

## Agricultural property monitoring using geospatial foundation models

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### Abstract

In this paper we present a preliminary study on the application of geospatial foundation models to the satellite-based monitoring of agricultural properties. Images from the Sentinel-2 mission are processed with the Clay foundation model in order to produce embeddings in the model's latent space, which are later reduced in dimension with a principal component analysis and plotted in 2 dimensions to enable visual inspection. A case study was carried out considering scenes from a property located in the Guia Lopes da Laguna agrotechnological district, a partner of Semear Digital. Two management situations were taken into account: a) traditional pasture; and b) initial preparation for an integrated livestock-forest system. Differences in the embeddings from both scenarios were analyzed, and early observations indicate that the method has potential and may become a consolidated practice in the area.

**Keywords:** Deep machine learning; Remote sensing; Livestock-forest integration.

### 1. Introduction

Geospatial foundation models (Zhang et al., 2024) are large, pretrained machine learning models, often based on deep learning architectures, that are trained on massive amounts of geospatial data like satellite imagery, aerial photos, or Earth observation data to understand and represent the Earth's surface in a generalizable way.

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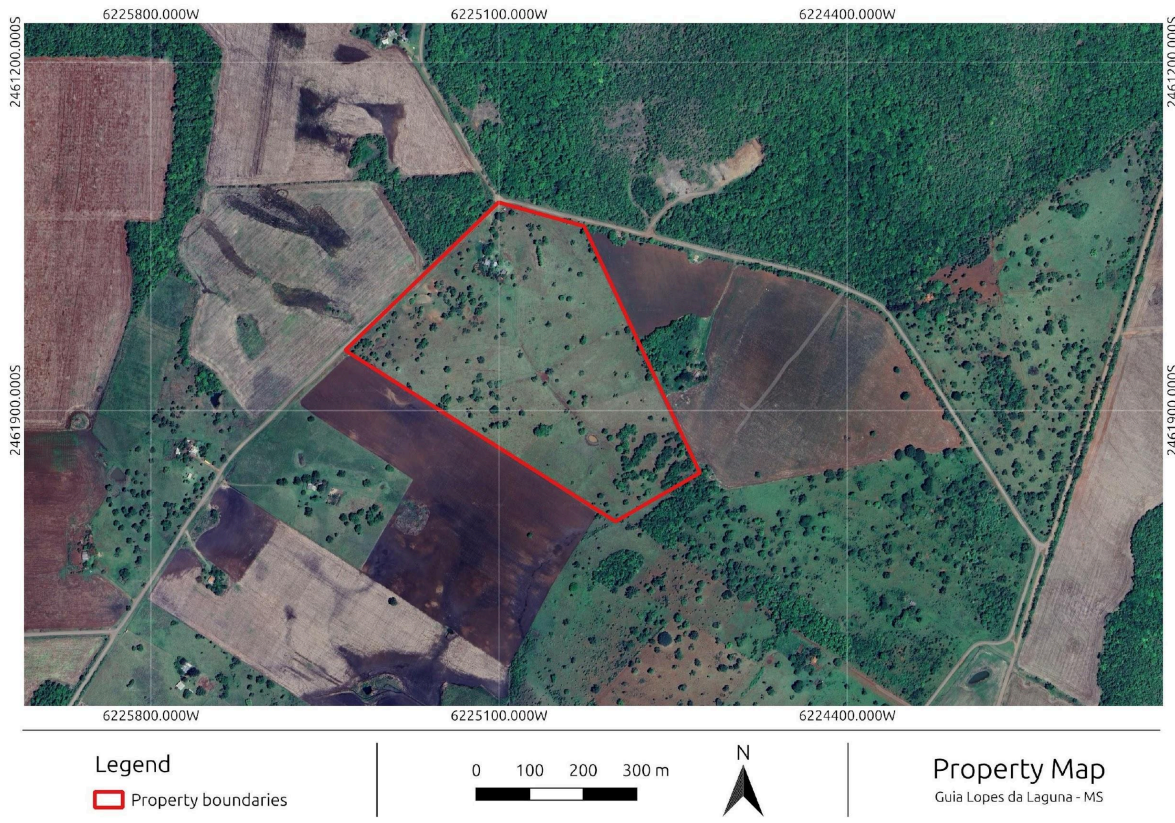
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Since labeling geospatial data is costly, many geospatial foundation models use self-supervised learning techniques (e.g., contrastive learning, masked autoencoders) to learn useful representations from unlabeled data. Once trained, they can be fine-tuned or used as feature extractors for a wide range of downstream geospatial tasks like land cover classification, change detection, disaster monitoring and crop mapping, among other examples, therefore enabling a faster and more efficient analysis of Earth observation data at scale, especially useful when annotated data is scarce.

In this study we are interested in the application of geospatial foundation models to the satellite-based monitoring of agricultural properties. In order to avoid a costly regular deep learning model training, we want to investigate if geospatial foundation models, as they are, with no extra training, are able to process scenes of different management situations and produce distinguishable embeddings in each case. No other work exploring the applications of foundation models specifically to agricultural property management was found; nevertheless, applications in agriculture are trending (Yin et al., 2025).

## 2. Methods

Our case study considered a property located in the Guia Lopes da Laguna agrotechnological district (Figure 1, taken from Google Maps and edited by the authors). During the last decade, the area was mainly used for the traditional pasture system, however, after partnering with Semear Digital and Rede ILPF the owner is now interested in the development of an integrated livestock-forest system (Bussoni et al., 2019).



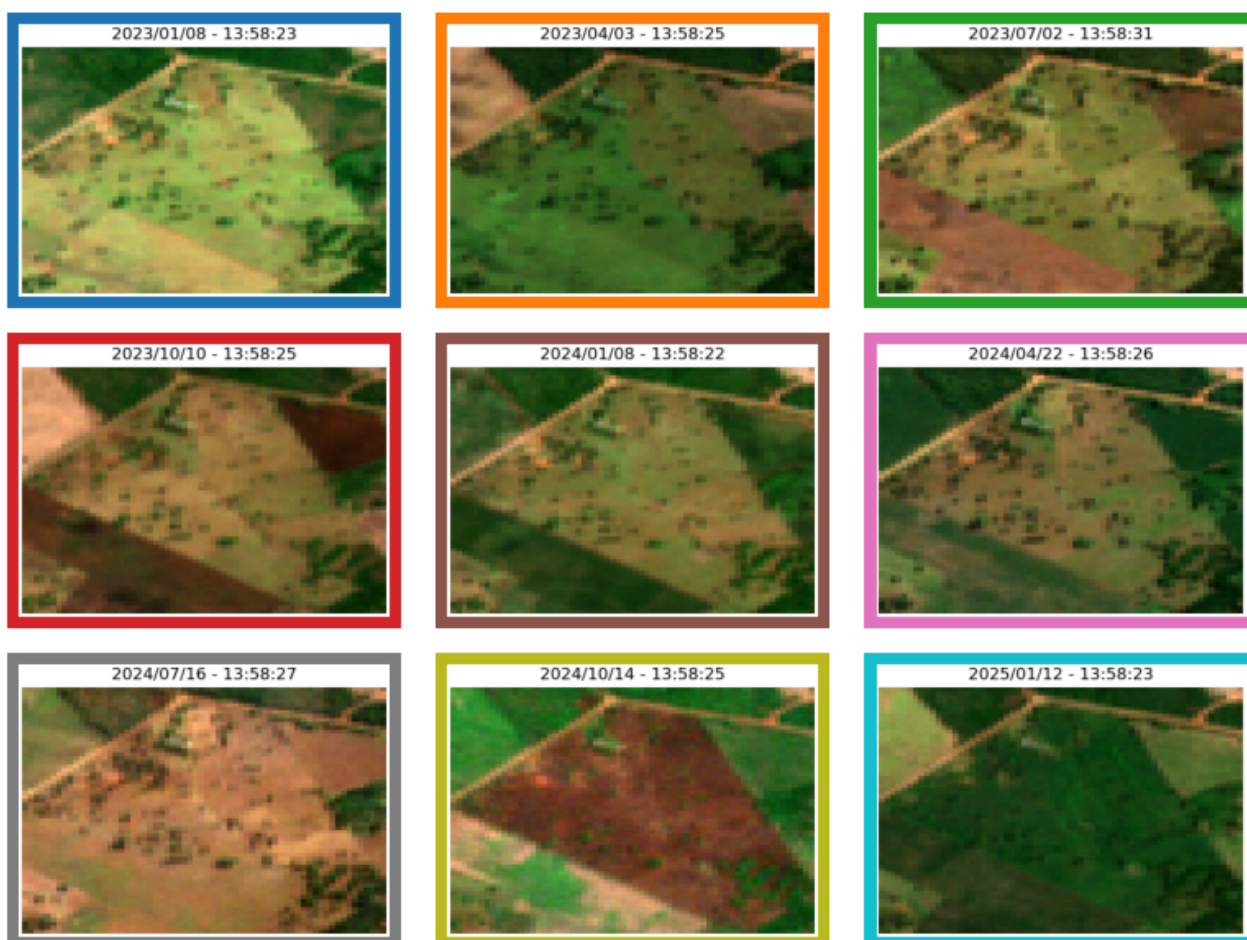
**Figure 1.** High definition satellite image of property (red polygon).

Series of images (256x256 pixels, RGB channels) from the Sentinel-2 mission (Sentinel-2, 2025) were collected, considering two distinct situations:

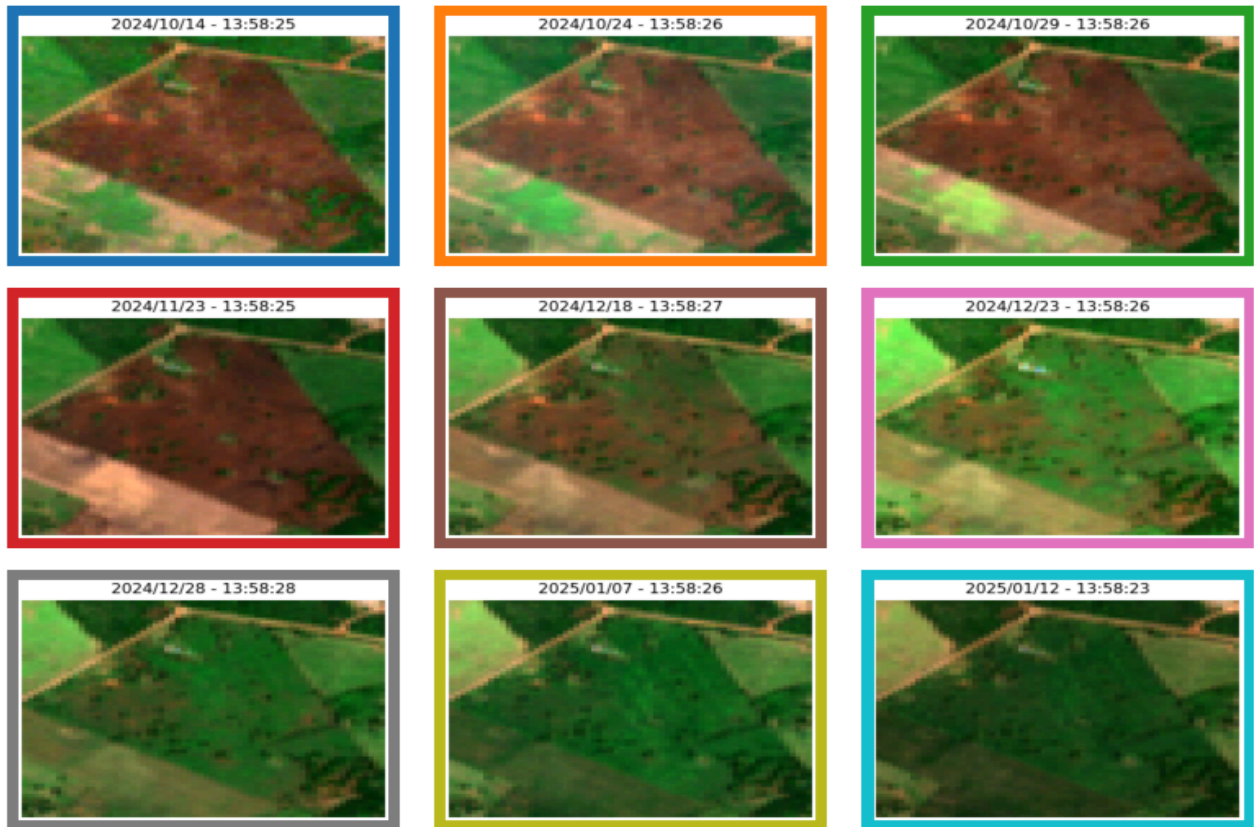
- scenario A: regular pasture management, from early 2023 up until early 2025, with an approximately 3-month separation between images (Figure 2, with images collected from the Sentinel-2 catalog and edited by the authors);
- scenario B: preparation for livestock-forest system, from October 2025, with shorter time windows separation, from roughly a week to a month (Figure 3, with images collected from the Sentinel-2 catalog and edited by the authors).

Both series were processed with the Clay Foundation Model (Radiant Earth, 2025). Each image was fed to the model, resulting in 768-dimensional embeddings. The embeddings were processed with the principal component analysis (Hotelling, 1933); 2

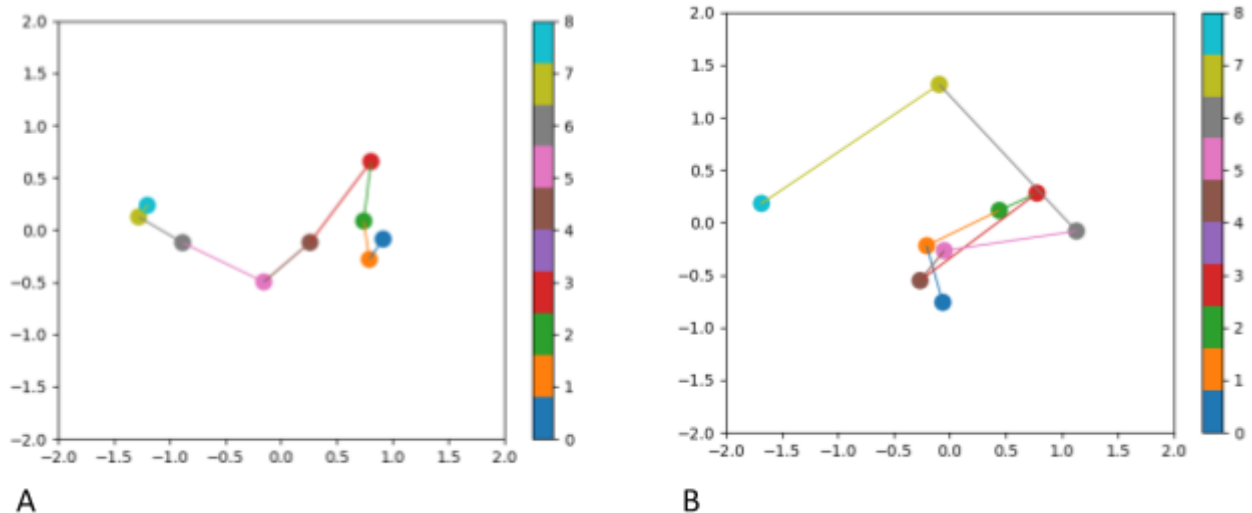
components from each embedding were kept; the series for both scenarios were plotted in the plane (Figure 4).



**Figure 2.** Sentinel-2 images for scenario A.  
Color frames refer to embeddings in Figure 4A.



**Figure 3.** Sentinel-2 images for scenario B.  
Color frames refer to embeddings in Figure 4B.



**Figure 4.** Embeddings for: (A) scenario A; (B) scenario B.  
Colorbars represent ordinality in the sequences.

### 3. Results and Discussion

The series of embeddings in Figure 4 highlights a smooth pattern for scenario B and a more clumsy pattern for scenario A. That can be explained by the fact that the B series shown in Figure 3 presents fluid transitions between images, and similar images are expected to produce close embeddings in the latent space. On the other hand, the A series shown in Figure 2 presents sharper transitions between contiguous images, which occur due to the fact that the images in this case were taken with a too long time interval, at least long enough so that changes due to season become evident and influence in the creation of embeddings.

It is quite early for a true assessment of an integrated system in the property considered in this study. In a few years, when the forest in that area is more developed, it will be possible to investigate the sensibility of the embeddings to the growth of trees in that patch of land, and hopefully, to fine-tune a system to be used as a management tool for that partner. In the meantime, similar studies considering not only integrated systems but any kind of land use problem, in any part of the world, can be performed using a similar framework.

#### 4. Conclusion

In this study a preliminary assessment on the exploration of geospatial foundation models for agricultural property management was presented. Remote sensing image time series were collected considering distinct contexts, namely, conventional pasture management, with 3-month separation between images, and land preparation for the implementation of an integrated livestock-forest system, with smaller time windows between images.

Even though the timeline for actual livestock-forest management in that property is still too short since the forest part of the system takes time to grow, the series considered in the study present complementary patterns in terms of agricultural contexts. The embedding dynamics observed for each case were distinct, which serves as an early indication that the method has potential, but more experiments are necessary to confirm if actual tree developments can be tracked with such a framework.

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#### References

BUSSONI, A.; ALVAREZ, J.; CUBBAGE, F.; FERREIRA, G.; PICASSO, V. Diverse strategies for integration of forestry and livestock production. **Agroforestry Systems**, v. 93, p. 333-344, 2019. DOI: <https://doi.org/10.1007/s10457-017-0092-7>.

HOTELLING, H. Analysis of a complex of statistical variables into principal components, **Journal of Educational Psychology**, v. 24, n. 6, p. 417-441, 1933. DOI: <https://doi.org/10.1037/h0071325>.

RADIANT EARTH. **Clay foundation model**: an open source AI model for Earth. Available at: <https://clay-foundation.github.io/model/index.html>. Accessed on: Aug. 8, 2025.

SENTINEL-2. Available at:

<https://dataspace.copernicus.eu/explore-data/data-collections/sentinel-data/sentinel-2>. Accessed on: May 25, 2025.

YIN, S.; XI, Y.; ZHANG, X.; SUN, C.; MAO, Q. Foundation models in agriculture: a comprehensive review. **Agriculture**, v. 15, n. 8, 847, 2025. DOI: <https://doi.org/10.3390/agriculture15080847>.

ZHANG, H.; XU, J. J.; CUI, H. W.; LI, L.; YANG, Y.; TANG, C. T. When geoscience meets foundation models: toward a general geoscience artificial intelligence system. **IEEE Geoscience and Remote Sensing Magazine**, 2024. Early access. DOI: <https://doi.org/10.1109/MGRS.2024.3496478>.