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SAR Technology Assessment Considering Atlantic Forest Monitoring

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Abstract

In this paper, an actualized study of synthetic aperture radar (SAR) technology and its potential application to Atlantic Forest preservation are presented. The special characteristics of this biome in the Province of Misiones, Argentina, are considered. It briefly actualizes the satellite and spaceborne systems applications in rainforest, and the applications of drone-borne SAR systems are analysed. In general, SAR images contribute to assessing the structural characteristics of preservation. However, instruments mounted to small unmanned aerial vehicles (UAVs), like drones, are a promising technology for biodiversity surveillance in relatively small reserves (smaller than 100 km^2) like most of the reserve areas of the Misiones.

Keywords *– Atlantic Forest, Drone, Preservation, Synthetic Aperture Radar, SAR.*

1. Introduction

The monitoring of the Atlantic Forest is a topic that has received so much attention in the last decades, unfortunately in the same way that it has become one of the most threatened ecosystems in the world. From an original area of 1,290,692.46 km² covered during the last centuries and including part of Brazil, Argentina and Paraguay; currently, it is limited to almost 162,000 km² (12.4% of the original area) [1]. One of the most preserved regions of the Atlantic Forest nowadays is limited to the province of Misiones in Argentina. In this context, the relevance of monitoring is justified by its critical role in evaluating the efficacy of restoration strategies, identifying triggers for corrective actions, comparing results across projects, and generally learning from past projects to inform future restoration efforts [2].

Several methods have been used to know about the preservation level of the Atlantic Forest. The most applied is *in situ* exploration, but it is restricted to small areas, with the possibility to extrapolate results to bigger ones, but with the corresponding estimation errors. Remote sensing techniques are now widely used for environmental studies, surveys and monitoring. Among the wide variety of

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techniques, synthetic aperture radar (SAR) remote sensing is a relatively new one. As opposed to optical systems, it is characterised by its capability to make clear observations through clouds and in the absence of solar illumination. It is an ideal instrument for monitoring in humid tropical areas.

SAR remote sensing data may prove to be a means of meeting the major information needs. Many types of imaging radar systems have been developed during the last years, according to different information requirements. Previous publications have indicated that using dedicated airborne radar systems in combination with aerial photography and operational satellite systems would provide a sound basis for efficient data acquisition in support of forest management [3]. However, during the last years, SAR instruments with the capacity to be mounted on a UAV have been developed [4-6] and have opened new perspectives for rainforest monitoring and survey. In this work we briefly actualize the satellite and spaceborne systems applications in forest environments, and the applications of drone-mounted SAR systems are analysed, concluding that the last strategy may appear to be the most appropriate for the reserves found in the Province of Misiones.

This paper is organised as follows. In Section 2, SAR technology fundamentals are presented. Section 3, satellite SAR technology is evaluated considering information for preservation necessities. Section 4, airborne SAR is analysed. Section 5, SAR for drone current advantages and disadvantages are presented. Finally, Section 6 concludes by evaluating the significance of SAR in support of prudent Atlantic Forest management.

2. SAR Technology

First, as an introduction to SAR technology, terminology and some classic questions about the topic will be answered in order to get a good first look at it.

Radar is a system that uses electromagnetic waves to measure distances, altitudes, directions, speeds of objects, weather formations, and the terrain itself. This equipment can be mounted on a flying object which moves around the area of interest. It usually flies for long periods of time and distances of space to cover more territory, gathering a lot of data and based on that information someone can make decisions that could be really important for a place.

A key aspect to remark before continuing because many people misunderstand the nature of radar is the differences with the classic optical satellite that everyone is familiar with. In order to highlight this issue, comparative images are presented in Fig. 1., extracted from [7].

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(a) *(b)*

Figure 1. Volcano Kamchatka, Russia, 5 oct. 1994 Source: Michigan Tech Volcanology & NASA ARSET. (a) Optical Image. (b) Radar Image.

As we can see, the difference relies on what can be seen in each one. People are most likely to be familiar with Fig. 1(a), which represents what an optical camera will show if we take a photo from a high altitude (optical image). Fig.1(b) shows a radar image of the same place. After having those two images next to each other, a few differences can be spotted:

- At first sight it is obvious that one of them is a volcano. On the other one it is not that easy to identify.
- It is easier to notice the high level on Fig.1(b) rather than Fig.1(a).

It is possible to keep making conclusions about, but that is not the point. The main thing it has to be noticed here is that when a radar image is used, it is basically to get data about altitudes, directions, and the terrain itself. At the same time, optical images are mostly used to see how a place looks. No image is better than the other. The images only have different information that can be interpreted differently and in a complemented way.

Based on what has been written before, it is crucial to understand the strong and weak points of SAR technology and why we would like to study it to achieve a specific goal. So, here is a resume of some of the advantage points to consider:

- It works under almost all-weather conditions.
- They observe the earth's surface all day and night (It works the same as with the absence of sunlight at night).
- They could penetrate the vegetation by using SAR radars operating at low frequency.
- They could penetrate the soil by using SAR radars operating at low frequencies.
- Atmospheric effects are minimal.

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- Sensitive to surface dielectric properties (frozen or thawed water).
- Sensitive to the structure of surface components.
- It does not interfere with any activities on the site.

On the other hand, the fact that information is sometimes difficult to interpret and the presence of the speckle noise, which introduces mottling (salt and pepper effect) on images could be indicated as disadvantages.

Now, there will be a brief mention of the parameters and information which are considered fundamental when using SAR.

2.1. Signal Parameters

An important parameter related to the signal penetration of the electromagnetic wave is the wavelength, which is related to the radar carrier frequency. Penetration through vegetation or soil increases the longer the wavelength. In Table 1, there is a compilation of information about the names of the different ranges of wavelength. In Fig. 2, typical penetration into a forest is shown, considering different bands.

Band Designation	Wavelength (λ [cm])	Frequency [Ghz]
Ka	0.8 to 1.1	40 to 26.5
K	1.1 to 1.7	26.5 to 18.0
Ku	1.7 to 2.4	18.0 to 12.5
X	2.4 to 3.8	12.5 to 8.0
C	3.9 to 7.5	8.0 to 4.0
S	7.5 to 15.0	4.0 to 2.0
L	15.0 to 30.0	2.0 to 1.0
P	30.0 to 100.0	1.0 to 0.2

Table 1. Band parameters.

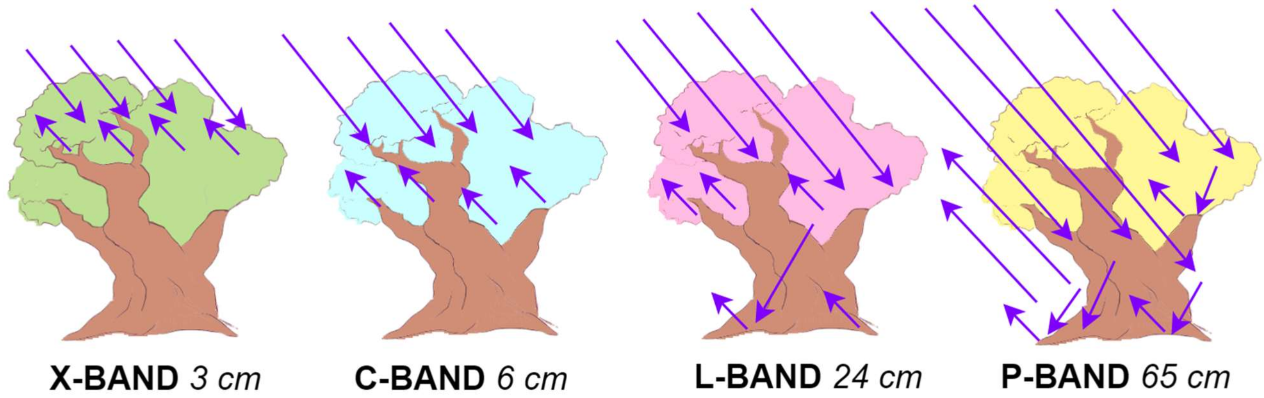

Figure 2. Penetration into a forest by different bands.

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Another important parameter is polarization. Radar measurements can usually be horizontal or vertical polarized according to the electric field position. In addition, the emitted signal and the receiving signal can have the same or different polarization, resulting in the following options:

- HH: Transmitted Horizontally, Received Horizontally
- HV: Transmitted Horizontally, Received Vertically
- VH: Transmitted Vertically, Received Horizontally
- VV: Vertically Transmitted, Vertically Received

Different polarizations can be used to determine the physical properties of the observed object.

2.2 Illumination Parameters

SAR radars are devices with "side view". It basically refers to the way the radar must be placed in order to collect data from a specific place. In Fig. 3, there is an example of how the electromagnetic waves travel on "side view" radars.

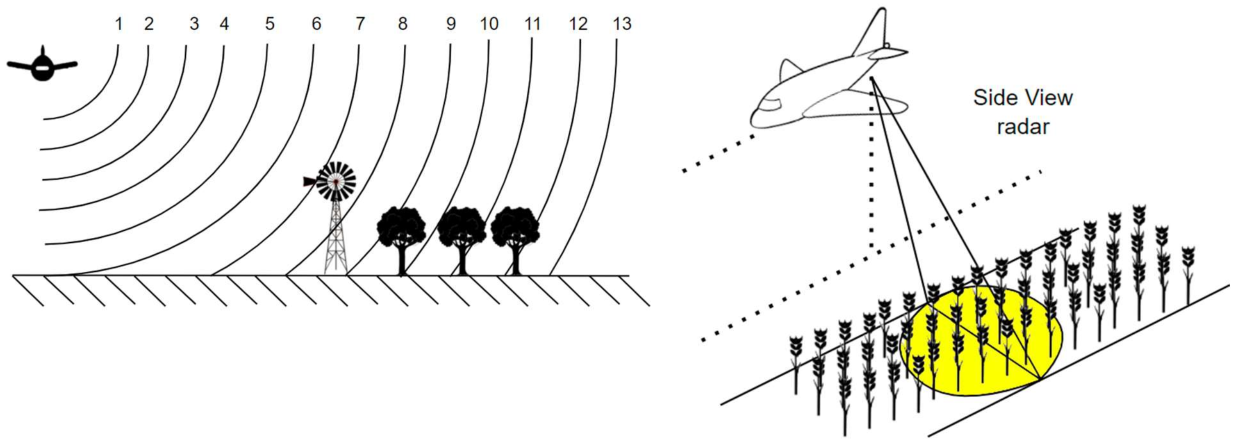

Figure 3. Side View of Radar Systems.

The angle between the direction of illumination of the radar and the vertical of the ground surface is the incidence angle. It is important to understand that the incidence angle changes depending on the height of the sensor, therefore, the geometry of the image changes from point to point in the range direction. The incidence angle has a lot of influence over the intensity of the image because it is directly linked to the bounce of the electromagnetic waves on the surface of the place.

2.3 How are SAR images formed?

As the sensor propagates it is possible to create a 2D image of the surface by recording and processing the signal based on the parameters mentioned before and the following:

1. The radar measures the amplitude (magnitude of the reflected echo) and the phase (position in which a point is located at a specific moment in the cycle of the wave).
2. The radar can only measure the part of the echo reflected in the direction of the antenna (backscatter).
3. The radar pulse travels at the speed of light.
4. Each pixel in the radar image represents a complex amount of energy reflected back to the sensor.
5. The magnitude of each pixel represents the intensity of the reflected signal

It is called synthetic aperture radar, because, during the radar carrier's flight, it forms a 'synthetic' radar antenna array. Thanks to that, it allows the creation of high-resolution images in cross-range dimensions (in the direction of the flight path) based on electromagnetic waves alterations and through the Doppler shift associated with the movement of the platform.

3. Satellite SAR Application on the Atlantic Forest

The usage of satellite SAR to propitiate sustainable use of tropical rainforests has been explored for over twenty years [3]. It is justified in the fact that the long wavelengths of radar radiation are not reflected or absorbed by clouds or haze, thereby allowing more frequent and systematic assessments of land cover changes and deforestation. The same principle allows penetration in the canopy to assess data on the trunks level, which increases the potential of distinction between different stages of regrowth [8].

Nowadays, an active line is related to the study of indicators of sustainable management. There are several indexes proposed, such as the above ground biomass (AGB), the enhanced vegetation index (EVI), and the normalised difference vegetation index (NDVI). Recently, a SAR closely related index was proposed, the dual polarisation SAR vegetation index (DPSVI). In addition, a study about the seasonal and spatial influences on the DPSVI index was also presented [9], indicating the importance of this kind of tool in inferring the structural characteristics of the Atlantic Forest. In the same line, applications of SAR data to estimate forest biophysical variables in Brazil with a focus on deforestation were proposed [10].

It could be concluded that satellite SAR is a necessary tool to access the structural characteristics of the Atlantic Forest at a macro level, but it fails in the determination of elements related to biodiversity because it is not possible to identify individuals given the current resolutions. Furthermore, the latency between successive surveys is a barrier for some monitoring applications.

4. Airborne SAR

Since the beginning, middleweight planes have always been the most classic place to mount and test the SAR radar technology, [11] that is mainly because SAR radars have a past related to military purposes [12]. So, it is no surprise that middleweight planes are the standard of how SAR radars are commonly implemented. Airborne SAR is commonly ahead of the abilities of spaceborne sensors by several years, in order to provide a test-bed for new imaging techniques and data processing approaches, as well as for implementing and validating new remote sensing applications. Additionally, airborne SAR is a valuable tool of itself, used in various scientific studies and with its own particular fields of application [13]. In this paper, the review is restricted to the forest monitoring application.

4.1. Advantages of airborne SAR for the Atlantic Forest.

Using SAR technology on planes would be one of the easiest and cheapest ways to implement it. That is because it is also possible to adapt other flying machines which serve for other purposes into a multifunction plane so the starting investment is reduced to only a SAR module and not an entire plane [14,15]. This consideration comes in handy when an institution or a private company already has a plane at their service. For example, fumigation planes and lightweight planes, can be easily adapted into a radar carrier with no problem at all, because the SAR module does not represent a heavy load for the flying machine. In this way, the investment costs are lower because it will require just to purchase a SAR radar and mount it on the plane.

The land covered by a single one of these flying machines can extend over kilometres of the jungle with ease. It only requires a qualified pilot with some training oriented on how the illumination parameters of the radar work in order to get a good scan of the zone and catch a good image of the zone of interest. Nevertheless, their lack of similarity can be noticed when the pilot of the plane does not have a sublime control of the plane and the images collected will sometimes be kind a different on every collection flight performed.

4.2. Lightweight Planes

Nowadays technology has advanced to the point where there’s no need for heavy flying machines in order to mount the radar device. Lightweight models can be acquired on the market that offer a remote control of a little plane that can be piloted around the area of interest in order to collect all the images of interest.

These scale plane models have great autonomy in addition to requiring little maintenance resources to work properly. But they usually require extra accessories such as launchers in order to lift off the ground, which will add an extra cost that must be considered.

To sum up, using a lightweight version of a plane is an alternative that can be worth considering. It will mostly depend on the available budget and the amount of land to be covered.

5. Drone Borne SAR

The use of satellites every time that it is necessary to do a scan of a forest could be seen as excessive and a dependent situation in more than a way. An alternative method of using SAR technology to scan a place in order to get information about it would be to use unpiloted or programmed drones. So, it is possible to supervise long field spaces and to keep a daily or weekly record of the multiple types of parameters on the site with almost no limitations on when and how the scans are made. It will be just up to the owner of the technology to define how regularly the drones will be released to do the work. This technology has been a part of the innovation of SAR during the past years and it has stimulated new applications in several areas. Also, the cost of miniaturised RADAR has been diminished in the wake of the miniaturisation and development of fast analog-to-digital converters (ADC), compact software defined radio (SDR) platforms, efficient computing platforms based on graphical processor unit (GPU) technology, as well as the availability of commercial-off-the-shelf (COTS) microwave components and even ready to use microwave radar front-ends [5]. While in the past SAR was primarily operated for airborne and spaceborne applications, novel operations for quite low altitude like surveillance of cities, local agricultural applications, or even buried object detection, are of new interest.

There are a few publications about SAR drone borne applied to forest, mainly to industrial forest inventory [16]. In compensations, there is a lot of information regarding rainforest preservation studies through technologies like optical images and photogrammetry. In [17], rainforest restoration structural parameters, such as tree density, tree height, and vegetation cover are accurately measured by remotely piloted aircraft. Only grass infestation, which is a less important indicator, presents medium accuracy. However, it could not accurately measure the forest biodiversity parameter in the Brazilian Atlantic Forest, and thus traditional fieldwork will continue being necessary.

5.1 Advantages of Drone Borne SAR for Forest Preservation

As indicated before, there is a lack of appropriate tools to determine parameters related with the biodiversity of the Atlantic Forest using remote sensing. So, drone-borne SAR could be a possible alternative in this sense. It could be thought that the most important parameter for biodiversity monitoring using SAR image is the resolution, allowing the obtaining of a very precise image of the area under observation. In such cases wideband systems operating at higher bands such as X and above could be used. In contrast, if it is necessary a good foliage penetration, for example for soil characteristics determination, very low bands must be utilised and if it is important the polarimetry properties of the ground reflectivity (for humidity or other parameters), is recommended to operate in different bands, such as P, L, S and C.

On the other hand, there are two major operational modes to be considered. The detection mode which is based on a straight flight trajectory along the scene using multistatic and multichannel array configuration on the drone; and the identification mode using a rather circular or helical trajectory around the scene to investigate the area at higher spatial resolution and to perform tomographic imaging.

Furthermore, the drone can operate autonomously in areas of difficult access, and it can be operated directly over hazardous areas nearly unlimited in most of the scenarios. In an even more advanced system escalation, several cooperative drones/UAVs can be used to produce additionally very high bistatic or multistatic incidence angles, further enhancing the system capabilities. For instance, in agriculture, crop identification with SAR images was reported [18] and underground water detection using such a strategy [19].

Albeit all these potential characteristics, one of the major problems for a drone operated SAR is the sufficiently precise knowledge of the actual flight path for proper motion compensation in the SAR processing, in order to achieve maximum spatial resolution and non-warped images. A combination of RTK GPS modules, photogrammetric sensors, and drone based IMU (Inertial measurement unit) information can provide those inputs for the SAR processor. In general, this is one of the key requirements besides the coherent synchronisation of the radar raw data, especially in case of multiple platforms.

5.2 Exploring the possibilities on the market

On the market there is plenty of information about companies who offer some models and alternatives for SAR [14, 15, 20, 21]. Now we will look into some of what those companies were able to archive.

Some drones were developed as a working tool for universities and research centres [5,20]. It is a turn-key system that operates with P, L and C bands simultaneously. In addition, it allows the operator to make his own data acquisition and processing.

- C-band 1-pass interferometry for surface model calculation;
- 1-pass interferometry in the P-band for terrain model calculation;
- Differential interferometry in the P, L and C bands to measure subsidence even with vegetation cover;
- Classification of targets and ground using polarimetric P, C and L bands;
- Helical flights in P, L and C bands for tomography.

Applications have been validated in sugarcane plantations, forestall fields, and other agriculture issue. The drone can perform a forest inventory of up to 500 hectares per day and the process runs automatically at night. Only two operators are needed to run two flights. The process is not assisted. The most common products are maps and localised values of tree height, DBH, volume, heights of dominant trees and basal area [16].

6. Conclusions

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As a result of the information previously developed it is possible to make some comparisons of the three methods (satellite, airplane, drone) in order to highlight what advantages each one has over the other. These thoughts are a summary of some of the most important aspects to consider when purchasing a SAR radar.

In terms of costs, the satellites outperform the others since there are public access satellites in several countries owned by the government, which means that accessing data will be cheaper than buying new equipment. Also, the zone covered by satellites is considerably bigger than what a plane or a drone can possibly travel. The main issue with a satellite comes when constant data collection is necessary, because satellites lack independence when it comes to private use of the technology. That's why both drones and planes have a big advantage over satellites, they can be used as much as required, if the weather conditions allow it of course.

The technology behind each device is different, being the drones the ones with the most modern technology. Their technology and image quality is certainly superior among the others. The main feature about them is that it is possible to code the flying machine in order to set a route to keep a record of data from a certain area continuously in the most accurate way. The precision of drone's images will certainly be better than what a pilot can manually archive, because the flying machine will follow the exact same instructions in every fly it does, it will all depend on how it is coded. However, it is worth considering that it is not easy for a drone to cover big distances without a recharge, so airplanes are definitely superior on this aspect because more terrain can be covered in less time with a good image quality. But unlike drones, the images collected in each flight will be a little different from each other because each flight will not be exactly identical to the previous one. This can be underproductive for growth supervision.

To sum up, the decision of picking one among the other will rely on three key factors, the size of land to scan with the radar, the costs of acquiring the technology necessary to get and process the data, and the need of process automation. Satellites can have a huge advantage in terms of field cover but the lack of control and image quality is something that can pass unnoticed. The airborne alternative might be the best when it comes to monitoring the jungle, that's mainly because it can cover a large amount of territory keeping a good image quality obtaining information with a certain periodicity. In case a periodic monitoring of a specific area is required, drones are definitely the best option. They have an easy setup, can charge up with electricity, have an amazing image quality, and do not require a lot of resources like pilots or plane tracks. For these reasons they are definitely the best for the job.

As a concluding remark, Table 2 shows a summary of the main characteristics to be considered when defining which kind of SAR technology is more appropriated.

	Satellite	Airborne	Drone
Description	A machine that orbits planet earth. with a SAR module attach to it	Private airplane with a SAR radar unit mounted on it. (The plane can be used for other purposes such as fumigation)	Private use of small drones. Which contains SAR modules.
Costs	There are several free-to-use models orbiting space.	- Uncertain.	-Uncertain.
Range	It can cover an entire country with enough time	About 1300Km it mainly depends on the plane. But large amounts of terrain can be covered in minutes.	Areas with less than 5000 km^2, with more drones it is possible to raise this number.
Weight	500kg -1000kg	500kg to 1000kg	5kg to25 kg
Availability	Poor. Hard to scan a specific region at any given moment.	Good. It takes some minutes to check if the plane is able to fly and it can be driven to the place with no problem.	Excellent. It can be used whenever the owner wants if they are fully charged.
Bad weather conditions	It can get images with no problem.	It is not recommended to make a person fly in bad weather.	It's impossible. Because it will severely damage the drone.
Data collection	Not very specific on small areas. Almost impossible to control.	It will mainly rely on the experience of the pilot to control the illumination parameters.	Once it's coded they will follow the exact same route with precision.
Picture quality	Standard	Good	Excellent
Supervision	Well prepared people with access to sensitive information is necessary	It requires a pilot on the plane with a good memory and a sense of how the images are collected.	A route can be coded and does not need to be supervised. It can be controlled with a remote controller if it needed
Technology	It can be considered old and it's almost difficult and expensive to upgrade	They have modern devices, and it can be upgradeable with ease.	They have modern devices, and it can be upgradeable with ease

Table 2. Summary of different SAR technologies

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