ADAclassifier: Trying to Ascertain Why the Ground Is Moving

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Abstract: The large availability of ground deformation measurements generated using Multi-Temporal Synthetic Aperture Radar (MT-InSAR), further increased by the contribution made by the European Ground Motion Service (EGMS), made displacement maps an increasingly common tool. However, their analysis is a complex task due to the large volume of Measurement Points (MPs) provided. ADAfinder, a tool within the ADAtools suite, allows for a reduction in the volume of information to be analyzed by identifying Active Deformation Areas (ADAs), i.e., areas of the terrain that actually move in a coherent and perceptible manner, including an estimate of the reliability of said identification. From here, the natural next step is identifying the reason why these areas are moving. This work presents ADAclassifier, another tool included in the ADAtools suite, still under development, aimed at evaluating up to five possible causes of ground movement, such as subsidence, landslide, uplift, sinkhole, and constructive settlement.

1 INTRODUCTION

In recent years, the widespread availability of displacement maps over large areas, generated using Multi-Temporal Synthetic Aperture Radar (MT-InSAR) satellite interferometry techniques, has significantly grown. The launch of the Copernicus Sentinel-1 satellites in 2014, which provide global and consistent data acquisitions under an open-access and free data distribution policy, represented a major shift in both their use and application.

A key result of this advancement has been the creation of regional, national, and continental ground motion services, offering detailed displacement maps that deliver in-depth insights into both human activities and natural events. Since 2022, the European Ground Motion Service (EGMS) (EGMS, 2017) has been freely offering billions of displacement Measurement Points (MP), updated annually, with coverage spanning almost all of Europe. These maps are known for their high accuracy and precision.

Although these maps hold great potential for territorial management and risk assessment, they remain underutilized due to the difficulties related to their interpretation; thus, automated tools that can streamline and speed up the processes of data extraction, analysis, and interpretation are needed. The creation of derived and simplified maps is essential to increase the adoption of said products by both expert and non-expert InSAR users. In this context, we introduce the ADAtools (Active Deformation Area tools (Barra et al., 2017; Tomás et al., 2019; Navarro et al., 2020).

The ADAtools include several tools; among them, it is important to highlight ADAfinder and ADAclassifier. The first one, ADAfinder, facilitates the automatic extraction and selection of the most significant Active Deformation Areas (ADAs) (Barra et al., 2017), serving as a critical first step in transforming a large number of individual MPs into a more manageable set of polygons for further analysis or appli-

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cation.

Figure 1 shows the process performed by ADAfinder. At the top, all existing MPs in some area can be observed. It can be seen that the volume of available information makes the analysis a difficult task. At the bottom, the ADAs detected by ADAfinder are displayed. It is important to emphasize that the amount of information the expert needs to analyze is significantly lower. Additionally, together with the polygons describing the areas of interest, an assessment of the reliability associated with the polygons is included, which establishes a scale of four values, ranging from 1, "very reliable" to 4 "very unreliable." This quality index let the expert focus on those findings that have a greater likelihood of being accurate.

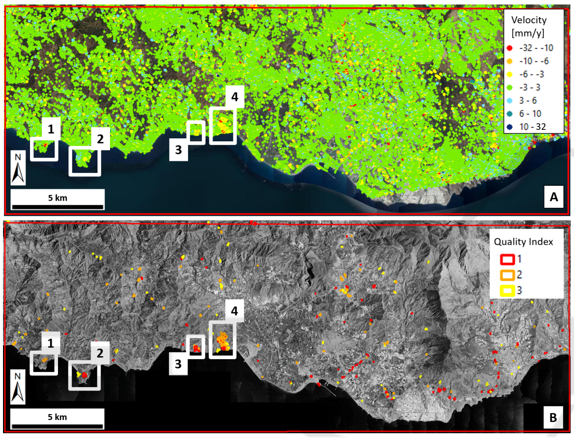

Figure 1: ADAfinder: from a plethora or measurement points to a few polygons depicting the Active Deformation Areas (ADAs). The quality index stands for the reliability of the results. ADAs in class 4 ("very unreliable") are not shown. Source: (Barra et al., 2017).

ADAfinder is a well-seasoned tool, used in numerous projects since 2017, including U-Geohaz (Solari et al., 2020) and MOMPA (Gasc-Barbier et al., 2021) among others. One of the most recent projects (Navarro et al., 2022; Navarro et al., 2023) aimed to publish ADAs for almost all of Europe on the web, processing MPs published by the EGMS (see Figure 2). (Navarro, 2024b) includes a very detailed description of the ADAfinder tool.

Once moving areas or ADAs have been identified, ADAclassifier—–this work's primary focus–—enables an initial assessment of the processes likely responsible for the displacement. By integrating auxiliary data—such as inventories of several kinds and a Digital Terrain Model (DTM)—each ADA is given a preliminary characterization with regard to five different ground movement processes: landslides, subsidence, sinkholes, construction settlements, or uplift. Like ADAfinder, ADAclassifier also provides an

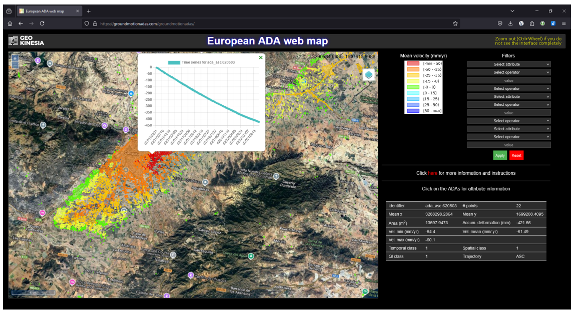

Figure 2: The European ADA web map (https://groundmotionadas.com). The ADAs were identified by the ADAfinder tool.

assessment of the reliability of the results obtained, again with the goal of helping the expert to analyze said results. This assessment is once again summarized into four levels of reliability, from best to worse.

Figure 3 shows the classification results produced by the original version of ADAclassifier for the example area shown in Figure 1, considering only three processes: landslides, subsidence, and constructive settlement. The reliability of the results has been highlighted using different colors: red, yellow and green (from positive to negative certainty).

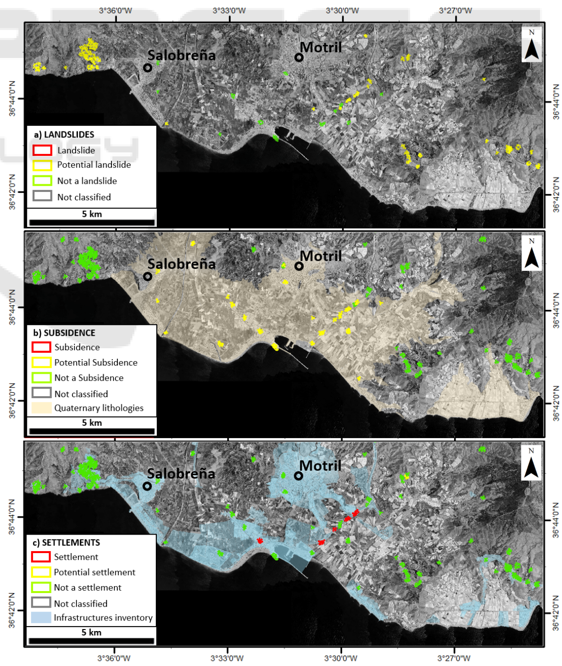

Figure 3: ADAclassifier (original version): for each ADA, its potential correspondence to one of the different types of analyzed ground movements is assessed. Source: (Navarro et al., 2020).

The first implementation of the ADAtools dates to 2017. Since then, they have been used in numerous projects and have undergone a series of improvements leading to the current version. ADAclassifier was included in the ADAtools since their very first version. However, unlike ADAfinder, its initial release had many limitations, which have recently been addressed. This work discusses how.

2 ADAclassifier

As just mentioned, the original version of ADAclassifier had several flaws, making it highly advisable to replace it with a new implementation that addressed these issues. This section describes these flaws and explains how the new version of the tool addressed them.

2.1 The First Version of the Tool

The core problem lay in the simplicity of the algorithms used to determine whether a ground movement corresponded to one phenomenon or another. Those algorithms were an *initial approach* to solving the problem. In fact, each of the tests aimed at determining whether a ground movement was due to a specific type of process (i.e., landslide or settlement) relied on a *unique* decision tree (one per process). For example, Figure 4 depicts the tree used by the landslide test. Additionally, the number of variables these algorithms considered, such as the slope value or horizontal ground displacement, was relatively limited. These algorithms were still far from modeling reality reasonably, as they can be considered a first and early attempt at approaching the problem.

Furthermore, these algorithms largely depended on the availability of inventories related to the type of process being evaluated, such as geological or construction settlement inventories. Their absence inevitably led to results that never confirmed that the ground movement in question was caused by the tested process. In other words, if a landslide inventory was not available, the ground movement would never be classified as a landslide; at best, it would be labeled as a "potential landslide". See again Figure 4.

The simplicity of the algorithms and the limited availability of inventories explain the low confidence in ADAclassifier's results. These algorithms only consider a small portion of the reality of ground movements, overlooking many factors. Additionally, the lack of inventories forces the algorithms into a more conservative mode, hindering their ability to confidently affirm the occurrence of a specific phenomenon. This undermines trust in the results.

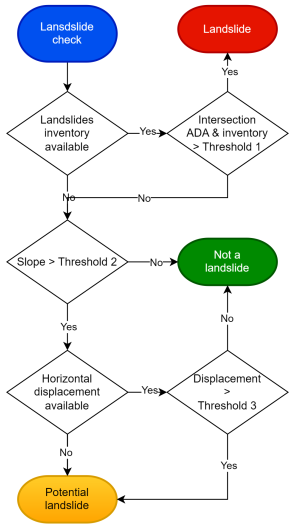

Figure 4: The unique algorithm (decision tree) used by the old version of ADAclassifier to decide whether a ground movement was produced by a landslide. The threshold values are provided by the user. Excerpted from (Tomás et al., 2019).

Another significant issue plaguing the first version of ADAclassifier was performance. As previously mentioned, inventories played a crucial role in the implementation of the old version of the tool. In fact, they were used (when available) by the algorithms implementing every ground motion detection process. From ADAclassifier's perspective, an inventory is a file containing polygons that define the areas of the terrain where a specific phenomenon occurs. Some inventories may also include additional data related to each polygon; the geological inventory is a clear example: a value states the type of lithology related to the polygon. The typical "inventory check" consisted of computing the percentage of intersection of the polygon defining the ADA with those included in said inventory. Due to the very poor implementation of this process, ADAclassifier's performance was far from satisfactory, making its use on projects with territorial coverage beyond the local level impossible.

The team responsible for both the development (and on many occasions also for the exploitation) of ADAclassifier were aware of the need for a redesign of the tool that could be relied upon. These are the reasons that led to the decision to create the new version of ADAclassifier that is described in the next section.

2.2 The New ADAclassifier

This section analyzes the changes undergone by ADAclassifier from different perspectives: its inputs, algorithms, outputs, performance and reliability.

2.2.1 The Inputs

From a user standpoint, the new version of ADAclassifier is virtually identical to the original. In fact, almost all of the input files are the same in both cases. The following is a brief list of these files, indicating when applicable which ones are needed only in the new version.

1. ADAs (polygons) and the points used to construct them.
2. Digital Terrain Model (DTM) or, alternatively, slope and aspect maps (the last two being exclusive to the new version).
3. Inventories: landslides, sinkholes, subsidence, constructive settlements, geological.
4. Horizontal displacement and, only for the new version, vertical displacement.

From the previous list, only the files from points 1 and 2 are mandatory, and, in fact, in point 2, it is possible to choose between the DTM or slope and aspect data. If the DTM is provided, then ADAclassifier computes both the slope and aspect; if not, the user must provide these two files as input instead of the DTM. The rest of the files are optional, as in the original version.

Actually, there are two additional input files in the latest version of ADAclassifier (scores and score-to-classes defaults). However, it is very rare for the end user to have to manipulate them, as they include default values that should not normally be changed unless you are an expert in the subject. The content of these files will be discussed later, since they are crucial to making ADAclassifier a very flexible tool.

2.2.2 The Algorithms

The most significant changes have been made to ADAclassifier's algorithms. Within the framework of the RASTOOL project (Montserrat et al., 2024; RASTOOL project, 2024), a major effort has been made to characterize the reasons behind different types of ground movements. Specifically, for landslides, constructive settlements, sinkholes, subsidence and, new for this version of ADAclassifier, also uplifts.

Several changes have affected the algorithms. Firstly, their complexity has increased. Unlike the initial version, where a single decision tree based on a few parameters was used to check a specific ground movement process, now multiple trees have been incorporated. More specifically, these are 4 for landslides, 6 for constructive settlements, 5 for sinkholes, 5 for subsidence, and 4 for uplifts. This sums up to a total of 24 checks, compared to the original 5. Figure 5 shows two of the four decision trees implementing the landslide detection process. Note the THLA*nn* (thresholds) and SCLA*nn* (scores) labels in said Figure. These are values input by the user controlling the behavior of the algorithms and will be discussed below.

This increase in the number of decision trees used by the tool makes the detection processes for the different kinds of ground movements more exhaustive. Additionally, the set of physical magnitudes being checked has been expanded, including horizontal and vertical displacement velocities, line of sight velocity, aspect, slope, the percentage of intersection of the ADA with different inventories, and the r^2 coefficient of fit of the deformation time series and an inverse exponential function. Some relationships between these magnitudes are also checked. This is expected to result in greater reliability of the obtained results.

Together with the notable improvement resulting from the increased number of decision trees and physical magnitudes involved, another significant key improvement factor is the way in which all these elements (trees, magnitudes, relationships) contribute to the final outcome. In the first version of ADAclassifier, all decision trees reached *a definitive conclusion* about whether a given ground movement could be labeled one way or another. This was materialized with three possible outcomes for each kind of process: "Not *X*", "Potential *X*" or "Is *X*", where "*X*" stands for the different process types being checked (such as sinkhole or subsidence). The user could only control the values of the thresholds used in the decision trees (see Figure 4).

Now, the procedure (for each type of process) consists of adding or subtracting points to a cumulative total or *score*. Each leaf of the decision trees contributes a specific number of points, either positive or negative, to the process evaluation.

These points are represented by the labels named *SCLAnn* in the leaves of the decision trees in Figure 5, where *SC* stands for "Scoring", *LA* indicates that this score refers to the landslide process, and *nn* is a numeral to distinguish one score from another. These labels change depending on the detected process; for example, in the case of sinkholes, the pattern is *SCSInn*, where *SI* denotes the said sinkhole process. Note that the thresholds for some magnitudes follow a similar pattern; in this case these start with the letters *TH* instead of *SC*.

Each of the leaves of the decision trees involved in the detection contributes a certain number of points to the final score, which will subsequently be used to decide the status of the ground movement with respect

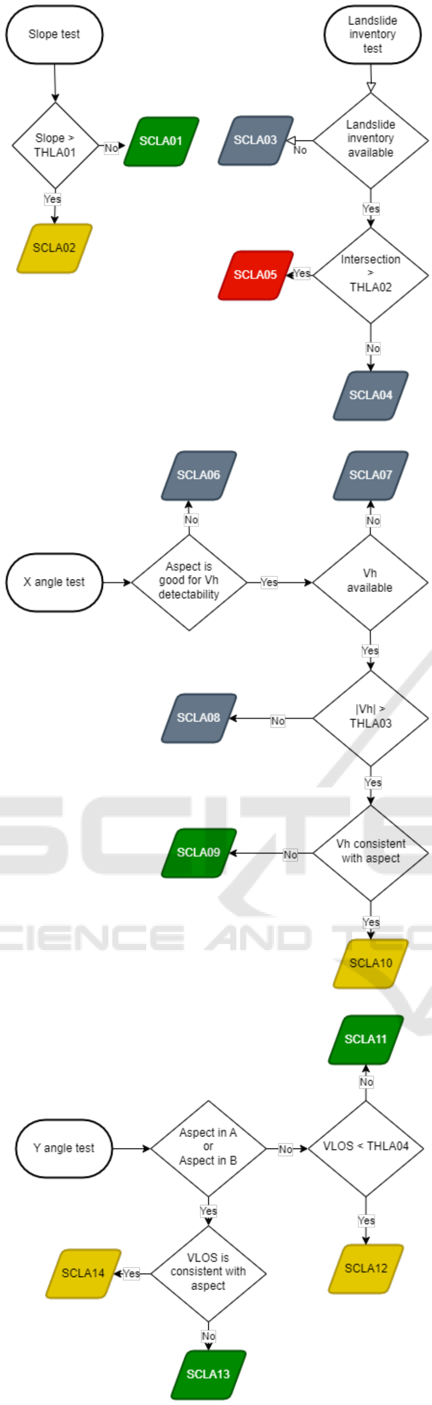

Figure 5: The four decision trees used by the new version of ADAclassifier to determine if a ground movement might be a landslide. Thresholds and scores are denoted by labels like THLA*nn* and SCLA*nn*.

to the process being identified. For instance, in the case of subsidence, there are five decision trees; consequently, the final score will consist of the sum of the points obtained in each of them.

The sum of both improvements (better decision trees plus scoring) makes the detection of the type of ground movement in which an ADA is involved more reliable than before, since more situations are now evaluated. In fact, it can be stated that the new version of ADAclassifier is more resilient, as the score assigned to a given process is obtained through a combination of algorithms (the decision trees) and not from a single one as before. The unavailability of some data does not prevent an attempt to reach a conclusion.

It is worth noting that the values of thresholds and the number of points rewarded are customizable through the tool's configuration files. This offers experts a high degree of flexibility, allowing them to fine-tune those parameters without requiring code changes. For example, to accurately model real-world phenomena, threshold values such as slopes or horizontal velocities may need adjustment. With regard to scoring, changing the number of points assigned to the leaves makes possible giving more or less importance to the different cases depicted by the decision trees. Obviously, having greater flexibility implies greater complexity: only experts are capable of changing said values without breaking the application.

2.2.3 From Scores to Classes

Despite the increased flexibility and reliability provided by the scoring system, it is necessary to offer a final, simple categorization of the results. This implies that these must be expressed through a reduced number of classes. ADAclassifier performs this process, translating the points obtained for each process into a value that can be one of the following: "It is not *X*", "It may be *X*", "It should be *X*", and finally, "It is *X*, where *X*, once again, represents each of the processes being checked.

The key here is how the points are translated into classes. This is done through a configuration file that the expert can modify to fine-tune the system. In this file, for each process, the ranges of points corresponding to each class are specified. In this way, the tool becomes even more flexible, allowing the expert to make adjustments without needing to modify the tool itself.

2.2.4 The Output

The unique output file is an extension of the input file with ADAs. There, the original attributes are preserved, such as the polygon defining the perimeter of the ADA or the Quality Index (QI) stating its reliability. The interested reader may check the complete list of attributes in (Navarro, 2024b) or in (Navarro, 2024a).

The extra fields added by ADAclassifier for each ADA in the data set, which are related to the results of the classification process, are:

- The mean values of slope and aspect for the ADA,
- as well as an extra flag stating whether the value of the aspect above is good for some tests,
- the r^2 coefficient, measuring how good is the fit of the ADA's deformation time series and an inverse exponential function,
- the percentage of intersection between the ADA's polygon and those in every available inventory or geological maps,
- the score obtained and the corresponding class for each of the five processes tested and, finally,
- a summary of the results, stating which is (or are) the predominant process(es) making the ADA move.

As can be observed in the list above, ADAclassifier not only generates an answer regarding which process(es) possibly originate(s) the ADAs, but also exposes all the information used to reach that conclusion. This not only serves to justify the answer provided but also allows the expert to analyze the results in case they do not correspond to reality. Having this information will allow the adjustment of algorithms, thresholds, and scores, if necessary.

2.2.5 Performance Assessment. A Nationwide Project

As stated in section 2.1 the low performance of the first version of ADAclassifier was a serious problem, caused, mainly, but among other issues, by the poor implementation of the inventory checks. This new release has solved all the problems the authors were aware of, which has produced a noticeable boost in performance that makes it possible to tackle not only regional, but even nationwide projects.

In fact, to put the tool to the test, a total of 661 ADA datasets have already been processed, covering the entire surface of Spain, which is 506,000 km^2 and includes 21,526 ADAs. The ADAs were already available since they were computed using ADAfinder for the project described in (Navarro et al., 2022; Navarro et al., 2023). To this data, we added a DTM, as well as geological, landslide, and constructive settlement inventories covering the entire territory. The sinkhole inventory was only available for a very small region measuring 17,274 km^2, so its impact on performance is negligible. The slope and aspect maps for all Spain were calculated only once using the DTM. This way, ADAclassifier did not need to regenerate them when processing each data set.

The characteristics of the hardware follow:

- Processor (64-bit): 2 × Intel® Xeon® Silver 4309Y CPU @ 2.80 GHz, 2801 MHz, 8 Core(s), 16 Logical Processes.
- RAM: 384 Gb.
- Disk: 18 Tb, Magnetic (not SSD).
- Operating system: Microsoft Windows Server 2022 Standard.
- Year: 2020.

Processing the complete datasets (all Spain) took just 8 hours, that is, less than 0.06 seconds per km^2, 1.34 per ADA or 43.6 per data set. Note that the server described above was *not* fully dedicated to ADAclassifier for it is shared by about a dozen users launching CPU-consuming tasks. Therefore, results could be still better if no concurrent processes competed for the server's resources.

Looking at these results, the authors believe that the tool is well suited to process nationwide projects. Said results also seem to indicate that it could be used at a continental level.

2.2.6 Reliability Assessment

The reliability of the results has been continuously verified since the first release of the new version of ADAclassifier using some of the already available datasets. The results of these initial analyses have served to fine-tune the threshold and scoring files.

Thanks to the availability of EGMS data and thus the processing of the entire Spanish datasets, we now have a much larger volume of information to perform this verification. Obviously, this is a large task due to the overabundance of data (661 datasets), but it is precisely such abundance that will allow us to determine with a reasonable level of certainty whether the conclusions of ADAclassifier are correct or if, in some cases, the system needs further tuning.

In fact, and this is because the determination of the causes of ground movements is not a settled issue, some inconsistencies have already been detected in a very small number of cases: apparently, a few ADAs seems to be moving, according to ADAclassifier, because of both landslide (down) and uplift (up) processes, which is completely contradictory.

At the time of writing this work, the reason for this problem was being analyzed. These cases will be used to understand the algorithm behavior, thus to adjust some thresholds and scores or to modify some of the decision trees that control the affected processes—thus modifying the application.

Except for these rare exceptions, most ADAclassifier's results are reliable. However, verification by an expert will always be recommended to ensure that situations like the one just described do not go unnoticed.

3 CONCLUSION

Despite being available since 2018 as an integral part of the ADAtools, the original version of ADAclassifier has not been regularly used to attempt to determine the causes of ground movement due to this tool's performance issues but, primarily, because of the low reliability of the results offered, which were obtained by means of overly simplistic algorithms.

Recently, and within the framework of the RASTOOL project, a great effort has been made to identify the reasons why the five analyzed ground movement processes occur. Ultimately, this effort was aimed at improving the understanding of these processes, which has resulted in a set of detection algorithms closer to reality, materialized in the aforementioned decision trees.

ADAclassifier is not yet a mature tool, but today it is much closer to being able to be exploited regularly in expert environments not necessarily involved in research. It is true that notable defects have still been detected, such as the already mentioned landslide/uplift dichotomy, but this is one more step to be solved like the many others that have been overcome to reach the current state of ADAclassifier. The availability of a large volume of EGMS data making possible the processing of ADAs at a national level opened the doors to an extensive validation task, thanks to which the authors are reasonably satisfied with the reliability of the results produced by tool.

Perhaps it is adventurous to advance a date on which ADAclassifier can be considered a production tool (in expert environments), but the authors consider that, despite the aforementioned defects, that moment is not far off. Probably this will happen by the end of 2024 or the beginning of 2025.

ADAclassifier is part of the ADAtools, which can be downloaded for free at https://adatools.cttc.es.

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