for analyzing possible trajectories and intensities of tropical cyclones throughout this period, which is crucial for making good decisions that prevent vulnerable cities.

As shown in Figure 12, weathernerds provides us with the possible paths that the hurricane can take and in black it indicates the most probable path. The figure not only indicates that, it also indicates the position in which it will possibly be found every 24 hours and with the color symbology, the possible speed that it will have at each moment.

## 5. Conclusion

The use of geotechnological tools available in the LANOT laboratory, a unit of the Faculty of Geography of UAEMéx, represents a valuable contribution to addressing disruptive phenomena of various kinds. These tools allow for the precise identification of risk areas, the creation of detailed flood maps and the projection of scenarios in real time, facilitating a better understanding of the dynamics of disasters. This is crucial for the planning and execution of preventive and emergency response measures.

Thanks to these technologies, it is possible to design more effective evacuation strategies, ensuring that routes and refuge points are determined based on the data obtained in the laboratory. In addition, they allow for prioritizing the allocation of resources, ensuring that they are allocated to the most vulnerable areas and communities, thus optimizing their impact. These capabilities also encourage better coordination between the institutions involved in risk management, such as civil protection, emergency services and local authorities, which increases the effectiveness of joint actions.

It is vitally important that civil protection authorities know and understand these technological tools, since their integration into risk management strategies will not only help mitigate the impacts of disruptive events, but will also allow for joint work with the laboratory, which will strengthen both the laboratory's capabilities and the authorities' operations, resulting in a more efficient system to protect the population.

In addition to connecting the laboratory with potential decision-makers in civil protection matters, the products generated from the methodology described in this work have allowed for greater engagement with society in general, as well as with the media, which contributes to a better and more informed society about its geographical environment.

It is necessary to continue refining the methodological process to ensure that the analytical products are increasingly comprehensive, accurate, and, above all, understandable to the general public, thereby achieving greater impact. It is also important to generate other analytical products related to other hazards in the short term, such as winter weather, drought, forest fires, and air pollution, to name a few.

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