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Scientists as citizens and knowers in the detection of deforestation in the Amazon

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Abstract
This paper examines how scientists deal with tensions emerging from their role as providers of objective knowledge and as citizens concerned with how their research influences policy and politics in Brazil. This is accomplished through an ethnographic account of scientists using remote sensing technology, of their knowledge-making activities and of the broader socio-political controversies that permeate the detection of deforestation in the Amazon rainforest. Strategies for mitigating uncertainty are central aspects of the knowledge practices analyzed, bringing controversies 'external' to the laboratory 'into' the lab, making these boundaries conceptually problematic. In particular, the anticipation of alternative interpretations of rainforest cover is a crucial way that scientists bring the world into the lab, helping to shed light on how scientists, usually seen and analyzed as isolated, are in fact often in constant dialogue with the broader political controversies related to their work. These insights help question the idea that the monitoring of deforestation through remote sensing is a form of secluded research, drawing a more complex picture of the dual role of scientists as knowledge producers and concerned citizens.

Keywords
Amazon, Brazil, deforestation monitoring, secluded research, science-policy interface

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Introduction: Rethinking science/policy interfaces in Brazil

Remote sensing can be defined as a scientific field devoted to the 'detection, recognition, or evaluation of objects by means of distant sensing of recording devices' (Franklin, 2001). Therefore, the main concern of remote sensing is the establishment of reliable links between the output of sensors (e.g. a picture taken from an aircraft, infrared reading or satellite image) and the underlying 'ground truth' (e.g. a nuclear installation, the temperature of the ocean or a forest clearing). Because of the immense physical and symbolic distance between their signifiers and signifieds, remote sensing has to deal with an inherent uncertainty. The proper mitigation of that uncertainty in order to achieve 'usable', adequate images is an important part of working with this kind of data. Using remote sensing to analyze variables related to vegetation or land cover is especially complex, as technical specificities and possible modes of interpretation are multiple, generating results that vary depending on which satellite acquired the image or which analytical protocol was used to process the data (Cardozo et al., 2011).

Satellite-based remote sensing could be framed as an archetypical example of what Callon et al. (2009: 46) call 'secluded research', a form of producing knowledge theorized as 'withdrawn, cut off from the world, and consequently precise and effective'. The arrival of remote sensing in Brazil, however, has since its origins been linked to events that stretch well beyond the laboratory walls. Since the creation of the Brazilian Institute for Space Research (INPE) in the 1970s, remote sensing has become central to how deforestation in the Brazilian Amazon is monitored and measured and, as a consequence, to how development and conservation policies toward the region have been devised.

In this article we examine how scientists deal with tensions emerging from their roles as providers of objective knowledge and as citizens concerned with how their research influences policy and politics in Brazil. We accomplish this through an ethnographic account of scientists using remote sensing technology, their knowledge-making activities and the broader socio-political controversies that permeate the detection of deforestation in the Amazon rainforest. The ethnographic descriptions are part of fieldwork conducted by the second author in Brazil in 2007 and then between 2009 and 2010. During this period, he followed the production of deforestation data at INPE's laboratories in São José dos Campos, near São Paulo, and that data's circulation in policy-making in Brasília and law enforcement practices in the Amazon region (Rajão et al., 2012; Rajão and Georgiadou, 2014; Rajão and Hayes, 2009; Rajão and Vurdubakis, 2013). The description of remote sensing practices below were the result of participant observations done with INPE scientists and technicians, while that author worked as an interpreter of satellite images. When possible, a voice and computer screen recorder were used in order to register the operations performed by the technicians and their explanation of the image interpretation process.

It became clear through such participant observation with INPE scientists and technicians that uncertainty mitigation strategies are a central aspect of the production of reliable evidence. In addition to responding to scientific uncertainties that are 'inside' the laboratory, these strategies also deal with political controversies 'external' to the lab, making these boundaries conceptually problematic. Thus scientists, usually seen and analyzed as isolated, are in fact often in constant dialogue with the broader political responses to their work.

We aim to show that deforestation monitoring through remote sensing is not secluded research, instead drawing a more complex picture of the dual role of scientists as knowledge producers and concerned citizens. By exploring some of the ethical plateaus (Fortun and Fortun, 2005) that enable and constrain scientific work in remote sensing, we hope both to contribute to the understanding of how remote sensing knowledge about deforestation is produced in Brazil, but also to the reflection on how interfaces with policy can be imagined in novel ways. The production of data happens in a highly disputed context, where scientists (incessantly mitigating uncertainty) are also constantly reflecting on their role in broader environmental controversies, policies and actions, making this a rich locus for reflecting on remote sensing's civic science as related to controversies around deforestation and the scientists' perceived role in their outcomes (Fortun and Fortun, 2005).

Remote sensing as secluded research?

Scientists distance themselves from lay citizens by building laboratories and other spaces that are separate from the rest of the world, helping to separate everyday practices and the realm of opinion from scientific results and the realm of true knowledge. Furthermore, scientists are expected to maintain a distance from societal values and interests by 'taking leave of the world, tearing oneself free from opinion … and keeping at arm's length the interests that are supposed to contaminate scientific knowledge' (Callon et al., 2009: 100). Satellite-based remote sensing could be seen as an extreme example of secluded research for different reasons. First, its main research instruments are not only separated from the rest of society behind closed doors, but are in outer space, accessible to only a few expert scientists. Second, most of the results provided by satellites are presented in the form of images produced through automated means: a source of 'mechanically objective' knowledge thought to be untainted by subjective interpretations (Daston and Galison, 1992). Finally, by capturing in a single image vast areas of Earth's surface, remote sensing is believed to go beyond partial views, providing a God's-eye perspective of the world (Rajão, 2013). These characteristics may help to explain why the supporters of satellite-based remote sensing are very keen to highlight the potential of this technology to solve societal problems (e.g. Abler, 1993; Dobson, 1983), emphasized even more strongly in the promotion of a new type of 'data-driven environmentalism' beyond and above ideologies and political positions (Esty, 2001; Wise and Craglia, 2008).

Such claims to objectivity have not gone unnoticed by scholars studying the relation between government, space and technology from a critical perspective. In contrast to the strongly promotional character of the mainstream literature, critical geography has provided a bleak image of the social implications of remote sensing, suggesting, for instance, that the introduction of this technology furthers the digital divide (Pickles, 1995), provides opportunities for surveillance (Rose-Redwood, 2006) and leads to the neglect of non-Western or non-scientific epistemologies (Harwell, 2000; Kwan, 2002; Lefebvre, 1974; Pickles, 2004; Rajão, 2013; Roberts and Schein, 1995; Sheppard, 2005). Some studies have also added a political dimension to this epistemological critique by emphasizing the role of scientific representations in achieving control of local populations and natural resources (Fairhead and Leach, 1998; Hannah, 2000; Harvey, 1984; Harwell, 2000; Rose-Redwood, 2006; Scott, 1998).

Alongside critiques of remote sensing technology, a growing body of studies in STS has emphasized the insufficiency of thinking about science as separated from society, especially when thinking through science-policy interfaces and the governance of science in society (Irwin, 2008). Authors have proposed concepts such as 'post-normal science' (Funtowicz and Ravetz, 1993), 'indigenous technical knowledge' (Gadgil et al., 1993) 'civic science' (Bäckstrand, 2003), 'lay knowledge' (Wynne, 1996), 'hybrid forums' (Callon et al., 2009), and 'participatory GIS' (Puri, 2007) in order to highlight the importance of including the voices of non-scientists in remote sensing practices and policy-making. Jasanoff's (2004) work on biotechnology suggests the idea of civic epistemologies as a way to think through the situated character of the interface of science and policy, as co-produced by broader social orders and imaginaries that vary in different contexts. Seen as the ways though which societies develop and deploy knowledge claims for making collective choices, civic epistemologies help explain differences in how science relates to regulation. Science does not determine decision-making (and it shouldn't be asked to), because non-experts and broader social imaginaries have important roles to play in understanding policy-making in general.

Beyond thinking through non-experts in the production of science, work at the intersection of anthropology and STS has described scientists as situated actors, conditioned by values and broader imaginaries in the process of producing expert knowledge. Fortun and Fortun (2005: 44) argue that 'scientists themselves understand, strategize, and take responsibility for their own situatedness in social context'. This suggests that it is through a detailed analysis of knowledge production that such situatedness and interfacing with broader imaginaries becomes clear, challenging our views on how science can and should be deployed in policy and decision-making. But despite contributions from Fortun and Fortun (2005) and Jasanoff (2004), among others, a substantial share of STS research still conceives the inside and the outside of the lab, on the one hand, and the scientist and the citizen, on the other, as inherently distinct and separate. In the following sections we aim to examine empirically how scientists detecting deforestation in the Amazon deal with their dual role as producers of objective knowledge and concerned citizens. In this way we aim to further problematize the notion of 'secluded research' and its consequences for how the science-policy interface should be conceptualized and studied.

The politics of deforestation monitoring

Satellite-based remote data provided by the Brazilian Institute for Space Research (INPE) has over the years become the main 'thermometer' used by civil society and scientific communities, both Brazilian and international, to evaluate the government's performance in tackling deforestation (Rajão, 2013; Rajão and Georgiadou, 2014). INPE's data have been independently verified by different studies and are by far the most utilized source for studies of Amazon deforestation (Fearnside, 1993; Hammer et al., 2014; Skole and Tucker, 1993). For this reason, INPE's deforestation monitoring program is often cited in reports by environmental non-governmental organizations and scientific studies as the 'most advanced' studies available (May and Millikan, 2010: 14), 'the vanguard of technology' (IPAM, 2011: 14) and even 'the envy of the world' (Kintisch, 2007: 536).

While most in the scientific community consider INPE's monitoring systems to be uncontroversial sources of reliable deforestation data, the institute has faced constant criticisms from both inside and outside the government. The creation of PRODES in 1988, the first monitoring system that provided yearly deforestation figures for the entire Amazon, was followed by a heated controversy concerning the truth of the official figures provided by the Brazilian government. This scientific controversy attracted the attention of the local media, which not only highlighted the lack of scientific consensus and the uncertainty in the data provided by INPE, but also argued that the Brazilian government was deliberately underestimating the figures for political purposes or even 'making up' data in order to please then president José Sarney, who is from that region (Petit, 1989; Tuffani, 1989). INPE came back into the spotlight in 1997 and 1998 when the influential Brazilian magazine *Veja* published a series of articles accusing it of hiding from the public a 1995 spike in deforestation, in order to avoid interfering with the negotiation of the Kyoto Protocol (Rajão and Georgiadou, 2014).

In 2008, the controversy concerning deforestation figures reached new heights as Blairo Maggi, then governor of the state of Mato Grosso and one of the largest soybean producers in the world, suggested that INPE's scientists were lying in order to justify the approval of tougher environmental regulations by the Ministry of Environment (Sant'Anna, 2008). The issue escalated when then-President Lula da Silva gave weight to Maggi's declaration by affirming that INPE's numbers were 'under investigation' (Nogueira and Tomazela, 2008). Indeed, in the following weeks the governor of Mato Grosso launched a major operation in ground truthing, inspecting *in situ* the individual clearings identified remotely by INPE. Officials from the state-level environmental agency SEMA-MT reported that this operation was the largest that the state had ever done in relation to deforestation. Similarly, during the presidential elections that took place in 2014 some journalists and environmentalists accused INPE of delaying the release of data showing another increase in deforestation, to benefit then President Dilma Rousseff in her successful reelection campaign (Leite and Talento, 2014).

In the cases mentioned above, INPE scientists managed to dismiss the accusations on technical grounds or changed their data transparency policy in order to avoid further criticism (Rajão and Georgiadou, 2014). Nevertheless, these recurring controversies concerning deforestation data have made INPE's scientists and technicians aware of both the scientific and political significance of their work. During interviews, it was possible to detect a strong sense of commitment to the policies that aim to reduce deforestation in the Amazon. For this reason, many INPE scientists see themselves as 'guardians of the Amazon', watching over the forest and alerting policy-makers and civil society alike of dangerous deforestation trends. At the same time, they also understand that their ability to 'watch over' the Amazon relies on the scientific authority entrusted in INPE and to the possibility of any party, including political opponents such as Maggi at the time, to independently verify the data produced by its monitoring systems.

Because of that, throughout the process of producing deforestation measurements INPE scientists are extremely careful to avoid damaging the scientific credibility of their data. They actively participate in trying to direct the academic drift (Kaiserfeld, 2013) that tends to favor scientific activity over political activism. INPE's attempts to maintain scientific authority in the face of the 2008 controversy with Maggi is a clear example of how such investment in scientific legitimacy is at the same time an attempt at distancing themselves from the world of politics (through an investment in scientific credibility and objectivity), but also a powerful political tool in itself. Had INPE lost credibility as a scientific institution, it would have lost political weight in participating as a central actor in Brazil's environmental policies.

In the next section we present in detail an ethnographic account from the labs where deforestation data is produced. The second author participated in the analysis of remote-sensing images at INPE and investigated how they are transformed from raw satellite images into reliable measurements of deforestation. In this process, scientists take extreme care in sustaining scientific rigor at every step, through careful mitigation of uncertainty in the data. They are constantly reflecting on how the data will be read outside the laboratory, thus incorporating into their work anticipation of how the figures will become part of the ongoing controversies around deforestation. This reflexivity also relates to their struggle to maintain scientific credibility, which is a powerful asset in broader disputes around deforestation policies.

Mitigation of uncertainty in the laboratory

In order to fully appreciate the internal stakes of recent controversies such as Maggi's questioning of INPE data in Mato Grosso, it is important to understand how uncertainty in the data is managed at the image processing stage. As shown above, controversies around the detection of deforestation mobilize these uncertainties, allowing for strategies such as offering alternative and opposing accounts of clear-cut deforestation, mobilizing alternative truth-making mechanisms and forcing actors such as INPE to rally around the system to reaffirm the data's reliability. But why is such data able to be questioned in this way? The answer lies in the uncertainties inherent in the technology itself and in how satellite images become data through processing practices.

Navigating uncertainty is a practical skill that needs to be incorporated by the user of remote-sensing technology in order to allow scientists and technicians to make sense of what is actually being visualized (Coopmans et al., 2014; Lynch and Woolgar, 1990). As Alač (2008) and others have discussed in the parallel case of fMRI, analysis of talk and gesturing shows how scientific visualizations are complex (visual and embodied) practical accomplishments. They emerge relationally through interactions between corporeal practices and images on the screen, and are also constructed through complex body work which requires a deep engagement of the scientists' bodies-in-movement and not just their vision (Myers, 2008). These studies have shown empirically that visualizations in science are more than representations (Monteiro, 2010a, 2010b), and as such evidence emerges through corporeal engagements between scientists and data, including (but not restricted to) images.

Much of this embodied work involves dealing with uncertainty in data, which has to be mitigated in order for usable and reliable images to be produced. Thus mitigation of this inherent uncertainty is a large part of the work required to make sense of remote-sensing visual data. As analysts process and interpret images, they employ strategies to mitigate uncertainties, which include: (a) combining datasets by comparing inscriptions, (b) switching to collaborative analysis instead of the usual individual analysis, (c) validating the data through fieldwork and (d) anticipating opposing interpretations.

These mitigation strategies relate directly to broader controversies, since it is through the management of uncertainty that INPE's authority is both constructed and constantly attacked. Thus data work is the crucial locus of our reflection, as the practical instance where objective visual data is produced and where civic understandings emerge from the scientists own perceptions. The analysis presented here will focus on practices that seem to be bounded spatially to laboratories, but the boundaries of the experiments enacted by INPE researchers are open to debate (Callon et al., 2009; Davies, 2010). The analytical focus on the processing of visual data here seeks not to reinforce, but to question, a bounded image of remote-sensing knowledge, as the situatedness of the scientists' understanding of their work comes to light ethnographically. We analyze this in further detail below.

Combining datasets

The creation of reliable deforestation figures depends on the establishment of a stable correspondence between the data obtained remotely from a specific set of sensors and the object being observed. In this process it is particularly important to determine whether the output of a given instrument (e.g. spectral bands, spatial and temporal resolution) on board a satellite match the characteristics of the phenomena being measured at a distance (e.g. refractance, minimum size and frequency). From a strictly methodological point of view, after the data source of a given satellite-based remote sensing has been selected and validated, the comparison of images from that source at different time periods would be enough to detect changes in the forest cover in a reliable manner (INPE, 2008; Valeriano et al., 2004). In practice, however, INPE's scientists and technicians systematically combine and compare images from different sources and time periods in order to decide whether to ignore a given observed change or classify it as a recent deforestation. Since the scientists and technicians are working with second-order inscriptions, agreement is sought in terms of what different images or values say about similar areas. With this purpose, INPE scientists and technicians use images from as many satellites as are made available to them, since an image with a higher resolution from the same area and similar time period may confirm the presence of a new deforested area or reveal a potential misclassification.

The need to bring together images from different sources is particularly marked in the case of the Near-Real Time Deforestation Detection System (DETER). This system was created in 2004 following a demand by the forest rangers from the federal environmental agency (IBAMA). While IBAMA recognized the policy relevance of the annual deforestation rates provided by PRODES, IBAMA rangers complained that by the time they got the data (usually one year after the detection) it was already too late to launch law enforcement operations to arrest the perpetrators of illegal deforestation. INPE took on the task of developing a system able to provide deforestation "alerts" with high frequency. But in order to do this it was not possible to use the same high resolution images as PRODES that are provided by the Landsat family of satellites (from NASA), or

Brazil's own satellite CBERS, launched in collaboration with China. For this reason, INPE developed PRODES based mainly on the images from the Moderate Resolution Imaging Spectroradiometer (MODIS) flown on Terra and Aqua, two NASA satellites. In contrast to the Landsat satellites that provide a single image with a spatial resolution of thirty meters every fifteen days, MODIS images are available daily but with a resolution of only 250 meters (i.e. every pixel in the image corresponds to 250 meters on the ground). In this way MODIS has a higher chance of providing a cloud-free, albeit 'blurry' image of the Amazon every two weeks.

Because of this low resolution of MODIS, the uncertainty of DETER increases considerably. In order to mitigate this uncertainty, INPE interpreters go beyond DETER's stated methodology (Anderson et al., 2005) and also use images from other satellites with higher resolutions. Even if these images are usually a few weeks (or even months) older than the MODIS images, they are deemed crucial to the validation process as they allow interpreters to avoid misclassifying large forest fires, clouds, rocks and other features as deforestation. Their concern with positive misclassification is important if we consider that the main evidence presented by the governor of Mato Grosso as proof that INPE was 'lying' consisted of photos taken from helicopters showing an apparently pristine forest in areas detected by DETER as degraded or deforested.

In the sequence of screenshots shown in Figure 1 it is possible to see the actions performed by DETER interpreters in order to identify a new area of deforestation or forest degradation. In the top left frame, it is possible to see the use of a tool called 'Connect view' provided by the GIS, whereby users can create a rectangle that allows them to see past the 'masks' of deforestation (i.e. previous classifications), and by scrolling with the mouse, switch between the previous and current MODIS image of that scene to check for differences (especially possible new deforested areas). In the frame at the top right we can see an older high-resolution image (in this specific case from Landsat 5) of the same area, superimposed on the newer one. The user can then switch between these old data and the new data by scrolling with the mouse in order to validate initial impressions through comparison. After confirming that the deforestation in the area under analysis has increased in size since the previous classification, the user uses the 'create polygon' tool in Figure 2 (bottom left frame) in order to mark the area newly classified as forest degradation.

Even though in theory a single satellite sensor can be used to establish deforestation, INPE's scientists and technicians draw upon all the means available to them in order to avoid misclassifications. By combining different data from the same region coming from different satellites (with different cameras and different spatial resolutions), interpreters build more confidence into their interpretation of deforestation and protect themselves against challenges coming from outside the laboratory.

Collaborative analysis

The methodological accounts of how PRODES and DETER work also indirectly suggest that INPE's deforestation data are the result of solitary interpreters operating in a cold and objective way (INPE, 2008; Valeriano et al., 2004). Indeed the interpretation of satellites images is often an individual activity: the technician or scientist deals directly with the image on their computer, and in many cases silently posts the work concerning a

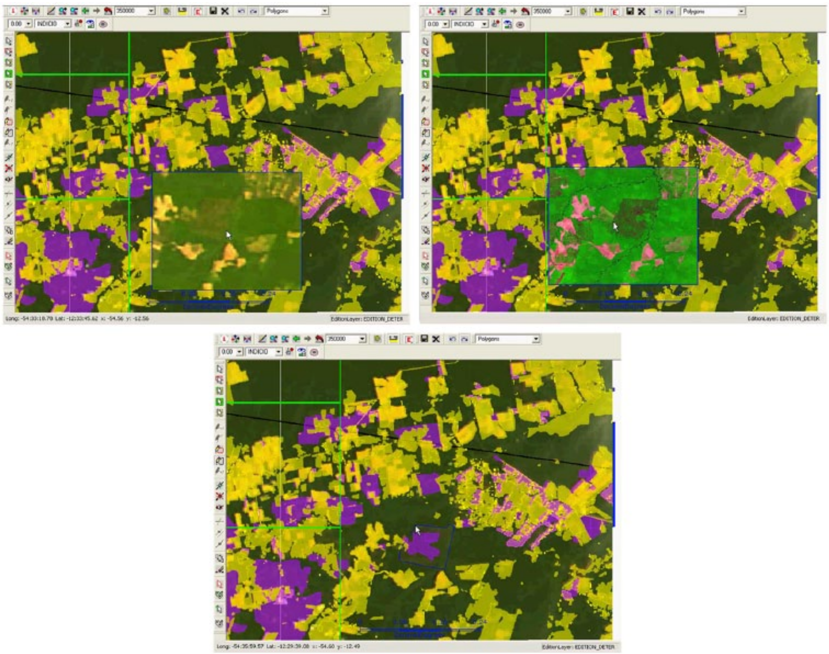

Figure 1. Screenshot showing: (top left) how a remote sensing interpreter identifies new deforestation by comparing a new MODIS image in the background and an old one within the rectangle; (top right) the validation of a potential new degraded area with a higher resolution image; and (bottom left) the classification of the new area as degraded forest.

specific part of the Amazon on a shared server so that these results can be aggregated and thus speak for the whole region. Yet this silent and individual work has crucial moments of discontinuity as these interpreters switch to collaborative forms of analysis.

In the case of PRODES, interpreters have to classify every pixel of the satellite image as either ‘forest’ or ‘clear-cut deforestation’ by drawing polygons over them using the same GIS presented in the case of DETER above (see Figure 1). This methodology was devised in the early 1970s when INPE’s main purpose was to identify whether the subsidies provided to big investors and companies such as Volkswagen were being used to create large cattle farms in the Amazon and not ending up in some corruption scheme (Loureiro and Pinto, 2005; Rajão and Hayes, 2009). In these cases the detection of deforestation is a straightforward process involving the comparison of the patches of homogeneous green (forest) and red (soil/deforestation) from an image taken in the current year with an image from the previous year. However, as a reaction to the creation of DETER and the increase of law enforcement actions in the region, farmers started to destroy the forest slowly rather than clear-cutting it at once, hoping to remain undetected by INPE systems (Rajão and Vurdubakis, 2013). Therefore instead of a binary forest/non-forest situation, INPE scientists increasingly have to analyze images that present different

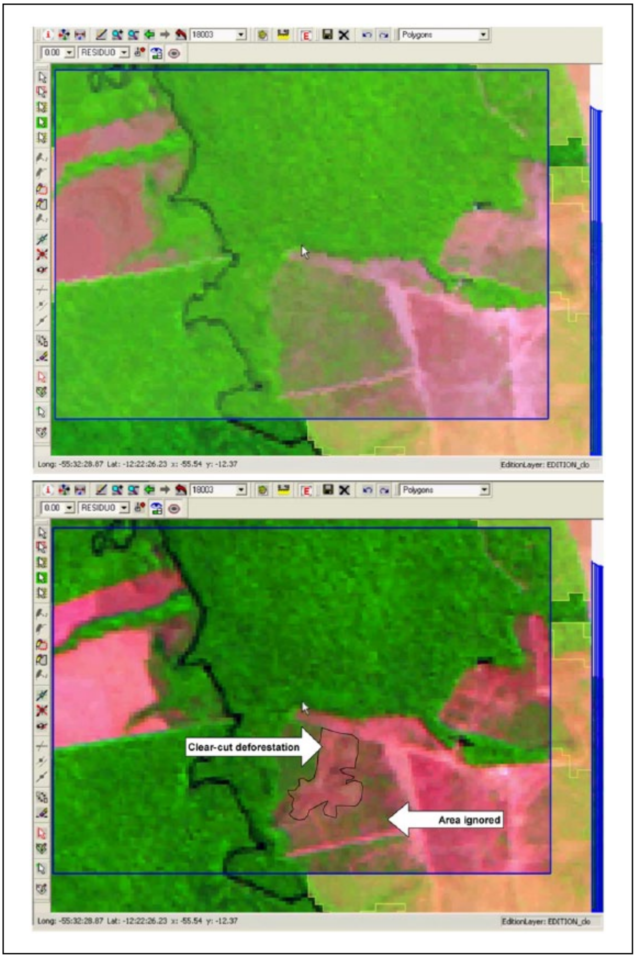

Figure 2. Screen capture taken during the dialogue between a novice (the researcher) and an experienced interpreter (INPE technician) concerning the classification of a newly deforested area reproduced below. On the top is a satellite image from the year under analysis (2009), and on the bottom is an image from the previous year, with indications of the area classified as clear-cut deforestation and as mere degradation (and thus ignored).

degrees of forest degradation (i.e. greens and reds mixed up) and decide whether to classify these areas as clear-cut deforestation or to leave them unmarked as if they were pristine forest.

These situations can get more complicated, as in years of drought some forested areas might look reddish because the trees lose their leaves and expose the underlying soil more markedly than they normally would. Also, the lack of alignment of satellite images, technical errors, small clouds and smoke can easily be taken to be clearings. Finally, in order to establish the current status of the area under analysis, interpreters have also to take into consideration the causes that have led to that situation. This implies that in the case of PRODES, areas that have been highly degraded due to intense fires but that have not been cleared completely have to be ignored by the interpreters.

In order to deal with these different sources of uncertainty, INPE interpreters often interrupt their solitary activities to seek help from their more experienced colleagues. If their more approachable co-workers are not able to solve the problem they also seek help from INPE's senior scientists. For three days the second author was able to shadow the coordinator of the Amazon program during his daily routine between INPE's campus and the technicians' workplace located in a building in the city center. As soon as the coordinator arrived each day, workers immediately stopped their normal activities to ask his advice. The coordinator would then patiently go from desk to desk, looking at satellite images and addressing doubts. In addition to this informal way of mitigating uncertainty via collaboration, the interpretations follow a strictly hierarchical workflow in order to crosscheck the classifications and avoid inconsistencies, as explained by an INPE senior scientist:

> We assign one image to each interpreter, who does the first analysis. The work of the interpreter is then reviewed first by an auditor and then by a homogenizer, who has more years of experience. If the interpreter has any doubt, they classify the polygon as a 'doubt', and then the reviewer can take a look and confirm the existence of the deforestation if that is the case. (Interview with Senior Scientists from INPE)

It is also relevant to notice the language used by INPE scientists and technicians to refer to the different levels of forest degradation. While image color is a useful starting point, it is not enough, since deforested areas converted to agricultural use can also have a 'green' aspect, and areas subject to intense fire can be dominated by shades of 'red'. Therefore, in addition to referring to the visual qualities of the images, interpreters often used tactile adjectives. In the case of PRODES, a green yet 'smooth' area is more probably a soybean field than a native forest cover. Similarly, a 'rough' yet reddish set of pixels may indicate that the area has too many standing trees to be considered deforested.

This kind of dynamic is at the same time similar to and different from the processing of visualizations in other contexts (Monteiro and Keating, 2009). Visual data is often handled by individuals working on computers, but here the informal consultations and formal workflows are important in terms of sharing results and collectively validating analyses (Coopmans and Button, 2014; Lynch and Woolgar, 1990). The switch to collaborative work is also a way to draw from tacit knowledge embodied in other researchers and their 'years of experience', benefitting from practical solutions achieved by other interpreters working on similar problems, or even drawing insights from solutions to very different problems. This tacit knowledge is crucial to scientific work in general (Collins, 1974; MacKenzie and Spinardi, 1995), and is especially important here, given the 'artisanal' character of digital image analysis (Monteiro, 2010a). While this is arguably usual for any data-work that involves visual material, these instances of cooperative analysis are relevant to how civic understandings of deforestation are also collectively shared and reinforced.

Ground and narrative-based 'truthing'

In their interviews interpreters from INPE defined fieldwork as being crucial to the validation of ambiguous or hard-to-process data. The trip to the field, besides having an emotional component for these researchers, becomes the decisive procedure for revealing the 'actual truth' of the territory shown by satellite images. This double work of dealing with visual evidence and actually 'being there' makes these researchers especially thoughtful about the possibilities and limitations of each method available. The work of moving from image to field-based data has been described as 'decontextualization' and 'recontextualization' (Almklov, 2008), where interpreters are required, as part of their skill set, to be able to handle the translation work between these two very different realms.

In addition to traditional forms of 'ground truthing', which involve costly fieldtrips to the Amazon, it was possible to observe the presence of what we might call here 'virtual fieldtrips'. Drawing upon the tacit knowledge accumulated over the years, more experienced scientists provide rich narratives to newcomers, containing key information about the Amazon that is not present in satellite images, such as typical demographic patterns, odd vegetation covers in certain regions and the effects of particularly dry years. A senior scientist exemplified in the following excerpt this form of virtual fieldwork:

> Today I was a bit in a hurry, but when I have time I try to teach the guys here about the Amazon. In those instances, when they are facing some difficulty to interpret an image I ask them 'Where are you?' and they reply, 'I'm in the image 7201', and I say 'Noooo! You are in the North of this state, in a region with this specific kind of colonization [which explains this land use pattern]. (Interview with senior INPE scientist)

In the excerpt above we can see how embodied experience from fieldtrips can be relevant and productive in orienting the interpretation of the images. 'Having been there' can give a more experienced interpreter authority to talk about certain vegetation and deforestation patterns that will guide novices in their understanding of the visual data. Therefore, the field experience 'comes back' as embodied experience, which is converted into analytical authority over the correct interpretation. These moments of sharing field experiences are instances of building shared understandings of the territory, and also rich moments of constructing specific civic understandings of the data being produced, as when they discuss colonization patterns in the quote.

In other moments, the relation between the satellite image and the underlying ground truth is established in relation to the knowledge of how the deforestation process takes place and when a given area should be classified as clear-cut deforestation. In the dialogue between the researcher who acted as a novice interpreter and an experienced technician analyzed below one can see how some of these tensions are resolved in the process of mitigating uncertainties of interpretations:

Anthropologist: Danilo [an INPE scientist] explained to me that PRODES detects only
clear-cut deforestation, right? Would this be a clear-cut deforestation?
[I point the mouse and zoom into a reddish section of the satellite image].
Technician: That is correct.

[I use the mouse to zoom into a portion of the image (Figure 2, above)]
Anthropologist: I found one.
Technician: You are right. This area most probably was not there [last year]. Maybe it was a set of small clearings here and there that was not caught because Danilo told us that it was not clear-cut, but now it is, can you see it?
[The technician takes control of the mouse and uses the scroll wheel in order to show the satellite images from the last two years for the same area]
Technician: Here, look, back then [last year] the process was starting…
Anthropologist: And now it seems to have finished …
Technician: And you cannot take it as a residue [an area wrongly ignored], because last year that [clear cut] deforestation was not there.
Anthropologist: But then I have to get this area here, is this [forest] degradation?
[Pointing my finger to the portion of the screen indicating a green area but with a lighter shades of green and red (Figure 2, below)]
Technician: … You are right, you need to leave it there … for next year
Anthropologist: For next year?
Technicians: It [the remaining forest there] will be gone as well.

The excerpt above provides some insights into the complexities and uncertainties involved in the interpretation of satellite images for PRODES. The dialogue starts with an attempt to confirm with a senior technician whether theoretical concepts and methodological guidelines explained to me earlier by one of INPE's scientists were being put into practice correctly (1-6). But before giving the final confirmation she grabbed the mouse from the anthropologist's hand to highlight the importance of comparing the latest satellite image with the one from the same area obtained in previous years. She also mentioned that the area had not been classified as deforestation before due to a directive from a senior scientist. In other words, the senior technician compared different datasets and remembered the role of collaborative analysis in order to mitigate the uncertainty in the interpretation (7-11).

The senior technician also emphasized that the deforested area in question was not a 'residue' (an area not classified as deforestation by mistake) from last year, since it was only in the current year that the area reached the clear-cut level (12-15). That is, she wanted to make clear that PRODES image interpreters try to perform their analysis as carefully as possible in order to avoid oversights. But this affirmation led to a question by the researcher, concerning an area that has become more degraded since the previous year, but it was unclear to the anthropologist whether it should be classified as deforestation or degradation and be left unmarked. After giving some thought she concludes that that the area in question is indeed degradation. But after another moment of silence the senior technician argues that in any case the area will probably be classified as deforestation 'next year' anyway (16-21).

This temporal strategy was not isolated. It was possible to observe that in many instances of unclear or ambiguous interpretations different interpreters have mobilized this argument to justify a specific way of classifying areas in the image. By drawing upon a temporal argument, interpreters are able to remain faithful to PRODES' scientific methodology and avoid classifying an ambiguous area as clear-cut deforestation even if the area clearly suffered different forms of human intervention.

In this way, the deterministic narratives concerning the almost certain transformation of highly degraded forests into clear-cut areas enable INPE interpreters to cope with the dilemma of having to ignore within PRODES a substantial share of the destruction of the Amazon. Therefore this crucial juxtaposition between narratives, both visual and field experiences, increased the truth-value of the resulting analysis while also dealing with the anxiety of the INPE interpreters as concerned citizens.

Anticipating opposing interpretations

It is possible to explain the adoption of uncertainty mitigation strategies by INPE's interpreters described above as the result of a strong commitment to the scientific method, that is, to the explicit and tacit rules that establish within the field of remote sensing what counts as valid knowledge. In this way, these scientists and technicians strive to create facts that can stand tests of force (Latour and Woolgar, 1986) posed by alternative interpretations and opposing positions, such as the ones coming from large soy producers and other critics of Brazil's deforestation policy. But in addition to anticipating the expectations of their own scientific communities, it was possible to observe that INPE scientists and interpreters were also concerned with how their work would be received beyond the scientific realm and with the political implications of their interpretations. In this sense, it is hard to separate this reflexive anticipation from the process of analysis and interpretation of images, since alternative interpretations were often present during the process of analysis itself.

The process of anticipating opposing interpretations is particularly evident in the effort made by INPE interpreters to mitigate the risks of both overestimating and underestimating deforestation figures. A common aspect that unites all technicians and scientists that were interviewed, observed and shadowed at INPE is a strong commitment to the preservation of the Amazon rainforest. For instance, in an interview a senior scientist reported that he and his colleagues consider themselves the 'guardians' of the Amazon, suggesting the presence of a strong emotional attachment to the forest. This commitment is manifested in the level of detail and attention invested in their image interpretation practices. This zealous approach sometimes clashes with the need to restrict the scope of PRODES to clear-cut deforestation. This means that some areas that are very degraded due to fires or selective logging must be left unreported, even if they clearly indicate a process of forest loss. In this case, the environmentalist ethos of the interpreters as well as their self-understanding as 'watchers' of the rainforest lead them to want to include as many areas as possible, pushing the definition of what counts as 'clear-cut' to the limit. Yet if they go beyond the boundaries imposed by PRODES' methodology they may be accused of being 'unscientific' by critics, including the 'ruralist' sector of the government. In addition, releasing numbers that show a hike in deforestation rates leads to more pressure on the government, and thus is always a sensitive issue.

Such ambiguous moments challenge the environmentally engaged analyst, as INPE may be underreporting relatively obvious deforestation and reporting only 'clear-cut deforestation', which has a specific definition under PRODES methodology. These considerations are constantly present during analysis of the images, and may inform the scientists' overall perception of what PRODES can and cannot show, how deforestation evolves and their own role in the politics of deforestation monitoring. But to lose objectivity in the numbers is to weaken the methodology and thus their authority. So it makes more (scientific and political) sense to INPE interpreters in their role as both scientists and citizens to remain cautious in the face of ambiguity.

Conclusion

In this article we have examined how scientists deal with their dual roles as producers of objective knowledge about deforestation and as concerned citizens, preoccupied with deforestation as a broader social problem. These tensions emerge, we have shown, in the practices of mitigating uncertainty in remote sensing images. The process is permeated by broader social values concerning the destruction of the Amazon. We argue that scientists are explicitly aware of their social situatedness as they attempt to produce the best knowledge possible about deforestation using remote sensing data.

By looking at the practical accomplishment of evidence in the laboratory, we see how technicians and scientists work very hard to mitigate uncertainty in remote sensing data, following strict scientific protocols but also drawing on a range of strategies that involve diverse data sets, field 'truthing' and reliance on tacit knowledge from more experienced interpreters. Through this we could see how awareness of the policy relevance of the data produced was also a factor in the practical everyday achievement of reliable, scientific data on deforestation.

This reflexive awareness, we argue, makes explicit the complexity of science/policy interfaces in the case of deforestation: it is through the numbers produced by INPE that the reality of deforestation is in a great measure established. The solidity of the monitoring system is a historical accomplishment, yet it is constantly being questioned and must continuously be maintained. This work is done in large degree by the scientists themselves through their everyday analytical work. Therefore, mitigating uncertainty is also a strategy of maintaining the reliability of the system and, in consequence, its scientific credibility and political effectiveness in environmental policy-making arenas.

Part of this work with uncertainty involves anticipating counter arguments based on their perceptions and experiences in a hotly disputed field. This uncertainty-work also helps frame policy issues by building a strong sense of how deforestation dynamics develop in the present and in the future. These scientists circulate in institutions and government, both formally and informally, and their perceptions (constructed inside and outside the lab) participate in various science/policy interfaces that go beyond institutionalized instances of providing advice to governments or producing policy reports. These interfaces are harder to capture through usual policy analysis, but are very important in defining how policy is both formulated and implemented.

We argue that the scientists are thus keenly aware of and actively participate in enacting specific policy frames and in bringing policy relevance to daily data-building practices. In this way we hope to show how complex these interfaces are – far more complex than might be imagined in images of secluded scientists producing 'objective data' for use in policy settings. Although many of these practices can be seen as spatially secluded, the accomplishment of reliable data in itself involves awareness of and reference to the politically disputed realities of deforestation in the public arena. The very careful epistemic work of achieving robust and usable data cannot be separated from the awareness of and involvement in public controversies. This complexity has consequences for how we understand and practice both science and environmental policy.

Deforestation politics has become increasingly conflicted in Brazil, as the country is trying at the same time to project a green image to the world and to maintain its position as an agricultural superpower (which puts immense pressure on forested lands). In the violent clashes over how to manage territory and natural resources, many controversies collide and intersect, from climate change negotiations to indigenous rights, from low carbon agriculture to biofuel policies. In each of these interrelated controversies, the actors will dispute objective measures of land-use change and the production of reliable evidence to determine what environmental, energy, agricultural and other policies can and should be promoted. This sociotechnical element has growing relevance to how decisions are made and policies are designed and implemented.

If INPE (and other) scientists are not ‘secluded’, this also puts in question any a priori separations between science and policy. If scientists are also concerned citizens, this also implies that STS can and should look at science and engage with it differently (Fortun and Fortun, 2005). Interfaces between science and policy are present throughout controversial spaces, including, but not restricted to, the laboratory. Thus, to understand such interfaces one needs to look beyond clearly defined scientific or policy domains, and draw more nuanced images of the process through which science and policy co-construct each other (Jasanoff, 2004). This does not mean that all scientists are necessarily attuned to the broader relevance and consequences of their work. But if science is not always (or merely) secluded, then interface with policy can happen in unanticipated ways and through routes that have been rarely discussed. This has implications for how we reflect on science-policy interfaces, but also has potential impact on how we understand the necessity of public engagement in scientific governance or how we argue for the necessity of engaging in responsible research and innovation.

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