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Ícaro Souza Vieira

A PESQUISA SOBRE SOLOS NA ANTÁRTICA:
um estudo cienciométrico-espacial

Belo Horizonte

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Ícaro Souza Vieira

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"A PESQUISA SOBRE SOLOS NA ANTÁRTICA: UM ESTUDO CIENCIOMÉTRICO-ESPACIAL"

ÍCARO SOUZA VIEIRA

Dissertação de Mestrado defendida e aprovada, no dia 12 de maio de 2023, pela Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em Geografia da Universidade Federal de Minas Gerais, constituída pelos seguintes professores:

Fábio Soares de Oliveira

IGC/UFMG

Diego Rodrigues Macedo

IGC/UFMG

Carlos Ernesto Gonçalves Reynaud Schaefer

UFV

Roberto Ferreira Machado Michel

UESC

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RESUMO

Esta dissertação se trata de um estudo cienciométrico-espacial da produção científica internacional e brasileira relacionada aos solos, cujo local de estudo tenha sido a Antártica. A importância dos solos criogênicos, como são conhecidos, é inegável. Informações a respeito de seus regimes térmico e hídrico são indicadores importantes e confiáveis das mudanças ambientais globais, suas dinâmicas bio-geo-físicas são centrais na compreensão das paisagens periglaciais e eles ainda se constituem de fontes notáveis de material biológico economicamente interessante. Tendo isso em vista, essa pesquisa objetivou: a) Caracterizar a situação da pesquisa científica global e brasileira sobre solos na Antártica através de indicadores de produção científica; b) Descrever e caracterizar a estrutura da comunidade científica envolvida através de redes de coautoria; c) Espacializar as pesquisas a partir dos locais de amostragem identificados. d) Descrever e caracterizar a dinâmica conceitual e espacial da pesquisa criopedológica antártica a partir dos países, assuntos e locais estudados. Para tanto, foram recuperados dados bibliográficos das bases de dados *Web of Science* e *Scopus* e após tratamento foram construídos indicadores e redes bibliométricas; os pontos de localização de amostragem foram plotados e mapeados. Identificou-se que o campo de pesquisa é produtivo e de grande interação entre grupos de autores e instituições ao redor do mundo. Temáticas relacionadas à microbiologia, poluição, biorremediação, biogeoquímica e monitoramento dos regimes térmico e hídrico dos solos foram os principais focos de pesquisa. Percebeu-se que o padrão de distribuição espacial dos pontos e a distância média de um ponto a uma infraestrutura são influenciados por fatores como o histórico de pesquisa na região (se é muito ou pouco conhecida e onde) bem como por elementos da paisagem como a localização das áreas livres de gelo, biodiversidade, relações ecológicas e climas locais. Além disso Brasil se destacou como o principal país a estudar os solos da Antártica Marítima além de sua produção científica ser prolífica, internacionalizada, de impacto na literatura e espacialmente ampla por toda a região que se insere. Espera-se que esta pesquisa contribua para que a comunidade científica possa conhecer melhor seu campo de atuação, além de embasar políticas públicas e investimentos na ciência criopedológica brasileira.

Palavras-chave: Antártica. Solo. Cienciometria. Cienciometria espacial.

ABSTRACT

This dissertation is a a scientometric-spatial study of the international and Brazilian scientific production related to soils, whose study site was Antarctica. The importance of cryogenic soils, as they are known, is undeniable. Data on their thermal and water regimes are important and reliable indicators of global environmental changes, their bio-geo-physical dynamics are central to the understanding of periglacial landscapes and they still constitute notable sources of economically interesting biological material. With that in mind, this research aimed to: a) Characterize the situation of global and Brazilian scientific research on soils in Antarctica through indicators of scientific production; b) Describe and characterize the structure of the scientific community involved through co-authorship networks; c) Spatialize the surveys from the identified sampling sites. d) Describe and characterize the conceptual and spatial dynamics of Antarctic cryopedological research based on the countries, subjects and places studied. For this purpose, bibliographic data were retrieved from the Web of Science and Scopus databases and, after treatment, indicators and bibliometric networks were built; sampling location points were plotted and mapped. It was identified that the research field is productive and of great interaction between groups of authors and institutions around the world. Topics related to microbiology, pollution, bioremediation, biogeochemistry and monitoring of soil thermal and water regimes were the main focus of research on Antarctic soils. It was noticed that the pattern of spatial distribution of the points and the average distance from a point to an infrastructure are influenced by factors such as the research history in the region (if it is well known or little known and where) as well as by landscape elements such as the location of ice-free areas, biodiversity, ecological relationships and local climate. In addition, Brazil stood out as the main country to study the soils of Maritime Antarctica, in addition to its scientific production being prolific, internationalized, with an impact on the literature and spatially wide throughout the region it is part of. It is hoped that this research will help the scientific community to better understand its field of action, in addition to supporting public policies and investments in Brazilian cryopedological science.

Keywords: Antarctica. Soil. Scientometrics. Spatial scientometrics.

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SUMÁRIO

INTRODUÇÃO

A atividade científica é a forma preponderante de ocupação humana atual na Antártica. Diferentes países exercem-na, seja por meio de suas estações de pesquisa ou por meio de parcerias de colaboração científica em diversos campos do conhecimento, entre eles, a Ciência do Solo.

Tradicionalmente aliada à produção de alimentos, essa Ciência demorou a dedicar atenção aos solos das regiões polares e de alta montanha, com baixo potencial agrícola (BOCKHEIM, 2015). Como consequência, os esquemas de classificação pedológica de referência global incluíram esses solos apenas a partir do fim da década de 1990.

Hoje a importância dos solos criogênicos, como são conhecidos, é inegável. Os dados sobre seus regimes térmico e hídrico são indicadores importantes e confiáveis das mudanças ambientais globais (SHUR; JORGENSON, 2007; JORGENSON et al., 2010; SCHUUR et al., 2015), suas dinâmicas bio-geo-físicas são centrais na compreensão das paisagens periglaciais e eles ainda se constituem de fontes notáveis de material biológico economicamente interessante.

Tendo em vista a importância da atividade científica no continente gelado, e em especial aquela focada em seus solos, esta pesquisa buscou compreender a estrutura conceitual e social a a distribuição espacial da Ciência do Solo na Antártica. Isto posto, alguns questionamentos foram colocados para nortear a investigação, são eles:

i. Como se caracteriza a pesquisa científica sobre os solos da Antártica em termos de produção científica?

ii. Qual é a estrutura social deste campo a partir dos pesquisadores, instituições e países?

iii. Qual a estrutura conceitual deste campo a partir de assuntos e temáticas de pesquisa?

iv. Quais localidades são pesquisadas, isto é, qual a distribuição geográfica de tais estudos?

v. Como o Brasil e sua comunidade científica se caracterizam no universo pesquisado?

Sabendo que a Cienciometria é o campo de conhecimento que fornece técnicas e metodologias que permitem estudar a atividade científica e, portanto, responder aos questionamentos colocados, os seguintes objetivos foram traçados:

a) Caracterizar a situação da pesquisa científica global e brasileira sobre solos na Antártica através de indicadores de produção científica;

b) Descrever e caracterizar a estrutura da comunidade científica envolvida através de redes de coautoria;

c) Espacializar as pesquisas a partir dos locais de amostragem identificados.

d) Descrever e caracterizar a dinâmica conceitual e espacial da pesquisa criopedológica antártica a partir dos países, assuntos e locais estudados.

A dissertação que se apresenta é constituída por, além desta Introdução, três capítulos. Apesar de dialogarem entre si, cada capítulo possui estrutura e metodologias próprias adequadas a cada problema e conjunto de dados utilizado. Assim, optamos por apresentar os procedimentos metodológicos em cada um dos capítulos. Com base nisso, a estrutura deste trabalho ficou, assim, organizada:

Capítulo 1 - dedicado à análise cienciométrica da produção científica global sobre os solos antárticos e sua estrutura social e conceitual.

Capítulo 2 - ocupa-se da análise espacial das pesquisas ao longo do tempo a partir das localidades, assuntos e país de filiação dos cientistas.

Capítulo 3 - concentra-se nos aspectos estatísticos, conceituais e espaciais da produção científica brasileira a fim de situar o Brasil neste campo de pesquisa tão importante na atualidade.

Por fim, apresentamos breves considerações fianis, indicandos os avanços centrais contidos na análise conjunta dos três capítulos e indicações de investimentos para pesquisas futuras.

CAPÍTULO 1 - CIENCIOMETRIA DA PESQUISA SOBRE SOLOS NA ANTÁRTICA: ANÁLISE E VISUALIZAÇÃO[1]

1. Introduction

Soil science is a branch of knowledge that integrates studies on the distribution, formation, morphology, and classification of soil, considering it as an indivisible natural body of the landscape (GREGORICH et al., 2001). Because soil science has traditionally been associated with food production, it was developed mainly from a farmer's perspective, which kept it from studying soils in cold regions with low agricultural potential.

For most of its history, soil science developed under the stigma of "soft science" and distanced itself from other branches of the earth sciences that are considered "hard" (CHESWORTH, 2008). However, a growing movement strengthened by the global climate change scenario has reconsidered this perception as polar and alpine soils become critical indicators of global environmental conditions (BREVIK, 2013).

In the 1960s and 1970s, researchers such as McCraw, MacNamara, Claridge, Campbell, Ugolini, and Tedrow pioneered the field and paved the way for Bockheim, who demonstrated the pedological character of Antarctic soils in 1982.

At that time, however, official soil classification systems did not include soils from polar and alpine regions. This did not happen until the late 1990s, when the classes of gelisols (Soil Taxonomy - ST - 1999) and cryosols (World Reference Base for Soil Resources - WRB - 2006) were officially introduced.

Such soils are under the influence of ice and are often affected by permafrost. The term "permafrost" is a physical term and does not refer to a soil class. It is defined as "terrestrial material that remains continuously at or below 0°C for at least two years" (BOCKHEIM, 2014).

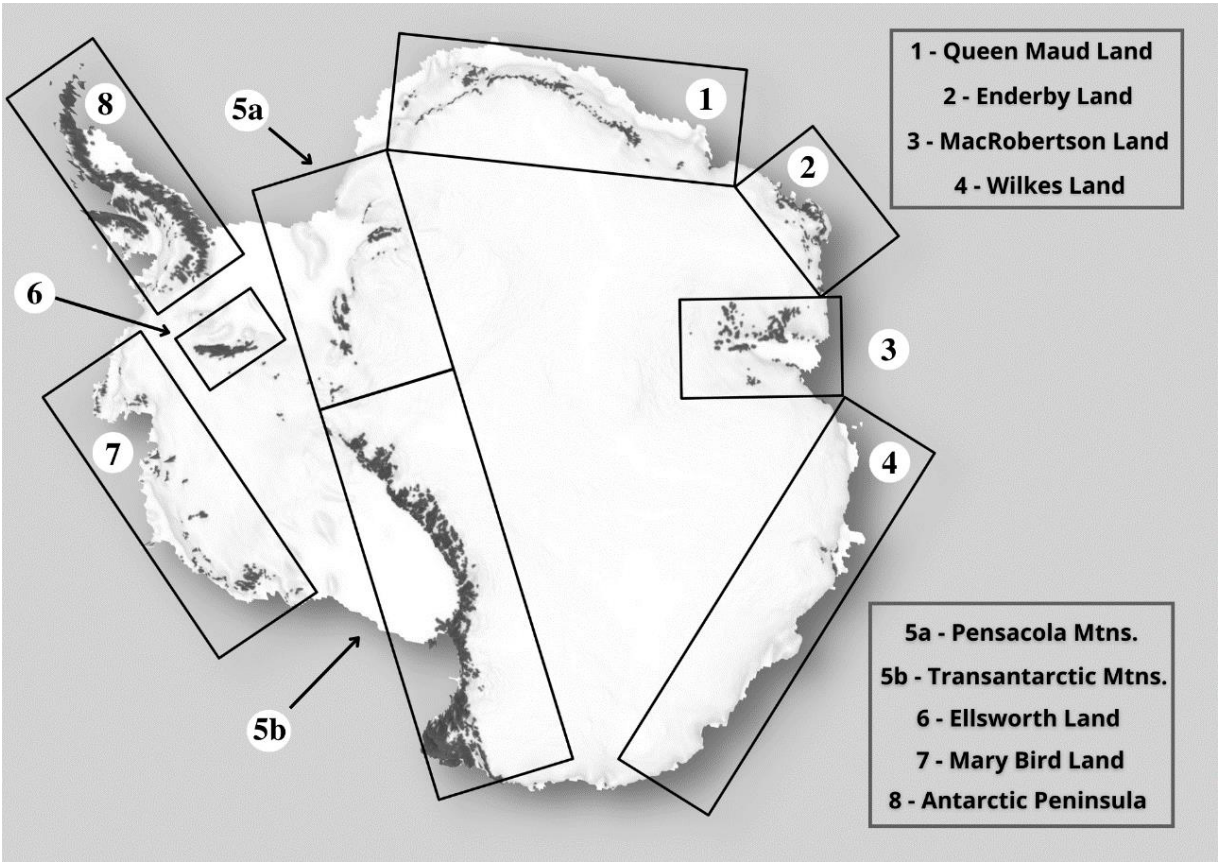
The WRB and the ST have different names for the soils discussed here, but both converge on the most important identifying aspect: the presence of permafrost at a depth of one meter below the surface or the presence of gel material and permafrost at a depth of two meters below the surface. Geographically, studies of Antarctic soils take place in ice-free regions (Figure 1) and focus on the Antarctic Peninsula and Transantarctic Mountains regions (BOCKHEIM, 2014).

[1] Título em inglês: Scientiometry of research on Antarctic soils: analysis and visualization.

The development of science, its fields and disciplines can be understood with the help of scientometrics, a branch of information science that deals with the quantitative and qualitative aspects of technical and scientific research activity, scientific communication, and science policy. For scientometrics, data and statistical information about science are not ends in themselves but form the basis for analyzing the collective dimension of scientific activity and the dynamic process of knowledge construction (CALLON et al., 1995). Scientometric studies are conducted to understand the development and reveal emerging trends in specific scientific fields, as well as to assess the performance and influence of countries, regions, researchers, and research institutions in each scientific field (HAUNSCHILD; BORNMANN; MARX, 2016).

In the context of soil science, studies of this type are still scarce. However, some studies stand out, such as those on soil erosion (ZHUANG et al., 2015), soil science in general (OLIVEIRA FILHO, 2020), and soil microbiology-vegetation relationships (HE et al., 2022). Global studies considering multiple countries have been conducted by Minasny, et al. (2010) and Hartemink (2019). However, a scientometric study of soil exploration in Antarctica has not yet been conducted.

Figure 1 – Ice-free regions of Antarctica



Source: Elaborated by the author based on Bockheim (2015). The ice-free areas (in grey) are exaggerated by four times.

The objective of this study was to conduct a scientometric review of the scientific literature on Antarctic soils and to provide an overview of this area of research during the period 1958-2021. The results may provide researchers with a better understanding of the development and current status of the subject and identify research priorities in the literature.

2. Methodology

The Web of Science (WOS) and Scopus databases were used for data retrieval. Together they cover a wide range of international and national scientific bibliographic data. Therefore, it is necessary to group the researched topic into keywords. The goal is to create a search structure with the widest coverage and accuracy in finding the desired data.

Thus, two sets of keywords were compiled that articulate the main ideas/concepts that the topic addresses. The books "The soils of Antarctica" and "Cryopedology", both organized and authored by James Bockheim, were used to select the keywords. The groups of words were labeled "Main Terms" and "Thematic Terms" as shown in Table 1.

Table 1 – Keyword sets used in data recovery

Main Terms	Thematic Terms	
Antarctica Antarctic	soil cryosol gelisol pedology cryogenic	permafrost active layer pedogeomorphology soilscape

Source: Elaborated by the author.

The terms formed the following search code: (TITLE ((Soil* OR Pedology* OR Pedogeomorphology* OR Cryosol* OR Gelisol* OR Soilscape* OR "active-layer" OR permafrost OR cryogenic*) AND antarctica*) OR AUTHKEY ((soil* OR pedology* OR pedogeomorphology* OR cryosol* OR gelisol* OR soilscape* OR "active-layer" OR permafrost OR cryogenic*) AND antarctica*)) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "ch")).

The search for terms was limited to the title and keywords fields, since the terms placed in these sections are the main topics of the works. Publications (articles and book chapters) on soils whose research had Antarctica as the study area, defined here by the Antarctic Treaty System area of responsibility (STA), i.e., at latitudes above 60º South, were analyzed.

Data were extracted in February 2022. Search parameters yielded 721 records in Scopus and 641 in WOS. After removing duplicates and cleaning the data, 553 publications remained, covering the period 1958-2021. Data were processed using Microsoft Excel 2016 and

VOSviewer 1.6.18 software. The latter is a tool for processing and displaying data and bibliometric networks. Such networks can include journals, authors, institutions, countries, publications, and keywords representing citation relationships, co-authorship, and others.

VOSviewer handles different file extensions coming from each database. Since the Scopus database provided a larger number of records, the Scopus database file was considered as the reference (.csv) for merging the information into a single file. For publications that existed in both databases, the information from the Scopus database was retained. In addition, publications were classified according to their main topic, with reference to the departments and committees of the scientific structure of the Brazilian Soil Science Society. Other classes were added as needed.

The data analysis used the science mapping approach, which is based on a visual representation of the structure of the research field by distributing elements (publications, authors, journals, words, etc.) in different groupings (clusters). The network visualization is then used to create a spatial representation of the results in analogy with geographic maps. Science mapping has a macro focus and seeks to find patterns in the literature, which is considered as a body of work (COBO et al., 2011; ZUPIC; ČATER, 2015). The bibliometric treatment was conducted according to the analysis protocol (Table 2).

Table 2 - Data treatment and analysis protocol

Step	Analyzed element	Purpose
Overview	Articles by year	Evaluate productivity over time.
Authors	Number of publications	Identify the most productive authors.
	Citations	Identify the most cited authors.
	Co-authorship	Identify groups of authors/research with great interaction
	Countries	Identify the most productive, most cited countries
	Cross-country collaboration	Identify partnerships between more productive countries
	Institutions	Identify the most productive institutions according to the affiliation of each author
	Collaboration between institutions	Identify partnerships between more productive institutions
Journals	Number of publications and citations	Identify the most relevant journals
Publications	Keywords	Identify the main themes and research subjects
	Citations	Identify publications with the greatest impact
	Thematic areas	Classification of publications according to the subject, with reference to the Divisions and Commissions of the Scientific Structure of the Brazilian Society of Soil Science.

Source: Elaborated by the author.

Scientific and technical research is limited by some factors, such as the non-universal coverage of databases, the impossibility of accessing some publications, and the low coverage of production in other languages. However, these problems do not diminish the usefulness and credibility of scientometric research, which aims to represent the literature and the community that produces it, to guide research, and to improve scientific activity.

3. Results and discussion

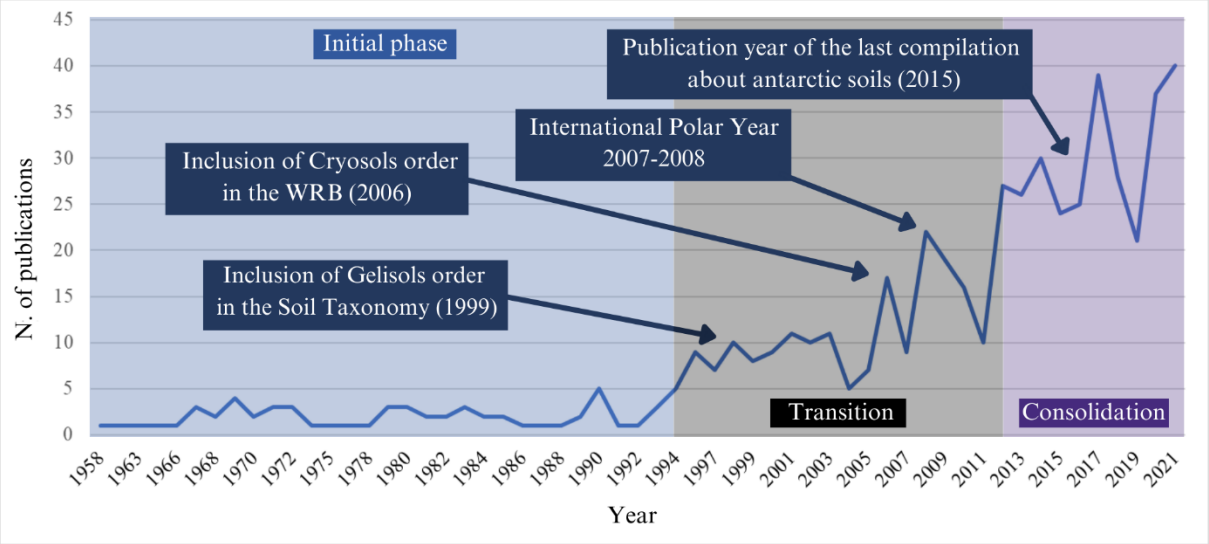
3.1 Overview and trends of publications

Based on the distribution of documents by publication date (Figure 2), it covers a considerable period of 64 years. A general upward trend can be seen from 1958 to 2021, which can be divided into three distinct periods, one of which is a transitional period. The fluctuations in the number and distribution of publications indicate a dynamic development in the research field, with high productivity starting in 2013.

The initial phase (1958-1994) is characterized by low field productivity with less than 5 annual publications. However, this period was fundamental in gathering initial information, establishing the foundations of Antarctic cryopedology, and developing classification schemes and analyzes of Antarctic soils. The work of researchers such as Campbell, Claridge, Tedrow, McCraw, MacNamara, Ugolini, Bockheim, Cameron, and others was fundamental. These publications account for 11.6% of the total.

The transition period (1995-2012) is characterized by fluctuating growth, accounting for 38.3% of the total publications. The publication pattern changed from 9 to 27 annual publications. Important events for cryopedology occurred during this period: the classes of gelsols and cryosols were officially introduced, and the research carried out in the framework of the International Polar Year 2007-2008 marked the beginning of a greater productivity that will be consolidated from 2012.

Figure 2 - Graph with number of publications per year between 1958-2021



Source: Elaborated by the author.

In addition, this period has seen increased concern about global climate change as it relates to the poles. An example of this was the adoption of the Protocol on Environmental Protection to the Antarctic Treaty in 1998, which reaffirmed the commitment to environmental protection and influenced several studies on pollution, remediation, and restoration of soils and terrestrial ecosystems.

The consolidation phase (2013-2021) is characterized by a high productivity of the area (50.18% of the total) and an increase in the number of scientists involved (from 100 authors in the first period to more than 900 in the third period). It is a period of productivity consolidation, a high level of co-authorship (Figure 3), and a high level of internationalization (Table 4 and Figure 4). Table 3 summarizes all the data.

Table 3 - Synthesis of data from publications in the Web Science and Scopus databases

Description	Results
Total Documents	553
Total Citations	16.515
Average publications per year	8,625
Average citations per document	29,86
Document type	4
Journal Article	543
Book chapter	6
Event Article	3
Data Article	1
Authors	1.431
Average number of documents per author	0,38
Average number of authors per document	2,59
Countries	49
Institutions	475

Language	7
English	536
Russian	8
Spanish	3
German	2
Korean	2
Chinese	1
Portuguese	1
Journals	178
Average citations per journal	92,78
Average number of documents per journal	3,1

Source: Elaborated by the author.

The soils of Antarctica have attracted the attention of researchers from around the world and have become a hotspot of research in the last 10 years. The set of publications (553 records) consists mainly of journal articles (98%), but also articles from events, data, and book chapters. 96% of them are in English language, but Russian, Spanish, Chinese, German, Korean, and Portuguese also occur. Aspects of citation and authorship are discussed in more detail in the following sections.

3.2. Co-authorship analysis

The bibliographic information on the authors of the publications makes it possible to identify the main researchers, institutions and countries involved in the literature, thus creating a network of co-authors for each of these elements.

3.2.1 Co-authorship network

Based on the distribution of publications by author, the 20 most prolific authors were identified. According to Table 4, Carlos Schaefer (Federal University of Viçosa), James Bockheim (University of Wisconsin-Madison), and Diana Wall (Colorado State University) are the authors with the highest number of publications.

Table 4 - The 20 most productive authors

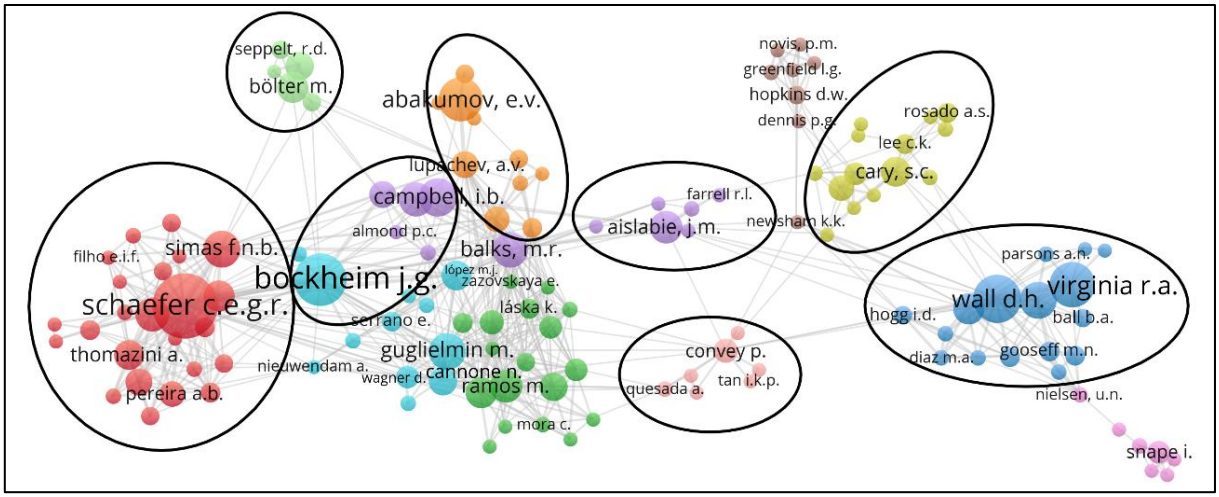
Author	Institution	Country	Pub.	Cit.	Cit./Pub.
Schaefer, C.E.G.R.	Univ. Fed. of Viçosa	Brazil	64	1679	26,23
Bockheim, J.G.	Univ. of Wisconsin–Madison	USA	36	1206	33,50
Wall, D.H.	Colorado State University	USA	31	1673	53,97
Virginia, R.A.	Dartmouth College	USA	29	1679	57,90
Abakumov, E.V.	Saint Petersburg State Univ.	Russia	25	236	9,44
Campbell, I.B.	Land and Soil Consult. Serv.	New Zealand	20	655	32,75
Simas, F.N.B.	Univ. Fed. of Viçosa	Brazil	19	798	42
Barrett, J.E.	Virginia Polytechnic Institute	USA	18	857	47,61
Guglielmin, M.	Univ. of Insubria	Italy	18	887	49,28
Francelino, M.R.	Univ. Fed. of Viçosa	Brazil	18	356	19,78
Balks, M.R.	Univ. of Waikato	New Zealand	17	730	42,94
Claridge, G.G.C.	Land and Soil Consult. Serv.	New Zealand	16	470	29,38
Aislabie, J.M.	Landcare Research	New Zealand	15	1149	76,60
Ramos, M.	University of Alcalá	Spain	15	484	32,27
Michel, R.F.M.	Univ. Est. of Santa Cruz	Brazil	15	451	30,07
Vieira, G.	University of Lisbon	Portugal	15	506	33,73
Adams, B.J.	Brigham Young Univ.	USA	14	446	31,86
Bölter, M.	University of Kiel	Germany	13	300	23,08
Cary, S.C.	University of Waikato	New Zealand	12	709	59,08
López, M. J.	Univ. Autonomous of Madrid	Spain	12	609	50,75

Source: Elaborated by the author.

When analyzed by number of citations, authors such as Ross Virgínia (Dartmouth College) stand out as the most cited along with Carlos Schaefer. The average number of citations per publication also shows authors such as Jackie Aislabie (Landcare Research) and Stephen Cary (College of Waikato) with 76.6 and 59.08 citations per publication, respectively.

Co-author network where each node represents an author and the links between them indicate collaboration through co-authorship in publications (Figure 3). Only authors with three or more publications were considered to create this network, i.e., 178 authors, of whom 133 were coauthors, resulting in 662 connections in the network. The size of the circle corresponds to the number of publications.

Figure 3 - Co-authorship network



Source: Elaborated by the author.

In terms of collaboration, there are several interconnected clusters in this network, indicating strong collaboration between the different clusters. Several research communities were identified (black circles) in which many authors collaborate with one or two very prolific authors (generally those listed in Table 4).

A node with high betweenness centrality generally links two or more clusters, as in the case of Bockheim, J. G., Campbell, I. B., Claridge, G. G. C., Balks, M. R. Such authors are involved to a greater extent in research and publications. When there is a large interaction between one or more scientific communities, there is no defined centrality, as in the case of the circle in which Guglielmin, M., Cannone, N., Ramos, M., Wagner D., etc. are found.

There is a certain coherence in the groups of authors when considering the information of institutions and countries, i.e., authors from the same institutions and/or country tend to be closer to each other, grouped in the co-authorship network, which can be seen in the circles where Schaefer, C.E.G.R., Abakumov, E.V., Boelter, M., and Wall, D.H. can be found.

Analyzing the distribution of the 10 most productive authors over the three periods (Figure 2), as shown in Table 5, productivity was lower in the first period than in the other two periods.

Table 5 - Most productive authors in each period by number of publications

1958-1994	1995-2012	2013-2021
1. Claridge, G.G.C. (12)	1. Virginia, R.A. (21)	1. Schaefer, C.E.G.R. (50)
2. Campbell, I.B. (11)	2. Wall, D.H. (21)	2. Abakumov, E.V. (22)
3. Bockheim, J.G. (7)	3. Bockheim, J.G. (16)	3. Bockheim, J.G. (13)
4. Cameron, R.E. (3)	4. Aislabie, J.M. (13)	4. Francelino, M.R. (13)
5. Macnamara, E.E. (3)	5. Schaefer, C.E.G.R. (13)	5. Ramos, M. (12)
6. Seppelt, R.D. (3)	6. Balks, M.R. (12)	6. Thomazini, A. (12)
7. Speir, T.W. (3)	7. Barrett, J.E. (12)	7. Vieira, G. (12)
8. Ugolini, F.C. (3)	8. Beyer, L. (11)	8. De Pablo, H. M. A. (10)

9. Bölter, M. (2) 10. Flint, E.A. (2)	9. Bölter, M. (10) 10. Guglielmin, M. (10)	9. Lupachev, A.V. (10) 10. Adams, B.J. (9)

Source: Elaborated by the author.

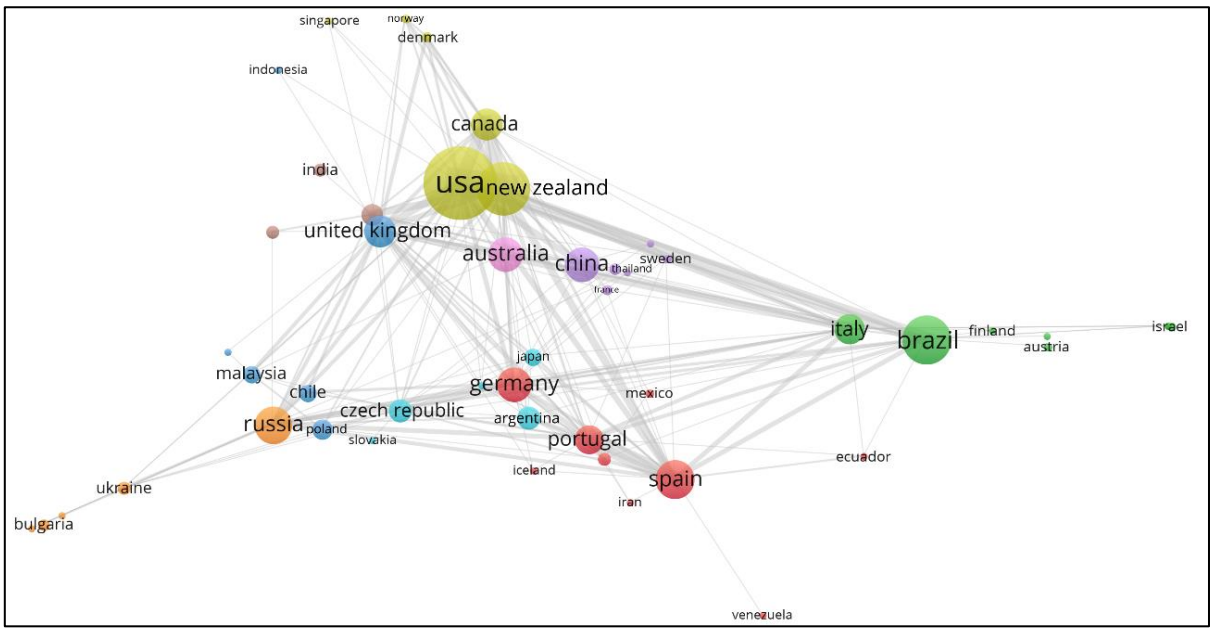
From this distribution, we can see the changes in the authors' contributions over time. At each stage different authors have contributed to the field, and some continue to be active in all areas, such as Bockheim, J. G., one of the pioneers of research on Antarctic soils.

3.2.2 Country and institution network

A network was created from the authors' institutions and countries of origin (Figure 4). This research network has 49 nodes and 222 connections. The size of the circles here also indicates the total number of publications. As shown in Figure 4 and Table 6, the United States (161 publications), New Zealand (88), and Brazil (85) were the largest contributors in terms of number of publications and citations, indicating a concentration of productivity and impact in the literature.

The U.S. has strong partnerships with New Zealand and Canada, but also has close collaborations with Australia, the United Kingdom, and China. Brazil has strong collaboration with the U.S., New Zealand, Italy, and Spain. Through the network, it is possible to identify the most important countries and those with contributions to the field.

Figure 4 - Co-authorship network by country



Source: Elaborated by the author.

Not surprisingly, the U.S. has made the largest contribution, being the country with the highest investment in its Antarctic program, its research stations having the largest staffing

capacity on the continents and being located in the most explored regions (Antarctic Peninsula and Transantarctic Mountains). The average number of citations per publication shows that countries such as South Africa, the United Kingdom, and Italy have a significant impact on the literature despite having fewer publications (Table 6).

Table 6 - Number of publications and citations by country

Country	Publications	Citations	Cit./pub.
USA	161	6411	39,82
New Zealand	88	3920	44,55
Brazil	85	2430	28,59
Spain	46	1270	27,61
Russia	44	688	15,64
Germany	40	1294	32,35
Australia	38	1276	33,58
China	36	695	19,31
UK	32	1481	46,28
Canada	30	1089	36,30
Italy	29	1247	43
Portugal	27	742	27,48
Argentina	17	435	25,59
Czech Republic	17	427	25,12
South Africa	15	928	61,87
Poland	13	237	18,23
South Korea	11	211	19,18
Chile	10	162	16,20
Japan	10	259	25,90
Malaysia	09	180	20,00

Source: Elaborated by the author.

When analyzing the distribution of contributions by country over time (Table 7), the role of the U.S. over the three periods is clear, but so is the rise of countries such as Brazil and Spain. The constancy of countries such as New Zealand, Australia, Germany, and China is striking. Also interesting is the case of Canada and Portugal, countries without Antarctic research stations, but which achieve relative productivity through scientific cooperation by sharing scientific expertise.

Table 7 - Most productive countries in each period by number of publications

1958-1994	1995-2012	2013-2021
1. EUA (23)	1. EUA (75)	1. EUA (63)
2. Nova Zelândia (19)	2. Nova Zelândia (43)	2. Brasil (62)
3. Japão (7)	3. Brasil (23)	3. Rússia (40)
4. Austrália (6)	4. Alemanha (19)	4. Espanha (33)
5. Alemanha (4)	5. Reino unido (18)	5. Nova Zelândia (25)
6. China (2)	6. Itália (17)	6. Portugal (24)
7. Canadá (1)	7. Austrália (16)	7. China (22)
8. Chile (1)	8. China (13)	8. Canadá (18)
9. Itália (1)	9. Espanha (13)	9. Alemanha (17)
10. Reino Unido (1)	10. Canadá (12)	10. Austrália (15)

Source: Elaborated by the author.

Institutional contributions were also identified (Table 8). Institutions involved in the development of research on Antarctic soils included the Federal University of Viçosa (66 publications), the University of Waikato (56), Colorado State University (43), and the University of Wisconsin-Madison (36). These institutions can be considered global research centers on this topic. Dartmouth University, the University of Insubria, the British Antarctic Survey and the Universidad Autónoma de Madrid are also characterised by a high average number of citations per publication.

Table 8 - Number of publications and citations by institution of affiliation

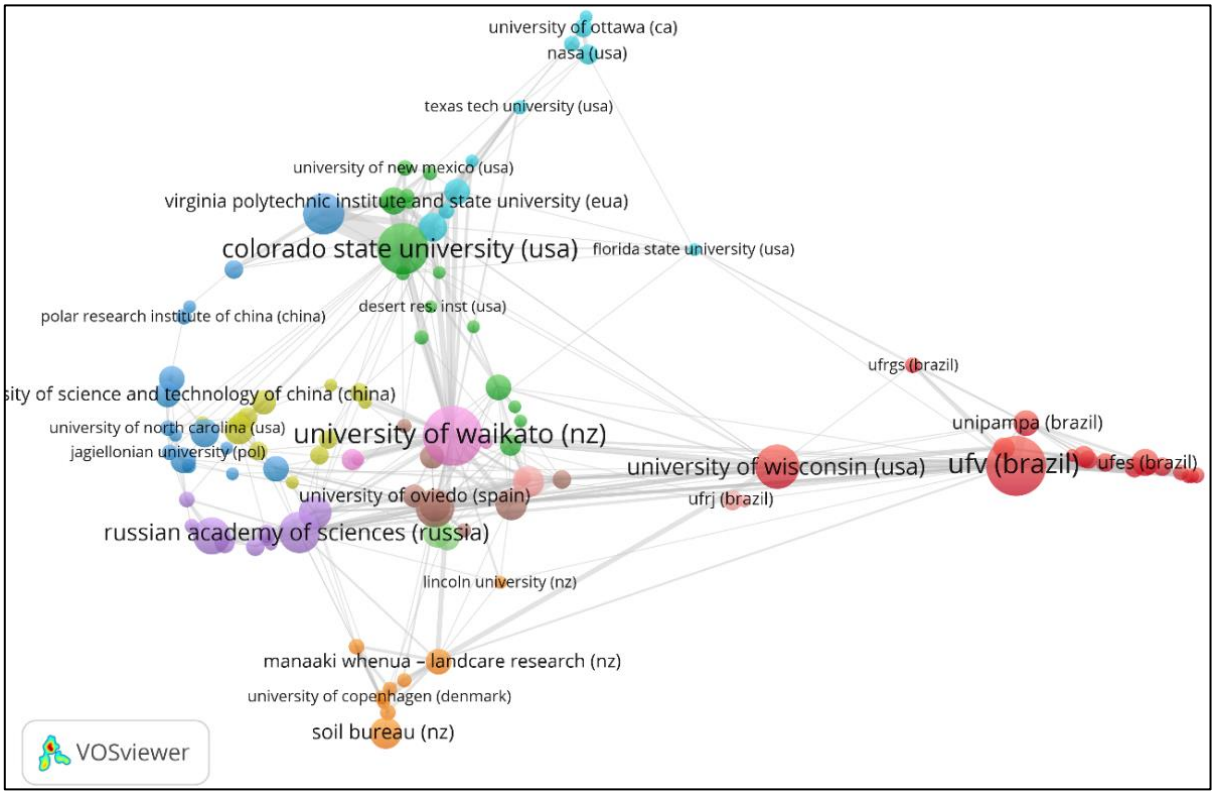
Institution	Country	Pub.	Cit.	Cit./Pub.
Federal University of Viçosa	Brazil	66	1952	29,58
University of Waikato	New Zealand	56	2843	50,77
Colorado State University	USA	43	2367	55,05
University of Wisconsin-Madison	USA	36	1205	33,47
Dartmouth College	USA	28	1671	59,68
Russian Academy of Sciences	Russia	28	471	16,82
University of Lisbon	Portugal	25	712	28,48
Saint Petersburg University	Russia	23	193	8,39
Soil Bureau	New Zealand	17	476	28,00
Universidad Autónoma de Madrid	Spain	17	756	44,47
University of Insubria	Italy	17	834	49,06
British Antarctic Survey	UK	16	751	46,94
University of Alcalá	Spain	16	508	31,75
Australian Antarctic Division	Australia	14	460	32,86
Brigham Young University	USA	14	446	31,86

Source: Elaborated by the author.

The network in Figure 5 was created from institutions with at least 3 publications, accounting for 123 institutions, 112 of which are coauthors. Countries and institutions with a high betweenness centrality were considered. Countries such as the United States, Germany, Australia, New Zealand, and institutions such as Colorado State University, the University of

Waikato, and the University of Wisconsin-Madison occupied key positions in the networks, linking research activities between different clusters (Figures 4 and 5).

Figure 5 - Co-authorship network by institution



Source: Elaborated by the author.

The contributions of institutions over time were also analyzed (Table 9). Over time, it can be observed that institutions from developing countries or those with a lesser scientific role are making an important contribution to this topic. Institutions in countries such as Brazil, Spain and Portugal showed high productivity in the last period, a trend that began in the previous period. In addition to the map of cooperation between countries and institutions, there is a lively scientific exchange between pioneer countries such as the United States, New Zealand and Germany and countries that started their research later, such as Brazil, Russia, Spain and Portugal.

Table 9 - Most productive institutions in each period by number of publications

1958-1994	1995-2012	2013-2021
1. Soil Bureau - 17	1. U. Waikato - 33	1. U. F. of Viçosa - 49
2. U. Mad-Wisc. - 6	2. Colorado St. U. - 28	2. Russian Acad. Sci. - 26
3. U. Tasmania - 5	3. Dartmouth Col. - 21	3. U. Lisbon - 22
4. Antarctic Div. - 3	4. U. Mad.-Wisc. - 17	4. U. of Waikato - 22
5. U. Washington - 3	5. U. F. of Viçosa - 17	5. St. Petersburg Univ. - 21
6. Lehigh Univ. - 2	6. British Ant. S. - 12	6. Colorado St. U. - 16
7. Ohio State U. - 2	7. U. of Kiel - 12	7. U. Alcalá - 13
8. Univ. of Kiel - 2	8. Landcare Research - 9	8. U. Mad-Wisc (EUA) - 13

9. Univ. of Tokyo - 2 10. Waseda Univ. - 2	9. U. of Insubria - 9 10. Aut. U. Madrid - 7	9. F. U. Esp. Santo - 10 10. F. U. Pampa - 10

Source: Elaborated by the author.

3.3 Keyword co-occurrence analysis

Keywords represent the central content of publications and show the development of research topics over time. In the WOS and Scopus databases, there are two types of keywords: (i) “author keywords”, which are provided by the authors, and (ii) “indexed keywords”, which are identified through journals. and summaries. For this analysis, priority was given to the first type. The indexed terms were only used in the absence of the previous one.

Keywords represent the focus of research and are intended to convey the essence of an entire text. In general, bibliometric analysis tools have a keyword co-occurrence analysis function that measures the number of occurrences of terms within the analyzed literature. In this work, the parameters were refined to reveal search foci, setting a threshold of at least three occurrences of keywords.

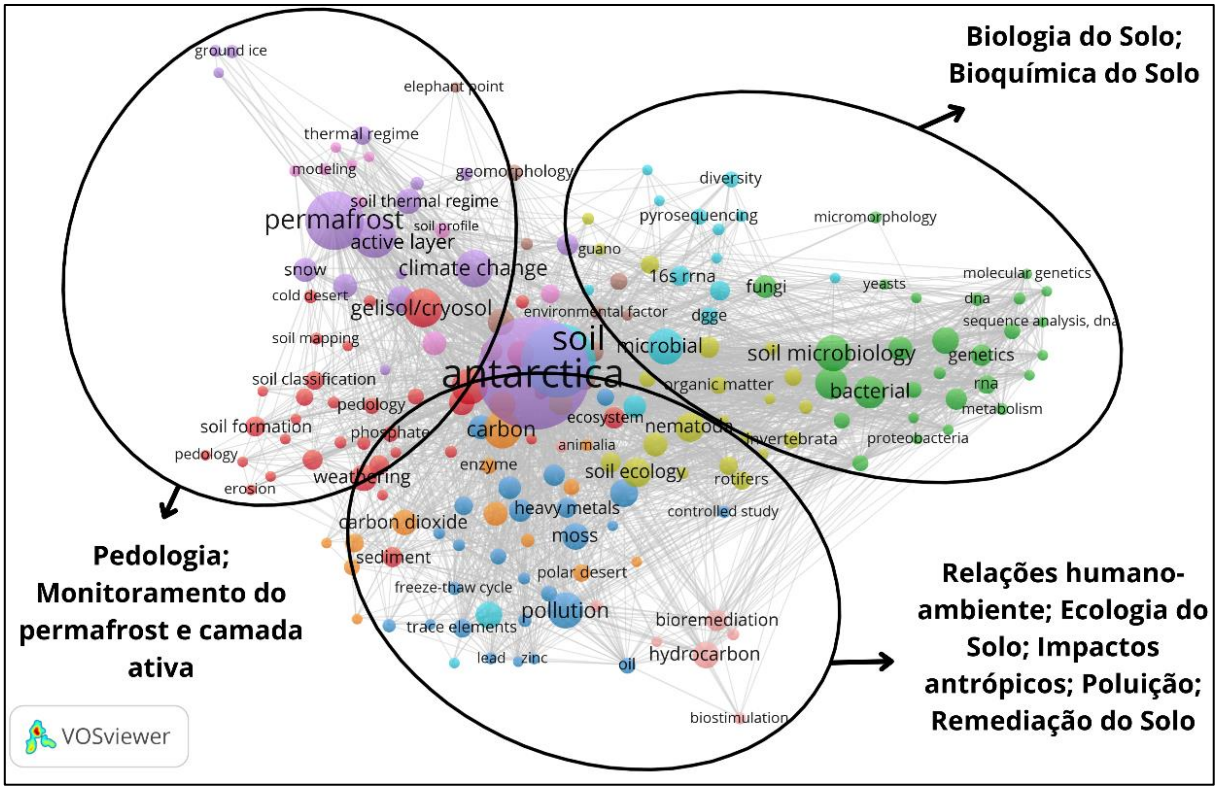
Of the total 1400 keywords, 213 occurred more than twice. Non-meaningful terms such as "article" or "research" were manually removed, as were toponyms (geographical locations) such as "dry valleys" or "Antarctic Peninsula". The map created provides an overview of the different disciplines involved in Antarctic soils research that can be grouped into larger study areas (Figure 6).

The size of the circle indicates how often the keyword occurs in the data set. The 10 most frequent keywords were "Antarctic" (frequency = 305), "soil" (133), "permafrost" (81), "active layer" (44), "gelsol/cryosol" (37), "carbon" (35), "climate change" (35), "microbial" (32), ornithogenic soils (32), and "pollution" (32).

This information shows that research on Antarctic gels/cryosols is mainly focused on the study of permafrost and the active layer. Soil chemistry topics, particularly carbon and pollution, are also informative. The class of ornithogenic soils, formed by the action of guano from birds, is also receiving considerable attention from researchers.

Soil microbial fauna is also the subject of intense research from various perspectives within soil microbiology and biogeography. Finally, climate change concerns can be interpreted as a background that permeates all research on Antarctic soils.

Figure 6 - Keyword co-occurrence network



Source: Elaborated by the author.

Three areas were identified for study: (i) the area of geoscience, where topics such as soil formation, morphology, classification, and thermal regimes predominate; (ii) the area of soil biology, with emphasis on soil microbiology and biogeography, genetic sequencing of species, biodiversity, and organic matter production; and (iii) the area of local anthropogenic impacts, primarily from hydrocarbon and heavy metal pollution, and the search for soil bioremediation strategies using local species.

To understand the changes in the research topics over time, the distribution of the occurrence of keywords in the three periods was observed, as shown in Table 10.

Table 10 - 20 most frequent keywords in each period

1958-1994	1995-2012	2013-2021
antarctica (24)	antarctica (37)	antarctica (144)
soil (13)	soil (51)	soil (69)
soil microbiology (10)	dry valleys (42)	permafrost (42)
pedology (9)	permafrost (35)	active layer (26)
permafrost (4)	gelisol/cryosol (18)	dry valleys (25)
weathering (4)	active layer (17)	climate change (19)
algae (3)	carbon (17)	gelisol/cryosol (19)
bacteria (3)	ornithogenic soils (17)	pollution (18)
carbon (3)	climate change (16)	maritime antarctica (16)
microbial (3)	nematoda (16)	microbial (16)
moraines (3)	east antarctica (15)	carbon (15)

salt (3)	soil microbiology (15)	bacterial (13)
boulders (2)	soil ecology (14)	ornithogenic soils (13)
clay (2)	microbial (13)	south shetland islands (13)
cold climate (2)	pollution (13)	polycyclic aromatic hydrocarbon (12)
cryopedology (2)	bacteria (12)	snow (12)
dry valleys (2)	bacterial (11)	soil microbiology (12)
ecology (2)	biodiversity (10)	bacteria (11)
elemental composition (2)	hydrocarbon (10)	geochemistry (11)
enderby land (2)	microbiology (10)	king george island (11)

Source: Elaborated by the author.

In this way it is possible to observe how the focus of research changed over time. In the first period, the study of Antarctic soils was essentially done through microbiology, especially in relation to bacteria, and soil science was mainly applied in this phase of exploration and initial understanding of the formation, weathering, and chemical composition of Antarctic soils.

In the second phase, attention was directed mainly to the study of permafrost, the active soil layer, and ornithogenic soils, and their relationships to climate change. In the field of soil biology, the focus is on the study of nematodes in addition to the study of bacteria. In this phase, the area of anthropogenic impact studies in Antarctica is being expanded with topics related to soil ecology and hydrocarbon pollution. It is also interesting to note that in this phase the terms "gelisol/cryosol" are already very common, which is due to the officialization of these pedological classifications.

The last period is similar to the previous one, but there is an increase in topics related to climate change as well as pollution by compounds called "polycyclic aromatic hydrocarbons". Studies in the field of geochemistry stand out when overlapping the three identified areas and researches.

The frequent occurrence of toponyms is also striking. The soils of the Antarctic Dry Valleys were the first and most studied soils on the continent over time and have been highlighted in the last two periods. Other regions, such as Enderby Land in East Antarctica, were highlighted in the first and second periods, respectively. In the last period, sites in the Antarctic Peninsula region became favorite study areas, especially the South Shetland Islands archipelago, with emphasis on King George Island.

3.4 Analysis of the research themes of the publications

To complement the traditional bibliometric analyses, each publication was classified according to its main topic based on the title, abstract, and, when necessary, access to the full text (Table 11).

To capture the different topics and their overlap in each publication, one or more topics were assigned to each document depending on the case and research focus, e.g., for an article on biochemical aspects of soil, the topics were "soil biology" and "soil chemistry". In this way, it was possible to identify the most frequent aspects and to illustrate the general profile of the publications. For the final analysis, each topic was counted individually.

Table 11 - Frequency of themes according to the classification of publications

Divisions	Committees/Themes of Work	Freq.
Soil in space and time	Genesis and Soil Morphology	63
	Soil Survey and Classification	44
	Pedometry[2]	88
	Paleopedology	7
Soil processes and properties	Soil Biology	130
	Soil Physics	42
	Soil Chemistry	141
	Soil Mineralogy	18
Soil use and management	Soil Fertility and Plant Nutrition	5
	Correctives and Fertilizers	0
	Management and Conservation of Soil and Water	5
	Land Use Planning	1
	Pollution, Soil Remediation and Recovery of Degraded Areas	74
Soil, Environment and Society	Soil Education and Public Perception of Soil	1
	Soils and Food Security	0
	History, Epistemology and Sociology of Science	0
Other themed classes added		
Soil Ecology		43
Pedogeomorphology		25
Soil Biogeography		12
Review Work		9
Soil Mapping		11
Remote Sensing and Modeling		3

Source: Elaborated by the author.

[2] Soil spatial analysis studies were included in Pedometry, with digital mapping of soil attributes and classes, use of geoprocessing tools, etc. Along with this area, studies of the thermal regime of soils and their monitoring by sensors to assess global climate change were included. The authors chose to highlight this theme because it has been receiving prestige in recent years. In addition, many of these measurements are performed by orbital or physical sensors, which make these studies related to the tools applied by pedometrics.

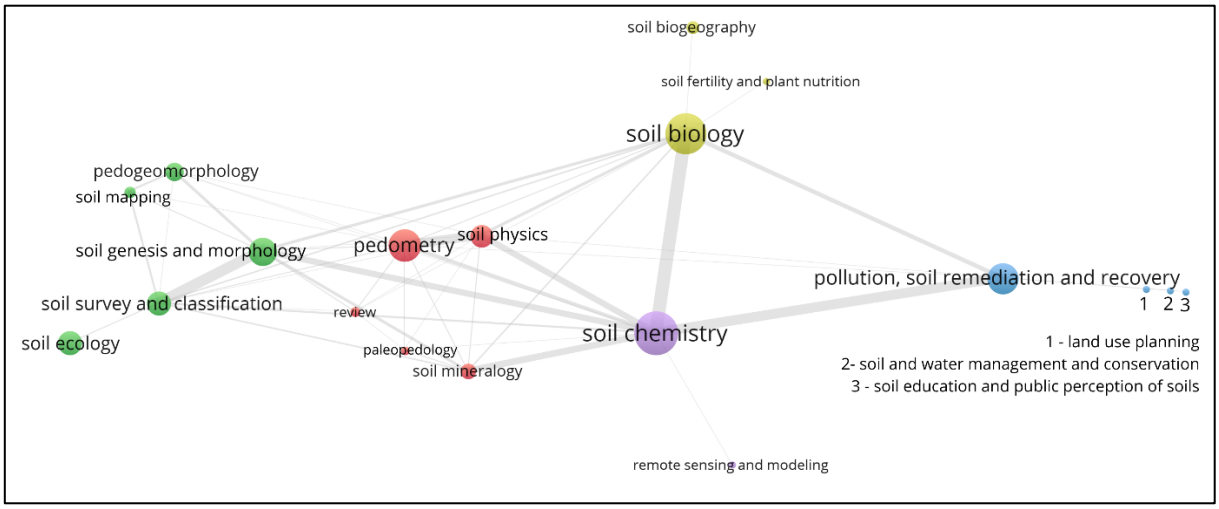
Various aspects of soil biology and chemistry are represented in the publications, probably due to the importance and extent of basic information on these two soil properties (Table 9). Pedometrics and and Global Climate Changes also stands out, primarily because of the monitoring of the heat and water balance of permafrost and the active layer.

As indicated by previous analyses, the research focus is clearly on soil contamination and remediation issues, and there is vigorous debate in this area, particularly with respect to the development of bioremediators using species native to Antarctica. However, there are few publications on areas of application of this knowledge that can help combat and solve the problem of pollution in the Antarctic environment.

Other topics were added to identify the other focus of the publications. Many dealt with the ecological aspect of soil, considering the relationships between biotic and abiotic components, and considering soil as an ecosystem. Pedogeomorphological approaches were also identified, i.e., when the focus of the study was on analysing the influences of relief on the formation and spatialization of soils and/or pedological influences on the modification of relief forms. When the focus was on studying the distribution of soil biodiversity, the composition of one or more communities in space at different scales, the subject was called "soil biogeography."

The data in Table 9 can be illustrated by the visualization map (Figure 7), which allows a better understanding of the differences in the occurrence of each subject, as well as their grouping based on occurrence relationships, i.e., the frequency of their co-occurrence in a classification.

Figure 7 - Research themes co-occurrence network



Source: Elaborated by the author.

The Figure 7 can be analyzed as complementary to the map of keyword co-occurrence, as both show similar patterns in grouping. Earth science topics tend to be placed on one side

and biology-related topics on the other. The Figure 7 also shows that each grouping (colors) has one or more major topics that are more common in the previous table.

Highlighted in red are the topics of genesis/morphology, survey/classification of soils, which often occur together because they are often processes that occur simultaneously or sequentially in the soil survey process. Soil mapping and soil geomorphology are associated with them and with each other, indicating the co-occurrence of these topics in the publications.

Pedometrics and the topics of soil physics, paleopedology, soil mineralogy, and review articles stand out in green. The review articles must be analyzed separately because they cover, although in small numbers, various topics such as genesis and morphology, survey and classification, paleopedology, soil biology, soil mineralogy, and soil physics.

Soil biology is closely related to the topics of biogeography, soil fertility, and plant nutrition, and is closely linked to soil chemistry and the topic of pollution and degraded land. The latter, in turn, is closely linked not only to soil chemistry, but also to issues of planning, use, management, and public perception of soil.

3.5 Journal analysis

From a total of 178 identified journals, the 15 most productive are listed in Table 12. With a 20% share of total publications, Polar Biology (42), Antarctic Science (42), and Geoderma (30) are the leading journals in the field of Antarctic soils.

Table 12 - Number of publications and citations per journal

Journal	Pub.	Cit.	Cit./Pub.
Antarctic Science	42	1165	27,74
Polar Biology	42	1232	29,33
Geoderma	30	1175	39,17
Soil Biology and Biochemistry	24	1333	55,54
Science of the Total Environment	23	427	18,57
Catena	19	344	18,11
Geomorphology	18	568	31,56
Permafrost and Periglacial Processes	11	491	44,64
Arctic, Antarctic and Alpine Research	10	475	47,5
Eurasian Soil Science	9	137	15,22
FEMS Microbiology Ecology	9	670	74,44
Frontiers in Microbiology	9	231	25,67
Soil Science	8	188	23,5
Microbial Ecology	7	425	60,71
New Zealand Journal of Geology and Geophysics	7	169	24,14

Source: Elaborated by the author.

Of the 15 journals presented, 7 are specific to the field of earth sciences, 5 are specific to biology, 3 are specific to polar sciences, and 1 is general in nature. The fields and research topics already discussed are also reflected in the fields of the journals. In terms of total number of citations, the most influential journals were Soil Biology and Biochemistry, Polar Biology, Geoderma, and Antarctic Science.

The average number of citations per document shows that FEMS Microbiology Ecology (74.44), Microbial Ecology (60.71), and Arctic, Antarctic, and Alpine Research (47.5) are other journals of interest to authors because they have an impact on the literature, even though they have the lowest number of publications.

3.6 Citation analysis

The influence of a publication in a field is primarily measured by citation analysis. The results of using the citations tool in both databases show that the total number of citations was 16,515, giving an average of 29.86 citations per document and giving a rough idea of the size of the scientific production on the topic covered.

The data on the most cited publications provide important information about the development of the research area under study. The 15 most cited articles were identified using the citation tool mentioned above, and the citation data for these articles are shown in Table 13.

Table 13 - Publications classified according to the number of citations

Reference	Citations	Cit./year
Schaefer *et al.*, (2005)	250	14,70
Teixeira *et al.*, (2010)	217	18,08
Freckman; Virginia, (1997)	211	8,44
Saul, *et al.*, (2005)	203	11,94
Lee, *et al.*, (2012)	190	19
Aislabie, *et al.*, 2006)	178	11,12
Retallack (1997)	168	6,72
Smith, *et al.*, (2006)	165	10,31
Klánová, *et al.*, (2008)	163	11,64
Vieira, *et al.*, (2010)	147	12,25
Van Goethem, *et al.*, (2018)	146	36,5
Arenz *et al.*, (2006)	145	9,06
Simas, *et al.*, (2007)	145	9,67
Hogg, *et al.*, (2006)	140	8,75
Van Dorst, *et al.*, (2014)	130	16,25

Source: Elaborated by the author.

The publication with the most citations is that of Schaefer et al. (2005), who studied heavy metal contamination in sediments and coastal soils near the Brazilian Antarctic Station on King George Island. The table shows that the most frequently cited publications relate to soil biology topics, especially biodiversity issues and terrestrial ecosystem relationships.

Topics such as pollution, thermal regime monitoring, carbon cycling and formation, and soil formation are also among the most cited. Teixeira et al. (2010) was the second most cited article, with 217 citations, addressing bacterial diversity in the rhizosphere in soil and how the bacterial community in soil can be altered by local climate changes.

This was followed by Virginia and Freckman (1997) (211 citations), who addressed the low diversity of nematodes in Dry Valleys soils; Saul et al. (2005) examined the effects of hydrocarbon pollution on soil bacterial communities; and Lee et al. (2012) sought to elucidate the factors shaping Dry Valleys terrestrial microbial communities and their biogeography.

The average citation data indicates the high importance of publications such as Van Goethem, et al. (2018) with 36.5 annual citations, which investigated the distribution of antibiotic resistant genes in primitive and remote soils near the Mackay Glacier in the United States. Dry Valleys. Another highlight is Van Dorst, et al. (2014) with 16.25 annual citations comparing genetic data of microbial fauna from Arctic and Antarctic soils.

3.7 Recent research trends

By analyzing the most frequently cited articles in the last 3 years and the most frequent keywords in the last 5 years, it was possible to highlight the most discussed research topics. According to Table 14, Hrbáček, et al. (2021), which summarized key data from monitoring active layer melting at various locations in Antarctica from 2006 to 2015, was the "hottest" article, with an average of 26 citations per year.

Table 14 - Most cited publications in the last 3 years and most frequent keywords in the last 5 years

Reference	Cit./Cit. by year	Keywords	Freq.
Wentzel, *et al.*, (2019)	31/10,33	antarctica	83
Daher *et al.*, (2019)	29/9,66	soil	48
Hrbáček *et al.*, (2021)	26/26	permafrost	20
Araújo *et al.*, (2020)	25/12,5	dry valleys	14
Acuña-Rodríguez, *et al.*, (2019)	20/6,66	active layer	13
Rodrigues, *et al.*, (2019)	20/6,66	pollution	12
Lopes, *et al.*, (2019)	17/5,66	microbial	11
Na, *et al.*, (2020)	16/8	maritime antarctica	10
Prietzel *et al.*, (2019)	14/4,66	climate change	9

Galera, *et al.*, (2019)	14/4,66	gelisol/cryosol	9
Gran-Scheuch, *et al.*, (2020)	14/7	ornithogenic soils	9
Da Silva, *et al.*, (2020)	12/6	polycyclic aromatic hydrocarbon	9
Hrbáček, *et al.*, (2020)	12/6	Moss	8
Lupachev, *et al.*, (2020)	12/6	snow	8
Deelaman, *et al.*, (2020)	12/6	soil microbiology	8

Source: Elaborated by the author.

Araújo, et al. (2020) on the biogeography of actinobacteria in soils near Davis and Casey Stations in West Antarctica with 12.5 annual citations; Wentzel, et al. (2019) surveying the fungal communities of soils of Admiralty Bay on King George Island with 10.33 annual citations; and Daher, et al. (2019a), who reported the main characteristics and effects of elevation on the pedogenesis of ornithogenic soils of Barrientos Island on the South Shetlands with 9.66 annual citations.

The topics of these publications and the keywords indicate that the focus in recent years has been on the study of soil microbial fauna under the approaches of biogeography and bioprospecting. Active layer and permafrost monitoring, pollution, and ornithogenic soils are current topics of Antarctic cryopedological research. The Dry Valleys and the maritime Antarctic region (Antarctic Peninsula) are the most studied areas.

4. Conclusions

Knowledge of the frozen soils of the South Pole has evolved and is critical to understanding the behavior of Earth's ecosystems and landscapes in a changing world. This study provides a scientifically sound overview of the status and trends in global research on Antarctic soils. Information on co-authorship, co-occurrence, citations, and research topics was used to visualize, characterize, and analyze the research field. It was noted that the scientific community in this field has grown over time and that more and more institutions from around the world are involved in this topic.

A distinct network with a high degree of collaboration between authors characterizes the field. The main institutions in the field were Universidade Federal de Viçosa (Brazil), Waikato College (New Zealand), Colorado State College (USA), College of Wisconsin-Madison (USA), Dartmouth College (USA), College of Insubria (Italy), British Antarctic Survey (UK), and Universidad Autónoma de Madrid (Spain). In addition, the United States, Brazil, and New Zealand were the countries with the most contributions in this field.

The scientific-ecological nature of the Antarctic Treaty System puts pressure on the activities carried out there to have as little impact on the environment as possible. Such a scenario can be a strong factor in the emergence and growth of issues related to soil pollution and remediation. Among the pollutants, polycyclic aromatic hydrocarbons are the most studied and represent an important research topic.

The area of soil biology was very extensive. Topics related to genetic sequencing, spatial distribution of species, bio-geo-chemical relationships from an ecosystem perspective, and research on the biotechnological potential of microorganisms were the most important areas in this field.

Earth sciences emerged as a third field of research. This field, first developed by American, English, and New Zealand researchers and later involving researchers of various nationalities, especially Brazilians, Italians, and Spaniards, pioneered the study of Antarctic soils.

The most important topics were thermal and water monitoring of cryosols/gelsols, soil investigation and classification, soil respiration, the effects of climate change on the pedogenomorphological landscape, and the study of the landscape from the perspective of pedogenomorphology.

Publications in the field of soil biology differ from those in the field of earth sciences. The former has a higher publication and citation rate among authors, which can be explained by the specifics of the field (e.g., larger number of authors) and/or by a greater investment in the field. The second group has a moderate publication and citation rate, but has a similar impact in the scientific literature as the first group.

This study provides valuable information for researchers and practitioners in the field of Antarctic soil science. Key scientists, countries and institutions, topics, and "hot" research topics were identified and discussed. This study will enable professionals and new researchers to know the most important aspects of the field to improve their activities and guide their research decisions.

CAPÍTULO 2 - DE ONDE VEM ESSA AMOSTRA? CIENCIOMETRIA ESPACIAL DA PESQUISA SOBRE SOLOS NA ANTÁRTICA[3]

1. Introduction

As far as it is possible, science has always shown a geography, a specific spatiality according to material conditions in each time and place (DORN, 1991; LIVINGSTONE, 2003; NAYLOR, 2005). In the literature on this topic, one group of authors explores the meaning of concepts such as "place and space, location and situation, locality and territoriality" for knowledge and scientific activity (LIVINGSTONE, 1995) in a field of study referred to as the "geography of science".

Another group of authors that has emerged in the last 20 years has proposed the spatialization of scientometric data and methods to analyze the geographic distribution of scientific publications, authors, citations, etc. (FRENKEN; HARDEMAN; HOEKMAN, 2009), applying spatial analysis through geographic information software (BORNMANN; WALTMAN, 2011; XUEMEI et al., 2014). This group calls the research field "Spatial Scientometrics".

Although the groups differ in their approach to their object of study, i.e., the geographic and spatial aspects of knowledge and/or scientific activity, both agree that the places where scientific activity takes place are central elements of this type of analysis.

One of these spaces of scientific importance is the field site, where samples and information about the object of study are directly collected. Site data from sampling locations are particularly important to the geosciences and other fields that use spatial information in their analyzes, such as architecture, health sciences, etc. In this study, these data are used to analyze the spatial distribution characteristics and research trends of soils in Antarctica.

There are few scientometric studies on soil science and none that use site data from study sites. On the other hand, several scientometric studies have been conducted on Antarctica, including studies such as those by Kim and Jung (2016) and Chignell et al. (2022), indicating that Antarctic science may be spatially oriented at regional and local scales, respectively.

Long before they became the subject of systematic scientific research, the oldest known collection of Antarctic soil samples was made by geologists Douglas Mawson and Raymond Priestley on Mount Erebus in the Transantarctic Mountains region and evaluated by geologist

[3] Título em inglês: Ehere does this sample come from? Space scientiometry of research on Antarctic soils.

Harald Jensen in 1916. Since then, Antarctic soils have attracted increasing scientific interest. Today, research on Antarctic soils is particularly important for monitoring climate change and searching for organisms of biotechnological interest.

This research takes place in ice-free areas where soil formation is possible (see Figure 1 in previous chapter). These are areas near the coast, on islands, on mountain tops, or in regions with milder climates such as the Antarctic Peninsula. As far as we know, no mapping of Antarctica has been done from sample sites. In this context, this article has attempted to provide a mapping and spatial analysis of ground research in Antarctica based on location, researchers (country of affiliation), historical and geographic context, and research topics.

2. Methodology

Our mapping approach is based on visualizing the occurrence of specific events. In this case, each event corresponds to the collection of a soil sample. For this purpose, geographic coordinates were extracted from 553 publications on Antarctic soils from the Web of Science and Scopus databases. Jensen's 1916 publication was added to the data as a historical milestone and benchmark for data interpretation.

Regarding the coordinate extraction process, it is important to clarify the following: If the publications contained coordinates and/or maps, all registered points were extracted. If there was only a textual indication of the area, physiographic element, or region, only one point (in the central area) was included. Therefore, coordinates were not checked if the location of the study was not known or if it was not possible to access the publication or its summary. Only locations below 60° south were considered.

In this way, a table was created with information on the location, year of publication, title, authors' countries of origin, and topic. The departments and commissions of the scientific structure of the Brazilian Society of Soil Science were used as reference for the topics. Other classes of topics were added as needed.

One or more topics were assigned to each document, depending on the case and the research focus, e.g., if the article deals with biochemical aspects of soil, the topics "soil biology" and "soil chemistry" are assigned to it; if it deals with the spatial distribution of soil organisms, the topic "soil biogeography" was checked. In this way, it was possible to identify the most frequent aspects and to illustrate the general profile of the publications. For the final analysis, each topic was counted individually.

The points were georeferenced using ArcGIS software, and density maps (kernel density) were created to identify the hotspots studied. The pattern of spatial distribution of the points at continental and regional scales was analyzed. The proximity between sampling points and existing infrastructure (research stations, camps, and laboratories) was also assessed.

3. Results and discussion

3.1 Overview and trends of publications

Of the 553 publications analyzed, no sites could be extracted in 60. This means that in 89.16% of the publications it was possible to extract some location information, allowing a spatial-bibliometric analysis of the subject (Table 15).

Table 15 - Synthesis of location data of publications on Antarctic soils

Description	Results
Overview	
Total Documents	553
Documents with Location Information	493
Documents without Location Information	60
Total Location Points	1884
Average points per year	29,43
Average points per document	3,82
Average distance from a point to an infrastructure	46,72 km
Infrastructure	
Research Stations	84
Semi-permanent camps	11
Laboratories	2

Source: Elaborated by the author.

A value of almost 4 points per publication reflects the larger number of publications with 1 to 5 points (84.6%). As shown in Table 16, half of the publications had 1 point and 34% of the publications had 2 to 5 points. The remaining publications (15.4%) are divided into 64 (13%) with 6 to 20 points and 12 (2.4%) that studied more than 20 sites.

The publication with the highest number of points (70) was that of Vieira et al. (2010), who presented the results obtained during the International Polar Year (API) on the thermal state of the permafrost and active layer throughout Antarctica, when the number of measurement points increased from 21 to 70.

Table 16 - Distribution of location points by publication

No. of sampling points	No. of publications	% of total pub. with location
1	250	50,7%
2	54	11,0%
3	53	10,8%
4	36	7,3%
5	24	4,9%
6	18	3,7%
7	7	1,4%
8	4	0,8%
9	6	1,2%
10	9	1,8%
11-20	20	4,1%
21-30	5	1,0%
31-50	4	0,8%
51-70	3	0,6%
1884	**493**	**100%**

Source: Elaborated by the author.

The average distance of 46.72 km from a collection site to one of the three infrastructures considered is a value that represents a middle ground between local and regional level studies. Among other factors, the straight-line reach of researchers is influenced by aspects such as climate, site accessibility, and the need to deepen scientific knowledge in specific locations (Table 17).

Table 17 - Distance from sampling points to some infrastructure

Distance (km)	Points	% of total points	Intervals	% of total points
0,1	74	3,93	0,1-0,5	13,75
0,5	333	17,68	0,5-1	9,77
1	517	27,44	1-5	22,40
5	939	49,84	5-10	5,47
10	1042	55,31	10-50	12,31
50	1274	67,62	50-100	15,55
100	1567	83,17	100-200	14,12
200	1833	97,29	200-300	0,80
300	1848	98,09	300-400	1,11
400	1869	99,20	400-500	0,42
500	1877	99,63	500-600	0,00
600	1877	99,63	600-700	0,37
700	**1884**	**100,00**	**>700**	**0,00**

Source: Elaborated by the author.

Almost half (49.84%) of the points are located at least 5 km from an infrastructure, with 17.68% and 27.44% within 500 m and 1 km, respectively. Thus, the range of 1 to 5 km is the

one that contains the most points, with 22.40% of the points. On the other hand, 16.83% of the points are at least 100 km away from a long-term human settlement, while 14.12% are between 100 and 200 km away. The most distant point was found by Russian researchers Lupachev and Abakumov (2013) in the Lindsay Islands in the Marie Byrd Land region. The point was 695 km from an American camp and more than 1000 km from Russkaya, the nearest Russian station.

As we seen at the previous chapter, basic research topics such as chemistry and soil biology were highlighted. The strong interest in this topic may be because soil biochemical information is fundamental for several other soil science analyses, and the high frequency of topics is understandable. The interest in monitoring the heat and water balance of Antarctic soils area also stands out, which is an important research topic in the publications. The context of climate change is driving research in Soil Science given the global implications of the changes occurring in Antarctica.

Concern about the environmental impacts that human activities (global, regional, and local) cause in the Antarctic ecosystem is also an issue that motivates research in the region. This is evidenced by how often the topic of pollution, soil remediation, and restoration of degraded areas appears in publications. Understanding the dynamics of the Antarctic landscape is the goal of many soil science researchers, especially in an environment so rich in endemic species. This can be seen in the frequency of topics such as soil genesis and morphology, soil investigation and classification, pedogeomorphology, and soil ecology.

Of the 60 publications without a location, most were by authors from the United States (17), New Zealand (14), Russia (6), China (6), and Brazil (6). The main topics of publications were soil biology (21), soil chemistry (11), reviews (9), pedometrics (8), and pollution, soil remediation, and restoration of degraded areas (6). The group is composed of publications from all decades between 1958 and 2021. Analyzing the sites grouped by time interval using the natural breaks method, we note that the number of sites and publications increased over time, accelerating from 67 (1974-1991) to 215 (1992-2006) beginning in 1992. (Table 18).

In the first period (1916-1973), with 28 sites and 24 publications, only the Transantarctic Mountains and Enderby Land regions were explored and were the first to attract scientific interest in soil science, led by countries such as the USA (9) and New Zealand (10). Of course, this first phase of research was concerned with surveying and classifying soil and understanding its genesis and morphology through its biology and chemistry (e.g., Boyd and Boyd (1963), Cameron (1970), Claridge (1965), Linkletter (1970), and Macnamara, 1969a, 1969b).

The second period (1974-1991), with 67 items and 31 publications, already includes research in at least 6 regions, with emphasis on the Transantarctic Mountains, Queen Maud

Land, and Ellsworth Land. The United States, New Zealand, and Japan are the major countries. The predominant themes are similar to those of the previous series, but with a greater emphasis on soil chemistry and soil genesis and morphology. Publications reflecting this scenario include the studies by Heatwole et al. (1989), Heine and Speir, (1989), Matsumoto et al. (1990), and Bockheim et al. (nineteen ninety).

Between 1992 and 2006, 215 points were counted in 6 regions, notably the Transantarctic Mountains, Antarctic Peninsula, and Wilkes Land. Researchers from the United States, New Zealand, Australia, and Germany stood out. The topic of pollution, soil remediation, and restoration of damaged areas is crystallizing as a strong research area that will consolidate in the following years. "Heavy metal contamination in coastal sediments and soils near the Brazilian Antarctic station King George Island" (SANTOS et al. 2005) is the publication with the most citations among the 553 analyzed.

In addition, issues of pedometrics, genesis and morphology, ecology, and soil physics also attracted greater interest during this period. Papers from this period such as Freckman and Virginia (1997), Burkins, Virginia, and Wall (2001), Sletten, (2003), Parsons et al. (2004), and Michel et al. (2006) were influential in their respective topics.

Table 18 - Synthesis of location data grouped by time periods

Period	Pub.	Pub. w/ loc.	Points	Region (points/pub.)	Subject (frequency)	Country (pub.)	AD pt. – infra.
1916 - 1973	24	20	28	TM (25/17); EL (3/3)	SSC (10); GSM (6); Biology (5) Chemistry (4); Pedometrics (2); Mineralogy (2); Pedogeomorphology (1); Soil Ecology (1)	USA (13); New Zealand (10); United Kingdom (1); Canada (1)	115,09 km
1974 - 1991	31	26	67	TM (32/12); EW (14/2); QM (11/3); PA (4/3); MR (1/1); WL (4/2); PM (1/1);	Chemistry (13); GSM (11); Biology (5); SSC (5); Mineralogy (3); Review (2); Pedogeomorphology (1); Physics (1); Pedometrics (1); PRR (1)	USA (10); New Zealand (8); Japan (7); Australia (2); Germany (2); Poland (1); Chile (1)	100,63 km
1992 - 2006	115	103	222	TM (145/53); PA (28/23); WL (21/18); MR (11/7); QM (7/7); EL (2/1); NR (2/2)	Chemistry (43); Biology (24); PRR (24); GSM (10); Pedometrics (10); Soil Ecology (10); Physics (10); SSC (7); Mineralogy (4); Biogeography (2); Paleopedology (2); Pedogeomorphology (2); FPN (1); Review (1); MCSW (1)	USA (41); New Zealand (20); Australia (14); Germany (13); Italy (7); Canada (7); China (7); United Kingdom (6); Brazil (5); Poland (4); South Africa (3); Czech Republic (2); Denmark (2); South Korea (2); Austria (2); Spain (2); India (2); Japan (2); Israel (2); Hungary (1); Argentina (1); France (1); Romania (1); Finland (1)	62,74 km
2007 - 2014	162	141	668	TM (315/62); PA (257/67); MR (26/10; WL (21/10); QM (19/4); MB (13/6) EL (3/2); NR (16/5)	Biology (48); Chemistry (32); Pedometrics (30); GSM (15); PRR (14) Pedogeomorphology (13); Physics (11); Soil Ecology (10); SSC (8); Mapping (8);	USA (46) New Zealand (32); Brazil (30); Spain (21); Italy (13); United Kingdom (12); Russia (12); China (11); Portugal (10); Canada (10); Australia (9); Argentina (8) Germany (7);	64,44 km

					Biogeography (5); Review (4); Mineralogy (3); MCSW (3); RSM (2); FPN (1); Paleopedology (1); SEPP (1)	Malaysia (5) South Africa (5); Norway (3); Bulgaria (3); South Korea (3); Switzerland (2); Denmark (2); Poland (2); Ukraine (2); Sweden (1); Venezuela (1); Thailand (1); Romania (1); Saudi Arabia (1); Czech Republic (1); France (1); India (1)	
2015 - 2021	221	203	899	PA (510/128); TM (172/45) QM (91/10); MR (56/15); WL (31/12); EL (25/8); EW (6/4); MB (3/3); NR (6/2)	Chemistry (50); Biology (48); Pedometrics (45); PRR (36); Soil Ecology (26); GSM (21); Physics (21); SSC (14); Pedogeomorphology (8); Mineralogy (6); Biogeography (6); Paleopedology (4); FNP (3); Mapping (3); Review (2); LUP (1); MCSW (1); RSM (1).	USA (50); Brazil (49); Russia (32); Spain (24); China (19); New Zealand (18); Portugal (16); Germany (16); Czech Republic (13); Canada (12); United Kingdom (11); Australia (10); Chile (10); Italy (8); Argentina (7); South Korea (6); Poland (6); Belgium (6); South Africa (6); Malaysia (4); Thailand (4); Ukraine (4); India (3); Mexico (3); Switzerland (2); Sweden (2); Bulgaria (2); Belarus (2); Ecuador (2); Netherlands (2); Uruguay (1); Singapore (1); Pakistan (1); Iceland (1); France (1); Israel (1); Slovakia (1); Colombia (1); Saudi Arabia (1); Japan (1); Hungary (1)	23,49 km
TOTAL	**553**	**493**	**1884**	**-**	**-**	**-**	**46,72 km**

Legend: AD pt-infra = Average Distance from a point to some infrastructure; TM = Transantarctic Mountains; EL = Enderby Land; PA = Peninsula Antarctica; QM = Queen Maud Land; MR = Mac Robertson Land; WL = Wilkes Land; EW = Ellsworth Land; PM = Pensacola Mountains; MB = Marie Byrd Land; NR = No Region; SSC = Soil Survey and Classification; GSM = Genesis and Soil Morphology; PRR = Pollution, Soil Remediation and Recovery of Degraded Areas; FPN = Soil Fertility and Plant Nutrition; MCSW = Management and Conservation of Soil and Water; RSM = Remote Sensing and Modeling; SEPP = Soil Education and Public Perception of Soil; LUP = Land Use Planning.

From 2007 to 2014, 668 samplings were conducted in 7 regions and countries such as the United States, New Zealand, Brazil, Spain, Italy, and the United Kingdom with additional publications. The research topics are diverse and characterised by biology (LEE et al., 2012; TEIXEIRA et al., 2010), chemistry (SCHAEFER et al., 2008; SIMAS et al., 2008), pedometrics (BOCKHEIM et al., 2013; VIEIRA et al., 2010), soil genesis and morphology (SIMAS et al., 2007), soil geomorphology (LÓPEZ-MARTÍNEZ et al., 2012; NAVAS et al., 2008), and pollution, soil remediation, and restoration of degraded areas (KLÁNOVÁ et al., 2008).

The last interval had the highest score of 899 points, in addition to 221 publications covering 8 of the 9 ice-free regions, focusing on the Peninsula and Transantarctic Mountains. The United States, Brazil, Russia, Spain, China, New Zealand, Germany, and Portugal were the countries with the most publications.

In addition to chemistry and biology, the following research interests are cited: Pedometrics and Soil Physics (HRBÁČEK; LÁSKA; ENGEL, 2016; OLIVA et al., 2017), Pollution, Soil Remediation and Restoration of Degraded Areas (AMARO et al., 2015) and Soil Ecology (ADRIAENSSENS et al., 2017). It is noted that research in chemistry and soil genesis and morphology is highlighted in all periods, indicating a strong and consolidated research branch. The continuous growth of the field of soil biology is also illustrated by the interest in ecology and bioremediation of degraded land.

In terms of countries, the pioneering spirit of United States and New Zealand scientists in Antarctic soil research is well known, especially through figures such as McCraw, Ugolini, Claridge, Campbell, Cameron, MacNamara and others. Today, other countries such as Brazil, Spain, Italy, Germany and Russia stand out.

It should also be noted that since 2007 the Antarctic Peninsula has been the region with the most publications and since 2015 it has received more publications and points, sharing the place of the most studied regions with the Transantarctic Mountains.

It is interesting to note that the average distance from points to infrastructure has decreased over time. Although these values are affected by the number of installations at any given time, they suggest that the range of sampling was initially greater due to limited knowledge of the soils and of Antarctica itself. As knowledge increased and the number of turbines increased, the distance between samples decreased, giving the surveys a more local character.

All points that were outside some of the ice-free regions (NR) were on Signy Island in the South Orkney Archipelago. A British research station is located on the island, which explains why the United Kingdom is involved in 8 of the 9 publications and 23 of the 24 points

located there, in partnership primarily with Malaysia and Italy. The publications took place between 2005 and 2020. The main research topics are soil biogeography (CHONG et al., 2010; DENNIS et al., 2012) and pedometrics (GUGLIELMIN; WORLAND; CANNONE, 2012).

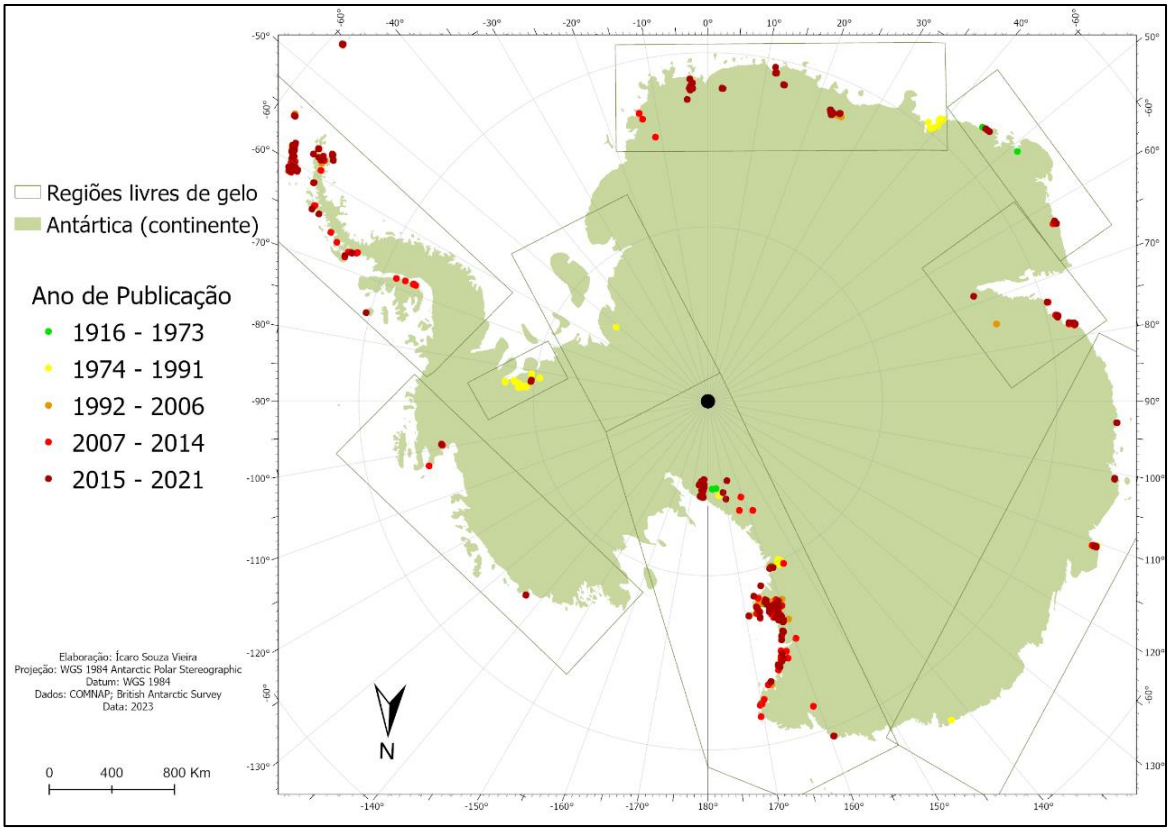
Finally, after the point density and distribution maps were prepared (Figures 8 and 9), a wide but uneven distribution of points was observed. The regions with the highest concentration were the Peninsula and Transantarctic Mountains. It was expected that these areas would be the most heavily surveyed because they have the largest ice-free areas on the continent. Specific results for each region are discussed below.

The Peninsula region is very well researched and monitored, with densities as high as 27.6 points per km², due to factors such as the highest concentration of research stations on the continent (40), with a focus on the South Shetland Islands area with 20 stations, a semi-permanent camp and laboratory, and several ice-free areas. Because of the historical spatial distribution of the data, the soils of the Transantarctic Mountain region were the first to be systematically studied and have continued to arouse interest ever since. The highest densities are found in the Vales Secos region, where 14 points per km² are reached.

There are sites that still have mostly earlier research (1974-1991), such as Ellsworth Land and the eastern portion of Queen Maud Land. In the Pensacola Mountains region, there was only one site in the U.S. for research aimed at understanding the physics, chemistry, and biology of local soils (PARKER et al., 1982).

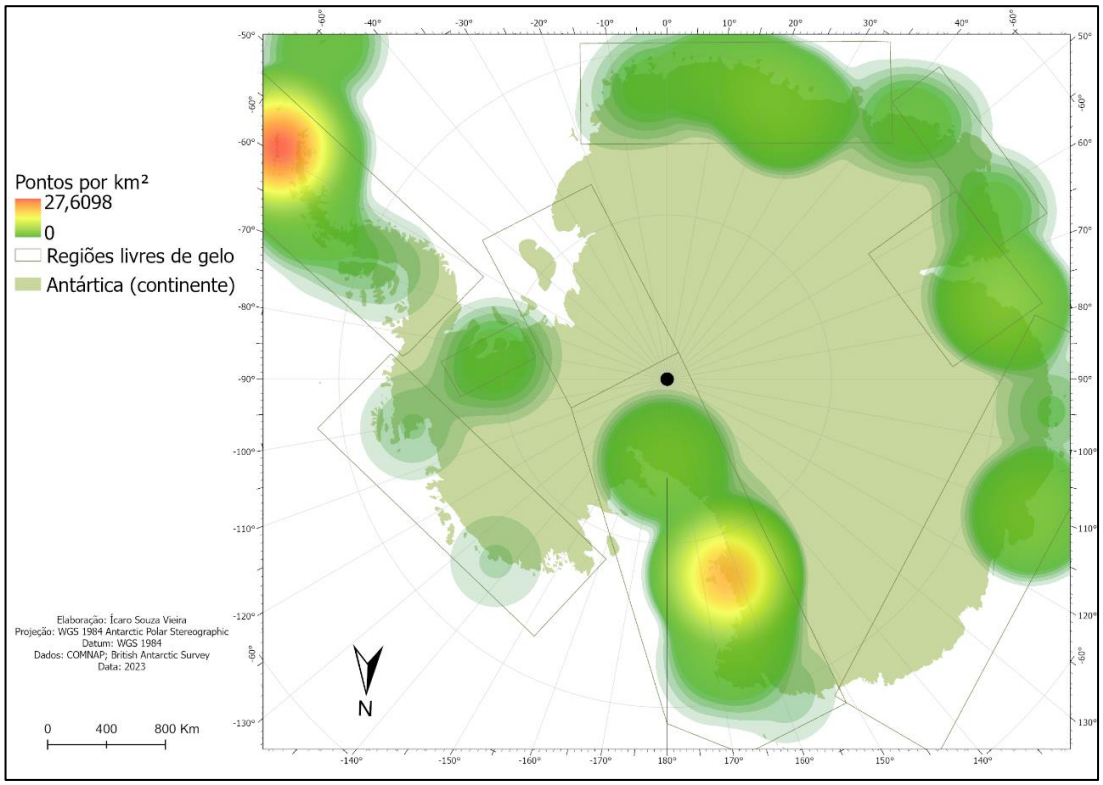
By looking at the spatial data at a regional scale, it was possible to compare them between different ice-free regions. Table 19 provides various spatiobibliometric information for each of the regions (with the exception of the Pensacola Mountains). Specific considerations for each region are provided below.

Figure 8 - Map of distribution of points classified in time intervals



Source: Elaborated by the author.

Figure 9 - Point density map (Kernel)



Source: Elaborated by the author.

Table 19 - Information by ice-free region

Region		MB	EW	EL	WL	MR	QM	TM	PA
Total area (km²)		715.455,01	130.855,13	195.676,26	1.273.818,19	562.534,44	834.987,85	1.296.265,27	408.571,08
Ice free area (km²)		700	2.095	1.500	700	5.400	3.400	24.200	10.000
Infrastructure	Stations	1	0	3	5	8	12	6	40
	Camps	0	1	0	1	1	1	2	2
	Laboratories	0	0	0	0	0	0	0	2
No. of points (% of total)		16 (0,85%)	20 (1,06%)	33 (1,76%)	77 (4,08%)	93 (4,93%)	128 (6,79%)	689 (36,55%)	804 (42,65%)
No. publications (% of total)		9 (1,63%)	6 (1,09%)	14 (2,54%)	42 (7,61%)	33 (5,98%)	24 (4,35%)	191 (34,60%)	224 (40,40%)
Points per publication		1,77	3,33	2,357	1,83	2,81	5,33	3,6	3,57
Citations by publication		28,33	16,33	20,28	27,07	23,37	20,08	40,99	23,22
Average distance to an infrastructure (km)		368	55,28	12,24	5,45	9,09	23,08	98,28	8,98
Average year of publication		2013	1991	2013	2009	2015	2012	2008	2015
Country with the most exclusive points (% of local points)		Russia (93,75%)	USA (75%)	Australia (54,54%)	Australia (48,05%)	Australia (48,38%)	Japan (9,37%)	USA (44,55%)	Brazil (18,84%)
Countries with most publications		Russia (9)	USA (4); Brazil (3)	Russia (8); USA (5)	Australia (19); Germany (13); Russia (9)	Russia (14); Australia (9); China (6)	Russia (7); Japan (6); India (5); Belgium (4); South Africa (4)	USA (112); New Zealand (72); Canada (20); Italy (19)	Brazil (66); Spain (37); China (24); Portugal (23) ; USA (23)
Country with the highest n. of infrastructures		Russia (1)	Chile (1)	Australia (1); Belarus (1); Russia (1)	Australia (2); France (2); Russia (2)	Russia (4)	Japan (3)	USA (2); Italy (2)	Argentina (11); Chile (11)

Subject with the highest exclusive frequency (% of points)	GSM (56,25%)	GSM (65%)	PRR and Soil Chemistry (48,48%)	Soil Biology (22,07%)	PRR and Soil Chemistry (33,33%)	Soil Biology (63,28%)	Soil Ecology (21,91%)	Soil Chemistry (20,97%)
Subjects with the highest total frequency (No. of publications)	GSM (5)	Each publication was a different subject.	Soil Chemistry (5); Soil Biology (4); Pedometry (4)	Soil Biology (14); Soil Chemistry (12); PRR (9)	Soil Chemistry (11); Soil Biology (11); PRR (8)	Soil Biology (9); Soil Chemistry (7); GSM (4)	Soil Chemistry (41); Soil Biology (40); Pedometry (33); GSM (25)	Soil Chemistry (35); Soil Biology (20); Pedometry (13); GSM (11)

Legend: TM = Transantarctic Mountains; EL = Enderby Land; PA = Peninsula Antarctica; QM = Queen Maud Land; MR = Mac Robertson Land; WL = Wilkes Land; EW = Ellsworth Land; MB = Marie Byrd Land; GSM = Genesis and Soil Morphology; PRR = Pollution, Soil Remediation and Recovery of Degraded Areas.

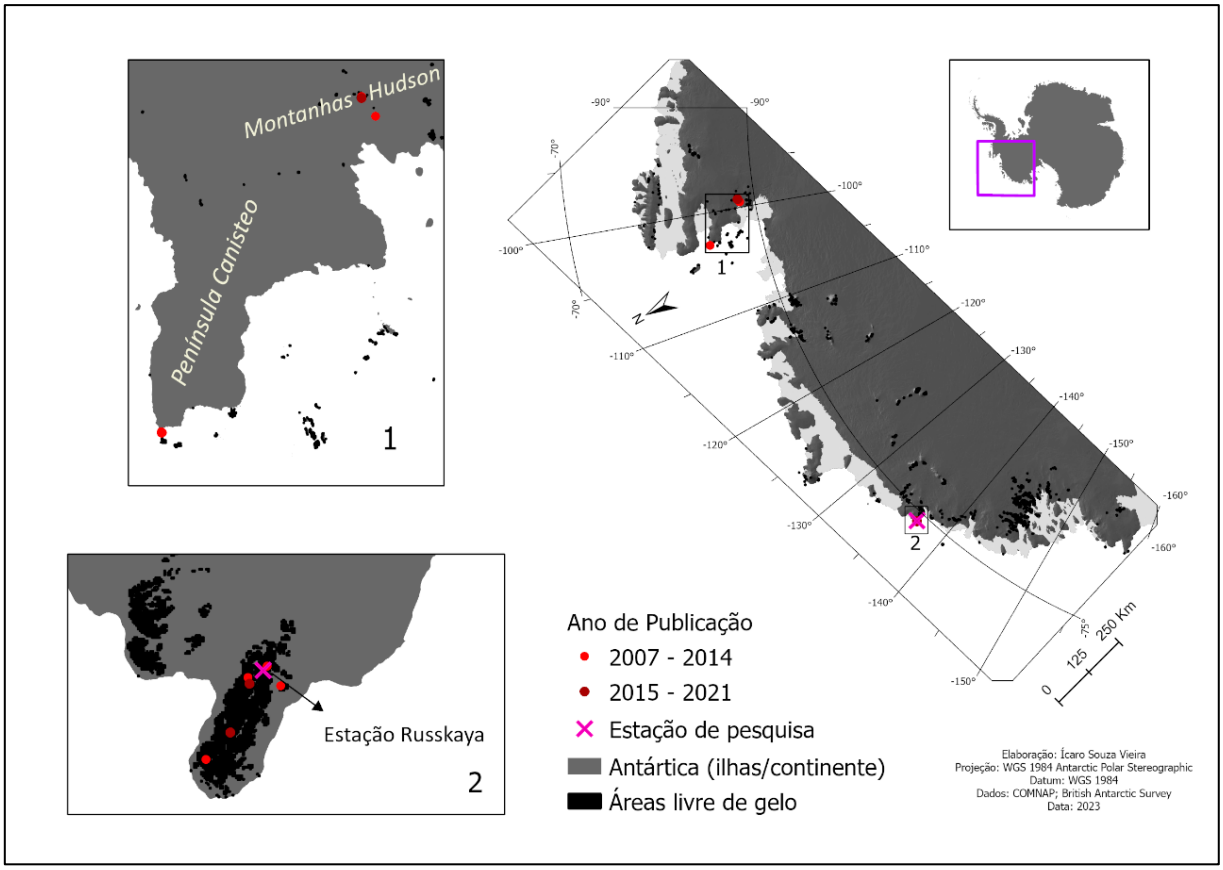
3.1.1 Marie Byrd Land

Despite a total area of over 700,000 km², ice-free sites on MB are rare, with an area of about 700 km² (1.4% of the total ice-free area of Antarctica). MB is one of the most remote and difficult-to-access areas of Antarctica, and the only one to which no nation lays claim. Russkaya Station, the only building in the region, has been closed since 1990 but has been used for cataloged surveys.

Only recently has it begun to study the soils of MB, with research occurring over the last 15 years, with an average publication year around 2013. These are generally underdeveloped soils (even by Antarctic standards), with an emphasis on soils of the lytic subgroups, in addition to the organic soils associated with coastal island penguins.

The map in Figure 10 shows the spatial distribution of sampling sites. A group distant from the research station on the coast of the Canisteo Peninsula (ABAKUMOV et al., 2014a, 2013; LUPACHEV; ABAKUMOV, 2013) (important point for penguins) and in the Hudson Mountains (ABAKUMOV, 2010a, 2010b). concentrated mainly around the Russian station (NIKITIN et al., 2017).

Figure 10 - Map of Marie Byrd Land



Source: Elaborated by the author.

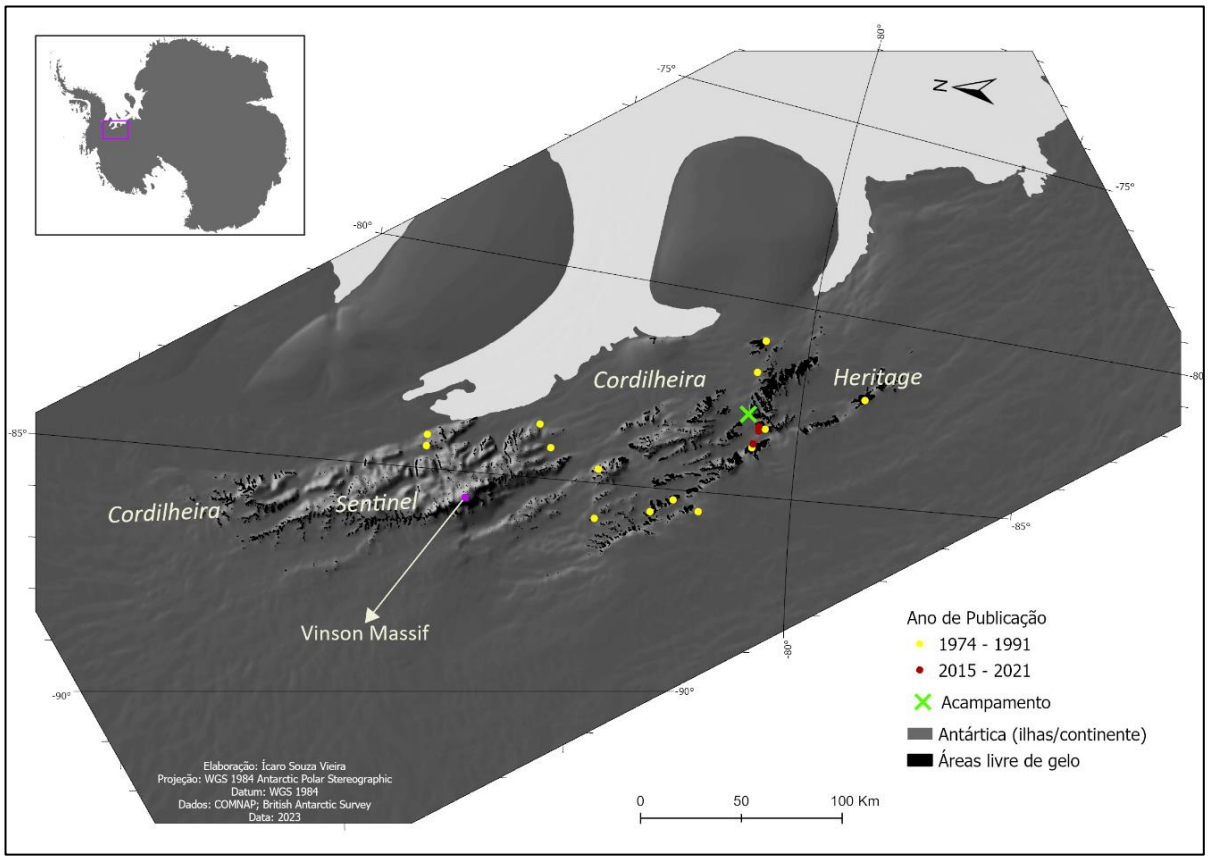
3.1.2. Ellsworth Land

In this region, ground surveys occur in the ice-free areas of the Ellsworth Mountains, which are divided into two elevation sections: the Heritage Range to the east and the Sentinel Range to the west (Figure 11). The latter hosts the highest peaks in Antarctica, including the Vinson Massif (4,897 m).

The region is very isolated and still poorly explored (20 points). Although there is a Chilean camp, studies conducted there were mainly by Americans in the 1980s and 1990s (BOCKHEIM; LEIDE, 1980; VENNUM; NEJEDLY, 1990) and more recently by Brazilian scientists (DELPUPO et al., 2017; SCHAEFER et al., 2017). Other publications report research by New Zealanders from the 1990s, but were not found in the databases searched.

With a substantial ice-free area of 2,095 km², there is still plenty of field work for future research. The predominant theme is genesis and soil morphology, indicating that knowledge in this area is still in the consolidation phase. Despite the difficult local conditions, the points are about 55 km from the nearest infrastructure.

Figure 11 - Map of Ellsworth Land



Source: Elaborated by the author.

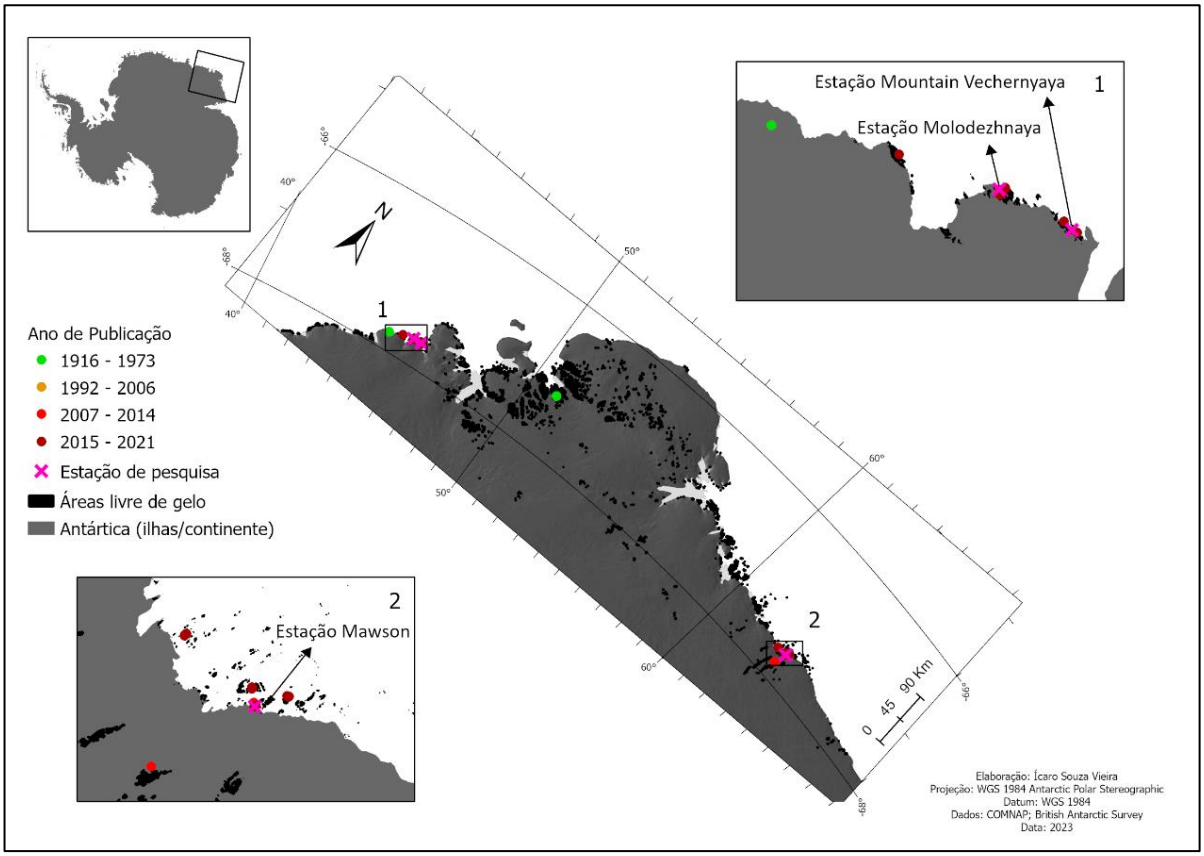
3.1.3. Enderby Land

Enderby Land is the part of East Antarctica that extends from 40° E to about 65° E (Figure 12). Although little explored, it is nearly 1,500 km² in area and is ice-free, including several coastal oases and nunataks that rise above the ice sheet in the central part. The first publications in this region were made in the late 1960s (MACNAMARA, 1969a, 1969b) in connection with exploration and sounding of the area.

Three research stations, Mawson (Australia), Molodezhnaya (Russia), and Mountain Vechernyaya (Belarus), are located in the region. The points are located an average of 12 km from them, indicating a local character of the surveys, which are generally conducted near the research stations. The country that stands out in terms of number of points is Australia, especially in terms of restoration of degraded lands (LEWIS et al., 2020). The map in Figure 5 also shows that there are still many areas for future surveys, especially in the central part and on the west coast of the Australian station.

However, the countries with the most publications were Russia and the U.S., with publications around the Russian station standing out, such as Zazovskaya et al. (2017) on the age of soils using radiocarbon dating, Nikitin et al. (2017) on the microbial biomass of soils, and Lupachev, Gubin, and Abakumov (2020), who addressed biogenic-abiogenic interaction in the structural organization of soils.

Figure 12 - Map of Enderby Land



Source: Elaborated by the author.

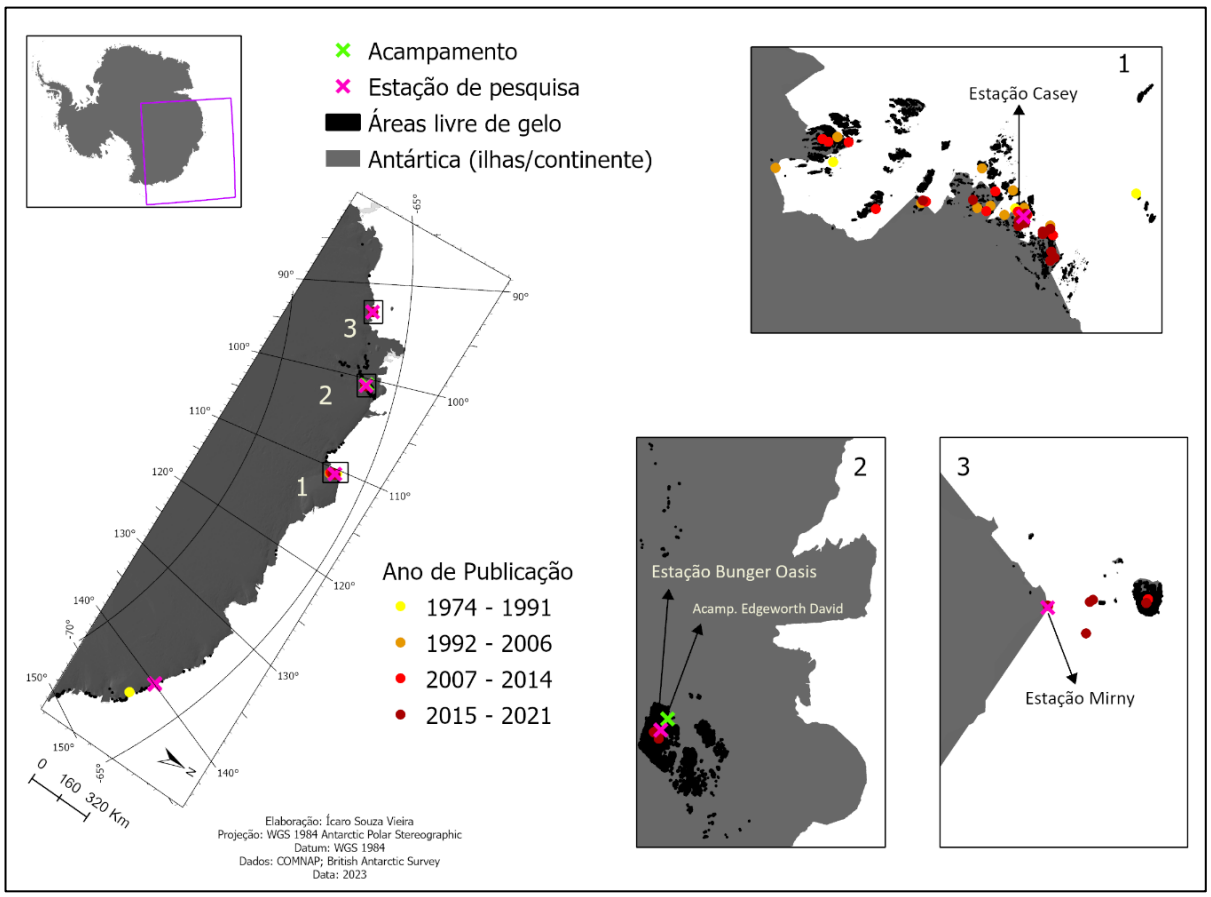
3.1.4. Wilkes Land

Despite its large area, Wilkes Land has about 700 km² of ice-free area distributed near the coast. The largest of these is the Windmill Islands and its surroundings with 500 km², near the Australian station Casey. This distribution and the extreme environmental conditions in the region constrain the distribution pattern of points near infrastructure, with an average distance of 5.45 km (Figure 13).

There are 5 research stations in the region: Mirny and Bunger Oasis (Russia), Casey (Australia), Dumont d'Urville (France), and Robert Guillard (France/Italy), and an Australian semi-permanent camp.

Despite the area restriction, systematic pedological studies have been conducted since the late 1980s, mainly by Australians (HEATWOLE et al., 1989; ROSER; SEPPELT; ASHBOLT, 1993) and Germans (BEYER et al., 1995; BOeLTER, 1990), and more recently by Russians (NIZAMUTDINOV; ANDREEV; ABAKUMOV, 2021). The cited publications represent the main research topics in this field (biology, chemistry, pollution, and restoration of degraded areas).

Figure 13 - Map of Wilkes Land



Source: Elaborated by the author.

Among the publications from the region that have made their way into the literature (larger number of citations) is that of Ferguson et al. (2003), who examined the effects of nitrogen (and phosphorus) amendments on mineralization by the soil microbial community to identify organisms of interest for bioremediation of hydrocarbon contaminants from samples near Casey Station.

In general, soils in the region are poorly developed and young, and most have a rocky subsoil in the first 50 cm, subdivided into lithic subgroups. However, the diversity of the landscape results from soils in waterlogged depressions, sandy areas, dry ridges, abandoned penguin trees, peat depressions, etc. Such a difference in habitats suggests biological and ecosystem diversity, which may explain the focus of research on soil biology.

3.1.5. Mac Robertson Land

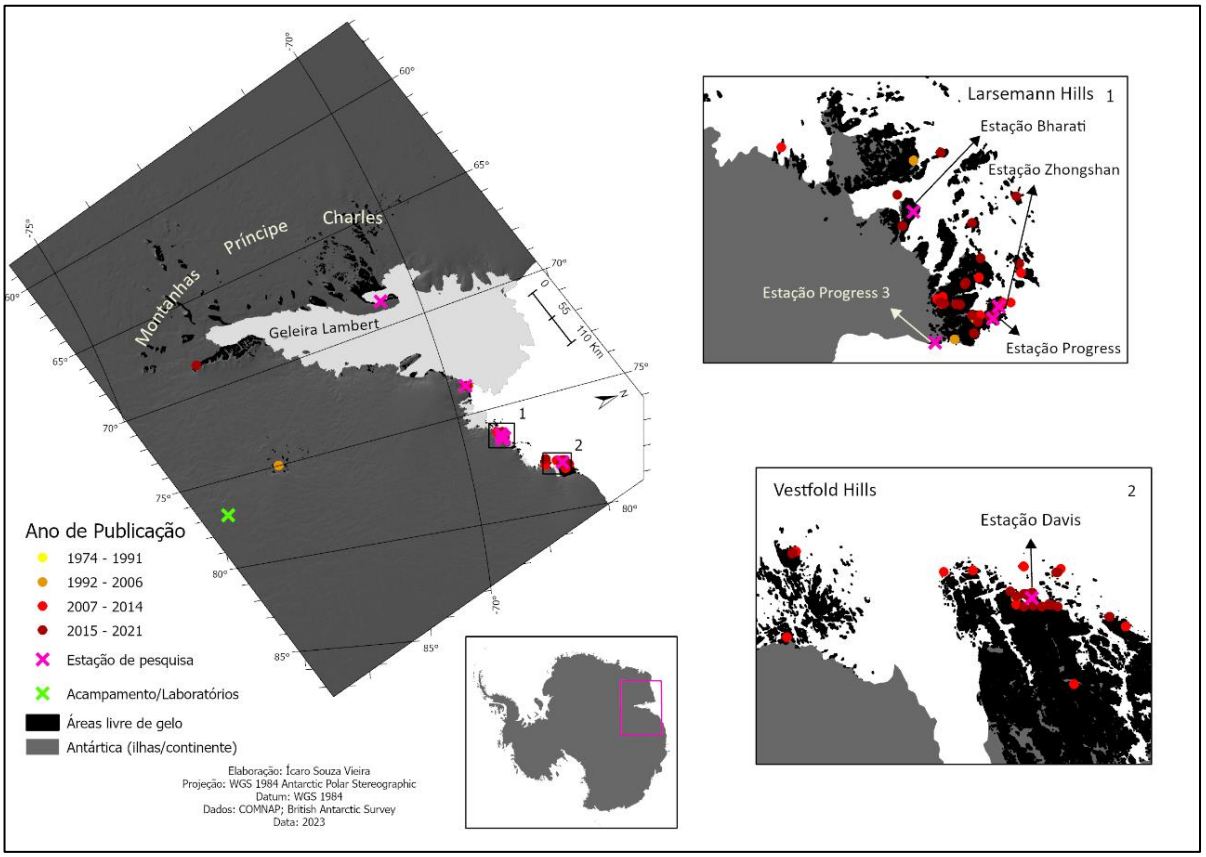
Mac Robertson Land, a small region of East Antarctica, is the third largest ice-free area on the continent. The Lambert glacier system, nunataks and oases in the region attract diverse scientific attention as there are 7 stations: Davis (Australia), Zhongshan (China), Bharati

(India), Law-Racoviță-Negoiță (Romania), Progress, Progress 3, Druzhnaya IV and Soyuz (Russia), the last two of which are temporarily closed. There is also 1 Chinese camp.

It was identified that the region has been studied since the end of the 1980s by Australians in themes of soil biology (LINE, 1988), bioremediation (GREEN; NICHOLS, 1995; KERRY, 1993) and in unusual themes in Antarctic pedology such as soil management (KIERNAN; MCCONNELL, 2001) and soil fertility and plant nutrition (LEISHMAN; WILD, 2001).

The sampling sites are mainly spread across the Vestfold and Larsemann hills along the Ingrid Christensen coast, where most of the sampling stations in the region are located (Figure 14). The spatial distribution pattern of the points in Mac Robertson Land is similar to that of Wilkes Land, as sites near stations are studied more, mainly on islands and coastal oases with an average distance of 9.09 km from a facility. It is noted that there are places of interest from a pedological point of view, such as the Prince Charles Mountains and other coastal areas where research is needed.

Figure 14 - Map of Mac Robertson Land



Source: Elaborated by the author.

The highest scoring area, Larsermann Hills, is mainly studied by Australians (VELASCO-CASTRILLÓN et al., 2014), Russians (ABAKUMOV et al., 2014b), Indians

(ROUT et al., 2020), and Chinese (ZHU et al., 2020). al., 2011), but also by Germans (BAJERSKI; WAGNER, 2013) and Romanians (NEGOITA et al., 2001). The main topics are related to biology, focusing on ecology, biogeography, and restoration of degraded areas. Soil chemistry is also an important research topic in the region.

3.1.6. Queen Maud Land

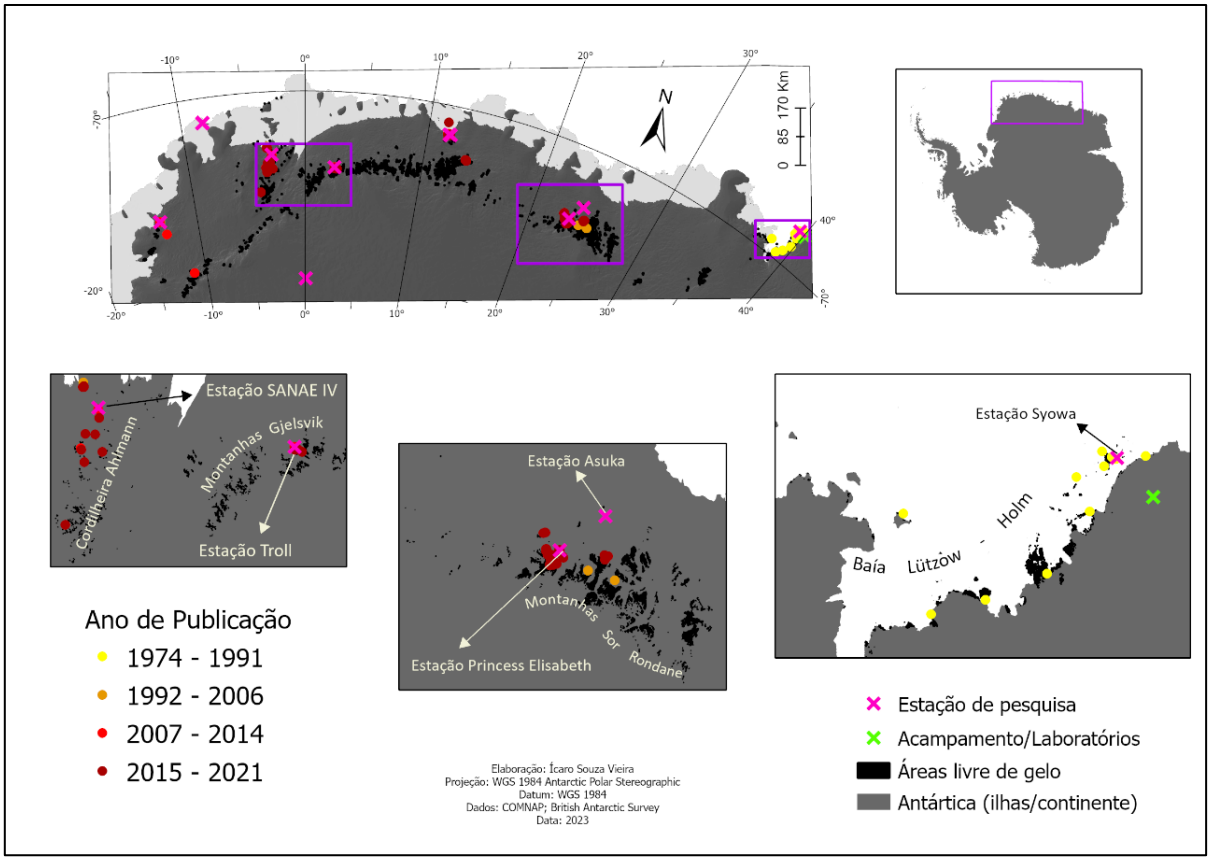
Queen Maud Land or Dronning Maud Land is a vast Antarctic region stretching from 20ºW to 45ºE, with 3,400 km², the fourth largest ice-free area on the continent. There are 12 research stations in the region, namely: Princess Elisabeth (Belgium), Aboa (Finland), Maitri (India), Asuka (temporarily closed) and Syowa (Japan), Troll (Norway), Novolazarevskaya (Russia), SANAE IV and SANAP (South Africa), Wasa (Sweden), Neumayer III and Kohnen (Germany), the latter of which is temporarily closed. There is still 1 Japanese camp.

The researchers state that the soils of the region were originally studied by MacNamara in the 1960s (1969c). At that time, he pointed out that pedogenesis in the area was not very informative. Subsequently, Japanese investigated the biology and chemistry of soils in the coastal region along Luetzow-Holm Bay in the 1970s and 1980s (INO et al., 1980; INO; NAKATSUBO, 1986; MIWA, 1975).

Since the 1990s, other countries have been the protagonists of research in the region, such as Russia (KOCHKINA et al., 2014), India (JOJO et al., 1995; SHIVAJI et al., 2004; WARRIER et al., 2021), Belgium (TAHON et al., 2016), and South Africa (COCKS et al., 1999), especially in the fields of biology, genesis and morphology, and soil chemistry.

Stations are mostly located on the coast or in inland mountains, a pattern reflected in the distribution of sampling sites with few exceptions far from infrastructure (Figure 15). The main study sites are the peaks of the Ahlmann Mountains south of the South African station, the Sor Rondane Mountains near the Belgian and Japanese stations, and the east coast of Luetzow-Holm Bay near the Syowa station.

Figure 15 - Map of Queen Maud Land



Source: Elaborated by the author.

Prevailing soils include mineral soils and lithic subgroups, which may occur under moss or algal cover, on lakeshores, mountain tops, and steep slopes. Polygonal soils also occur (MATSUOKA; HIRAKAWA, 2006). The soils of the region are less developed than in other regions of East Antarctica because they are farther from the coast and have not been influenced by penguins and other birds (ZAZOVSKAYA et al., 2015).

3.1.7. Transantarctic Mountains

It is the region with the largest ice-free area in Antarctica (48.9%) at 24 200 km² and one of the best studied. The Transantarctic Mountains area was where USA and New Zealanders (BLAKEMORE; SWINDALE, 1958; FLINT; STOUT, 1960; CLARIDGE, 1965; MCCRAW, 1967; CAMPBELL; CLARIDGE, 1969) first paid scientific attention to Antarctic soils in the late 1950s to understand the dynamics of the landscapes in this region.

As can be seen from the figures in Table 19, these countries remain the main scientific actors in the field, but since the 1990s they have been joined mainly by Japanese (MATSUMOTO et al., 1990b) and Italians (GUGLIELMIN, 2006) in researching and

publishing relevant work on the soils of the region. Canada should also be highlighted; although it does not have a scientific base in Antarctica, it is conducting research in partnership with the Americans because of its history and expertise in gelsols and cryosols.

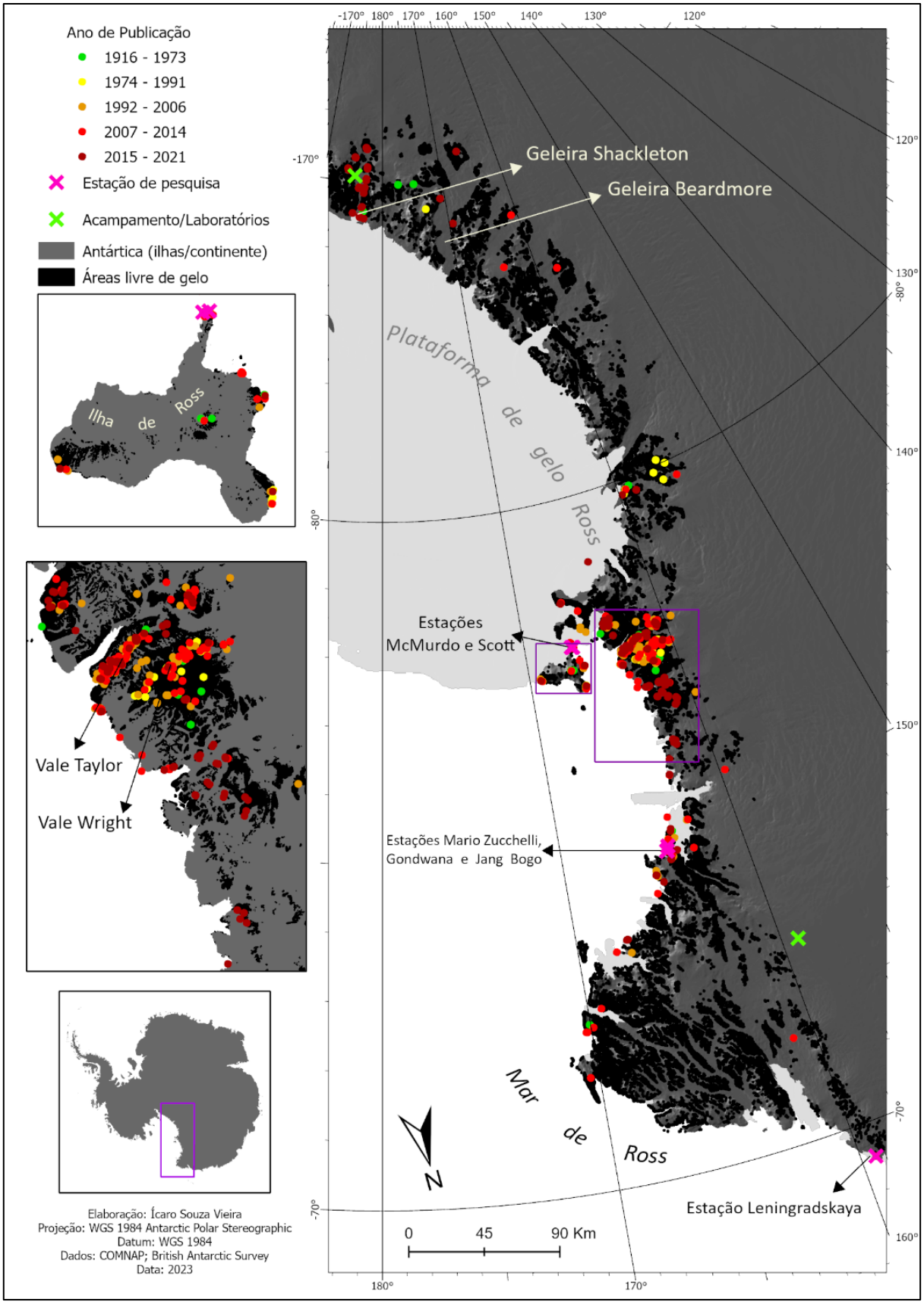
There are 6 research stations in the region: McMurdo (USA), Scott (New Zealand), Gondwana (Germany), Mario Zucchelli (Italy), Jang Bogo (South Korea), and Leningradskaya (Russia), as well as one American and one Italian station. With the exception of the Russian station, the others are located on islands or on the coast of the Ross Sea (Figure 16).

With unique landscapes such as the McMurdo Dry Valleys, the Transantarctic Mountains are a natural laboratory for the study of various topics and of great interest for soil formation in cold and dry environments (BOCKHEIM, 1979; WENTWORTH; MCKAY, 1983; BOCKHEIM; MCLEOD, 2006; GIBSON; ABAKUMOV, 2010b;).

Soil studies from an ecosystem perspective are also strong in the region, with work such as Courtright, et al. (2001), Polito, et al. (2002), Poage et al. (2008), Lee et al. (2012), and Andriuzzi et al. (2018). Unique ice-free areas near the South Pole, around the Shackleton and Beardmore glaciers at 85ºS, are sites of interest in understanding the dynamics of such extreme landscapes (LYONS et al., 2016; DIAZ et al., 2021;) and at the frontier of life on the planet (DRAGONE et al., 2021).

Sampling sites are distributed across all major ice-free areas in the region. The most studied sites are Ross Island and the dry valleys near McMurdo and Scott stations, with an emphasis on Taylor and Wright valleys and near the Italian and German stations. (Figure 16).

Figure 16 - Map of the Transantarctic Mountains



Source: Elaborated by the author.

3.1.8. Antarctic Peninsula

Together with the anterior region, this is the place where most Antarctic pedological studies take place, with almost 42% of the cataloged points and 40% of the publications. According to the specific bibliography and data of this research, the soils of the Antarctic Peninsula have been systematically studied since the 1970s (ALLEN; HEAL, 1970; EVERETT, 1976; MARTIN; PEEL, 1978). In the 1980s, research gained momentum and diversified its topics and scientific approaches.

Originally studied by British and Americans, the region's soils are now studied by researchers from more than 30 nations, including Brazilians, Spaniards, Portuguese, and Chinese. Because it is a vast peninsula surrounded by islands and home to 40 research stations, 2 laboratories, and 2 camps, sampling sites are generally located near the facilities, with an average distance of nearly 9 km.

The peninsula is the most "populated" part of Antarctica, as it is visited in summer not only by scientists but also by tourists, and is a preferred study area for research on pollution and environmental effects on soils. The milder and wetter climate from an Antarctic perspective and the rapid changes in the different landscapes of the Antarctic Peninsula arouse great scientific and pedological interest. Also, the warming observed in the region over the last 50 years draws even more attention to the monitoring of permafrost and the active layer to observe the environmental changes caused by climate change (BREVIK, 2013).

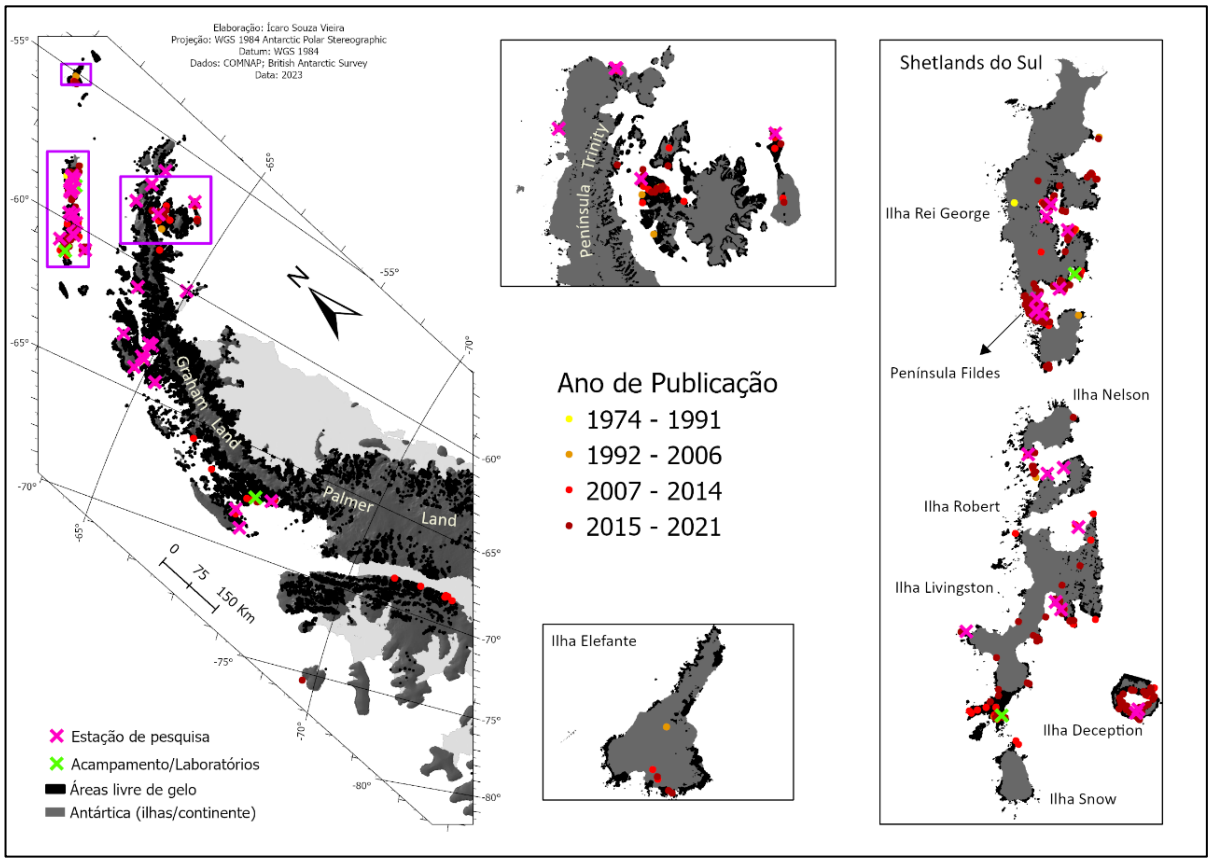
The pattern of spatial distribution of sampling sites shows a concentration in the South Shetland archipelago and on the edge of Graham Land, Trinity Peninsula and nearby islands (Figure 17). Half of the research stations in the region are located in this area, which also has the largest ice-free areas in the region and a large biodiversity of terrestrial ecosystems, making them preferred study sites.

Brazil's scientific work has been outstanding in this region. Brazil is the most important country for research on Antarctic Peninsula soils, with almost 19% of publications exclusively by Brazilians and 29.46% of publications in the region with at least one Brazilian researcher as a co-author, as well as a spatial distribution throughout the region. The country publishes significant papers in the literature, mainly on biology (TEIXEIRA et al., 2010), genesis and soil morphology (MICHEL et al., 2006; SCHAEFER et al., 2008; SIMAS et al., 2007, 2008), and pedogeomorphology (FRANCELINO et al., 2011; MICHEL et al., 2014; MOURA et al., 2012).

Portugal and Spain also stand out with research on various topics, but with emphasis on pedometrics (BOCKHEIM et al., 2013; DE PABLO et al., 2013) and pedogenomorphology (NAVAS et al., 2008; LÓPEZ-MARTÍNEZ et al., 2012; MICHEL et al., 2014).

China mainly researches the Fildes Peninsula, with emphasis on the areas of soil biology (WANG et al., 2015), soil chemistry (ZHU et al., 2011) pollution and bioremediation (ZHANG et al., 2015). Based on the information on the map in Figure 10 and being the second region in an ice-free area, the Antarctic Peninsula still has many locations with soils waiting to be analyzed and help to understand the dynamics of the different landscapes found in the region.

Figure 17 - Map of the Antarctic Peninsula



Source: Elaborated by the author.

4. Conclusions

In the frozen soils of the South Pole, knowledge of themselves has evolved and is critical to understanding the behavior of terrestrial ecosystems in a changing world. This study provides a spatial scientific overview of the status and trends of research on Antarctic soils.

The methods presented in this article allow spatial analysis of bibliometric data in a very specific way: through the locations of sampling sites. In this way, it was possible to use

geographic information software to analyze scientific activity from a geographic perspective over time.

Based on Scopus and Wef of Science data, the scientometric and spatial characteristics of research on soils in Antarctica were known. It was found that regions with a larger ice-free area tended to be better researched and had a greater number of sample points and publications. The location of infrastructures was found to be fundamental to the spatial distribution of points, as half of the points are at least 5 km from a facility, 22.33% are between 1 and 5 km, and almost 18% are up to 500 m away. At the same time, the scientific spirit goes further and explores difficult areas beyond 600 km from some infrastructures.

With the exception of the Antarctic Peninsula and Ellsworth Land, the countries with the most facilities in a given region tend to be the countries with the most publications in those regions. Also, with the exception of Enderby Land, the countries with the most exclusive points also tend to be the countries with the most publications. Thus, the country with the infrastructure in that region tends to publish more and alone. Co-authorships tend to have a lower weight in the number of publications from the most important countries in a given region.

Research topics, the pattern of spatial distribution of points, and the average distance from a point to an infrastructure were found to be influenced by factors such as the history of research in the region (whether it is well known or little known and where) as well as landscape elements such as the location of stations, ice-free areas, and local biodiversity and climate.

Mapping surveys at sample sites has made it possible to observe the behavior of scientists across time and space. There is a tendency to begin studies in a particular region with soil genesis and morphology, surveying, and classification, and later turn to topics such as soil biology, PRR, soil ecology, and more recently pedometrics, remote sensing, and soil mapping. Research emphases over time reflect the specific historical contexts of the scientific community and study areas.

Despite the advantages of this mapping approach to illustrate the historical-spatial dynamics of science, the limitations of using bibliographic data are well known:

(1) There is no guarantee that the addresses listed in a publication reflect the actual places of work or even the nationalities of the authors.

(2) Many times, the research is carried out with the setting up of camps that last only for the summer period. Thus, the location of a scientific station is not the limit of the researchers' spatial scope.

(3) Each literature database covers only a portion of the world's published articles, which is mainly influenced by language biases.

(4) There are different publication and citation patterns in different scientific fields, which makes direct comparison problematic.

(5) There is no standard technique for thematic classification of articles.

(6) Publications are only one of several types of scientific activities.

(7) Not all fields of knowledge deal with location information, and this study is indicated for those researches where location is an important element of their realization.

In addition to these general issues related to bibliometric data, there are others inherent to the specific approach proposed here:

(1) Study locations do not have a standardized format, requiring a significant amount of time dedicated to manually cleaning and extracting location information from publications.

(2) This mapping may not be useful for very small data sets. There must be significant temporal and geographic coverage to perform the historical-spatial analysis of the data.

From what has been seen so far, the methods used can be used at different spatial scales of research as long as there is a sufficient amount and coverage of data to undertake the analysis. The results of this research showed that there is no way to understand the statistical and spatial patterns of different locations in a continental dimension without considering the different historical and geographic factors that influence decisions in scientific activity. It is believed that the same happens at other spatial scales of analysis.

The proposed method allows the generation of maps that provide new insights about places with a particular focus of research in a given field of science. It is useful to evaluate the search spatial dynamics comparing maps in long time intervals, different search themes and different regions. It can also be used to detect new potential research sites.

CAPÍTULO 3 - ANÁLISE CIENCIOMÉTRICA E ESPACIAL DA PRODUÇÃO CIENTÍFICA BRASILEIRA SOBRE OS SOLOS NA ANTÁRTICA[4]

1. Introdução

O desenvolvimento da Ciência e da atividade científica pode ser analisado por meio da Cienciometria, ramo da Ciência da Informação entendido como o estudo dos aspectos quantitativos e qualitativos da atividade de pesquisa técnica e científica, da comunicação científica e da política científica. Os dados e informações estatísticas sobre a Ciência não são sua finalidade em si, mas são a base para se analisar a dimensão coletiva e o processo dinâmico da construção do conhecimento (CALLON et al., 1995).

Estudos cienciométricos são realizados para entender a evolução e indicar tendências emergentes bem como avaliar o desempenho e a influência de países, regiões, pesquisadores e instituições de pesquisa na ciência como um todo (ROEMER; BORCHARDT, 2015) ou em temas e campos específicos, como por exemplo, as mudanças climáticas (HAUNSCHILD; BORNMANN; MARX, 2016).

Dentre os diferentes métodos e estudos cienciométricos podem-se citar aqueles que utilizam informações geográficas em suas análises. Florescido nos últimos 20 anos, o campo de pesquisa conhecido como "cienciometria espacial" tem espacializado dados bibliométricos afim de analisar a distribuição geográfica de publicações científicas, autores, citações, etc. (FRENKEN; HARDEMAN; HOEKMAN, 2009) aplicando análises espaciais por meio de softwares de informação geográfica (BORNMANN; WALTMAN, 2011; XUEMEI et al., 2014) em diferentes escalas.

A conjugação das abordagens cienciométrica e espacial traz contribuições aos campos da Sociologia e da Geografia da Ciência. As possibilidades de investigação são diversas e importantes estudos foram produzidos, dentre eles, o clássico "*The Distribution of World Science*" de Frame, Narin e Carpenter (1977) sobre a distribuição de publicações e autores entre países e os de Ponds, *et al.* (2007), Bornmann *et al.* (2011) e Wang *et al.* (2011) que demonstraram vieses espaciais entre organizações, países e localidades de estudo, respectivamente.

Estudos como o de Kim e Jung (2016) e o de Chignell, *et al*, (2022) já revelaram diferentes aspectos espaciais da atividade científica no Continente Antártico a partir de redes

[4] Título em inglês: Scientiometric and spatial analysis of Brazilian scientific production on Antarctic soils.

de colaboração e áreas de pesquisa. Nesse contexto, este artigo se esforçou em realizar uma análise cienciométrica e espacial da produção científica brasileira sobre os solos da Antártica a partir de informações de coautoria, citação, temas de pesquisa e locais de amostragem a fim de compreender a estrutura social e teórica bem como a dinâmica espacial deste campo de estudo no Brasil nos últimos 25 anos.

2. Metodologia

Dados de citação, coautoria e localização geográfica foram extraídos de 85 publicações provenientes das bases de dados Scopus e Web of Science. Todas as publicações têm como autor ou coautor autores filiados a instituições brasileiras. Foram analisados aspectos de produtividade (publicação e citação), de redes de coautoria além de nuvem de palavras-chave.

Os dados são provenientes de estudos anteriores nos quais se estudou a produção científica global sobre os solos antárticos. As publicações foram classificadas de acordo com os assuntos de pesquisa tomando como referência a estrutura científica da Sociedade Brasileira de Ciência do Solo. Outras classes de assunto foram acrescentadas quando foi necessário. Foi conferido um ou mais assuntos para cada documento a depender do caso e foco da pesquisa, por exemplo, se o artigo é sobre aspectos bioquímicos do solo, será atribuído a ele os temas "Biologia do Solo" e "Química do Solo". Para a análise final, cada tema foi contabilizado individualmente.

Os dados de localização geográfica se referem aos locais de amostragem de solo ou pontos de monitoramento pedológico. Quando houveram coordenadas e/ou mapas nas publicações, todos os pontos registrados foram extraídos. Quando houve apenas a indicação textual da área, elemento fisiográfico ou região de estudo, apenas um ponto de indicação (colocado na área central da localidade) foi conferido à publicação. Desse modo, não foram conferidas coordenadas quando não houve identificação da localidade do estudo ou quando não foi possível acessar a publicação. Foram apenas consideradas as localizações ao sul dos 60º Sul[5].

Os pontos foram geoprocessados no software ArcGIS e gerados mapas de localização dos pontos. Foi analisado os padrões de distribuição espacial e temporal dos pontos. O comportamento temporal e espacial dos temas de pesquisa e de coautoria também foi analisado. Além disso também buscou-se identificar potenciais novas localidades de pesquisa.

[5] Área de jurisdição do Tratado da Antártica (1959).

3. Resultados e Discussão

3.1 Aspectos cienciométricos

As publicações cobrem um período total de 24 anos, de 1998 a 2021. A comunidade científica analisada é composta por 287 autores com uma média de 3,54 publicações/ano. Com um impacto médio na literatura de 28,58 citações por documento, distribuídos em 38 periódicos e envolvendo em média 3 autores por publicação, a pesquisa brasileira figura entre as principais dentre as que possuem os solos antárticos como objeto de estudo (Tabela 20).

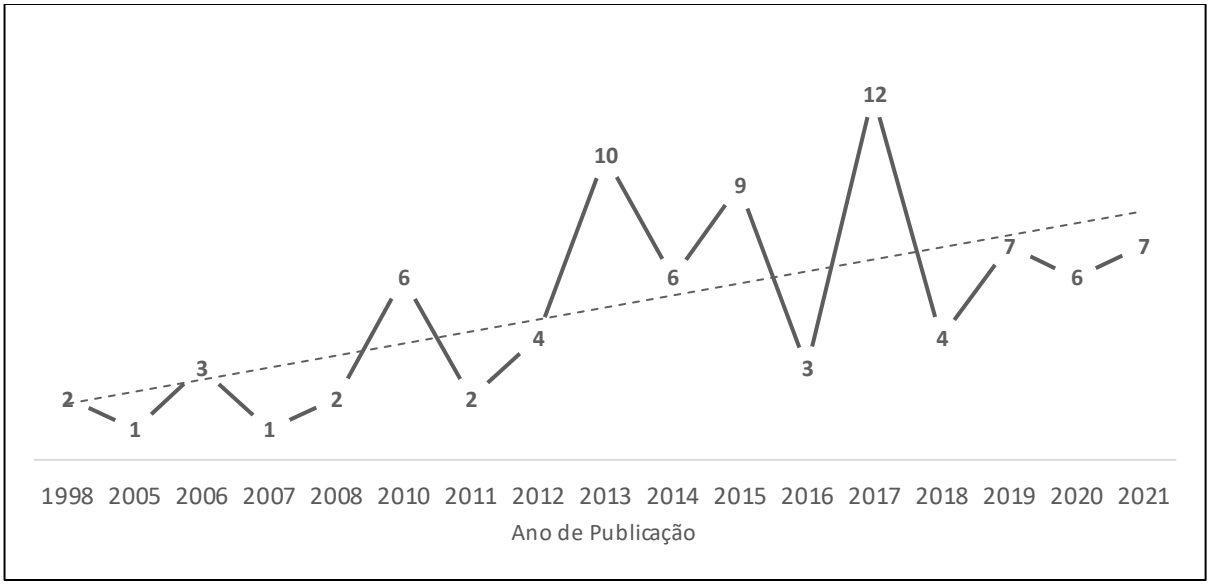
Tabela 20 - Informações gerais das publicações

Descrição	Resultados
Informações Gerais	
Total de Documentos	85
Média de publicações por ano	3,54
Média de citações por documento	28,58
Ano médio de publicação	
Tipos de Documento	2
Artigo de Periódico	81
Capítulo de Livro	4
Autores	287
Média de documentos por autor	0,29
Média de autores por documento	3,37
Países parceiros	22
Instituições	89
Idioma	7
Inglês	84
Português	1
Periódicos	37
Média de citações por periódico	58,91
Média de documentos por periódico	2,27

Fonte: Elaborado pelo autor.

Identificou-se um padrão de "zigue-zague" na distribuição dos registros ao longo do tempo, o que pode ser relacionado ao ritmo da atividade científica onde há um ano de menor produtividade (trabalho de campo/escrita da pesquisa) seguido por outro de maior (publicação) (Figura 18). A partir de 2013 houve um aumento do número médio de publicações e a linha de tendência dos dados demonstra que houve um crescimento geral da produtividade de publicações ao longo do tempo.

Figura 18 - Número de publicações ao longo do tempo



Fonte: Elaborado pelo autor.

A coleta e análise de dados revela a natureza geopolítica da ciência antártica. O compromisso do Brasil com o desenvolvimento científico, conforme determina o Tratado da Antártica, impulsionou-o à posição atual de um dos países líderes em termos de produtividade e impacto na literatura científica. Este tratado promoveu um fluxo contínuo de recursos, apoio logístico e conhecimento. Ele serve como uma prova dos resultados notáveis que podem ser alcançados por meio de investimentos de longo prazo em pesquisa científica e exploração.

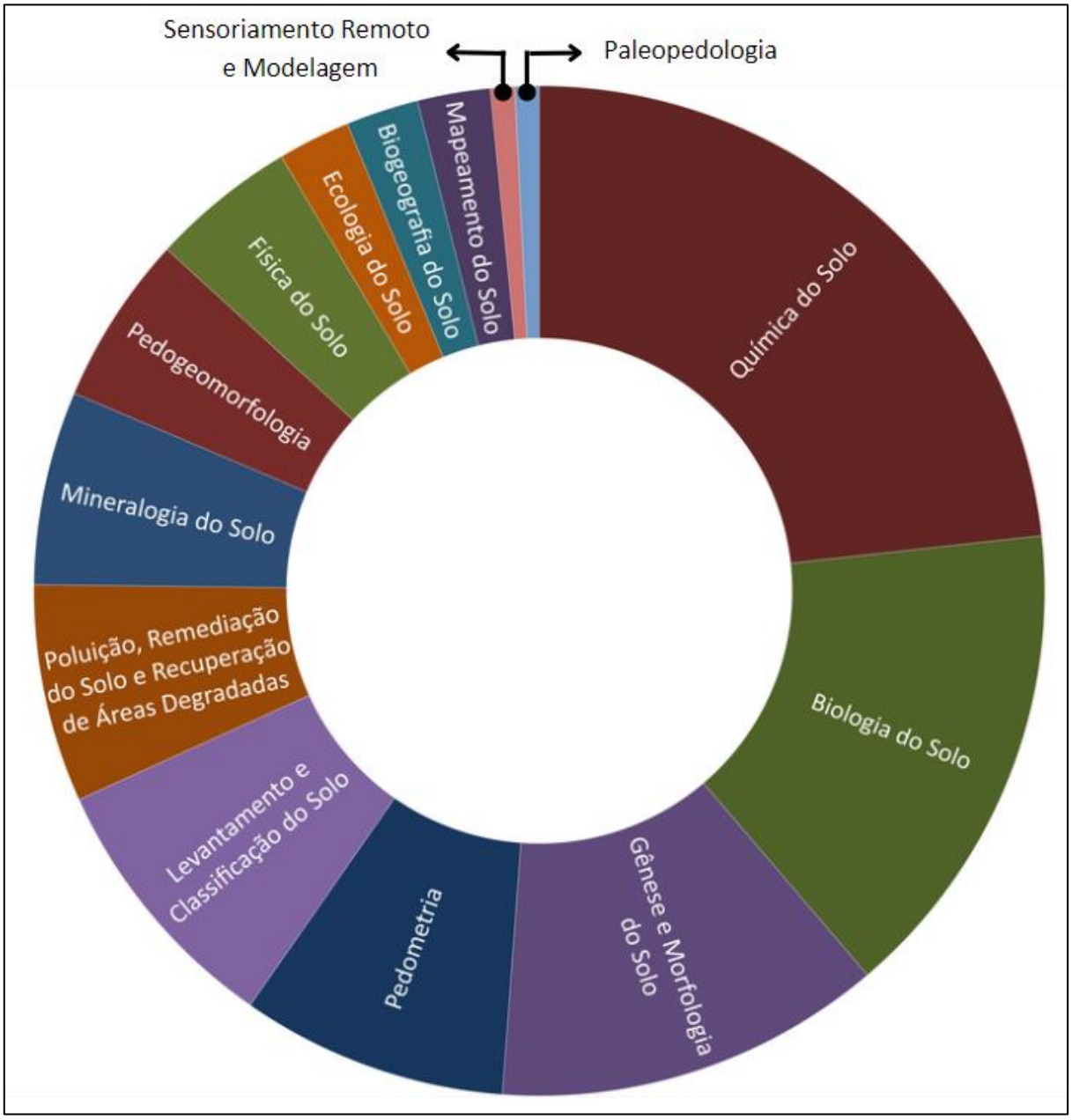
Os primeiros estudos de solos da Antártica realizados por pesquisadores brasileiros foram o de Kuzmann (1998), que avaliou a mineralogia de solos da Ilha Rei George, e o de Godoy et al. (1998) que analisou as concentrações de elementos radioativos em solos no Arquipélago das Shetlands do Sul. Em 2002 surge o embrião do futuro principal grupo de pesquisa sobre os solos antárticos no país, o projeto Criossolos Austrais, fomentado pelo professor Carlos Schaefer da Universidade Federal de Viçosa (UFV).

O projeto Criossolos Austrais foi a base para o surgimento do Núcleo Terrantar (NT), focado na pesquisa sobre o permafrost, criossolos e ecossistemas terrestres na Antártica. O grupo possui considerável produção e contribuições científicas no assunto, destacando-se como um dos principais no mundo envolvendo pesquisadores de todos os níveis de instrução e instituições de todo o país. O crescimento do número de publicações a partir da segunda metade dos anos 2000 no Brasil está diretamente relacionado ao trabalho deste grupo de pesquisa.

O incremento na quantidade de publicações também ocorreu em função do avanço nos estudos na área da biologia do solo com ênfase na ecologia, biogeografia e biologia molecular. De modo geral as publicações brasileiras acompanharam a tendência da pesquisa internacional,

onde há a dominância das áreas de Biologia, Geociência e Relações humano-solo nos estudos dos solos da Antártica (Figura 19).

Figura 19 - Proporção dos assuntos de pesquisa das publicações



Fonte: Elaborado pelo autor.

Conhecer os aspectos biológicos e químicos do solo é basilar para empreender quaisquer outras análises sobre o perfil, ecossistema ou paisagem em estudo estando, portanto, presente na maior parte das publicações. Os temas de Gênese e Morfologia (GMS), Pedometria e Levantamento e Classificação (LCS) são predominantes na pesquisa pedológica antártica brasileira. Importantes publicações na área se destacam como MICHEL et al. (2006) e SIMAS et al. (2007, 2008) que estudaram a formação dos criossolos, principalmente ornitogênicos na

Antártica Marítima e MORAES et al. (2017) que realizou um mapeamento das propriedades do solo na Península Keller.

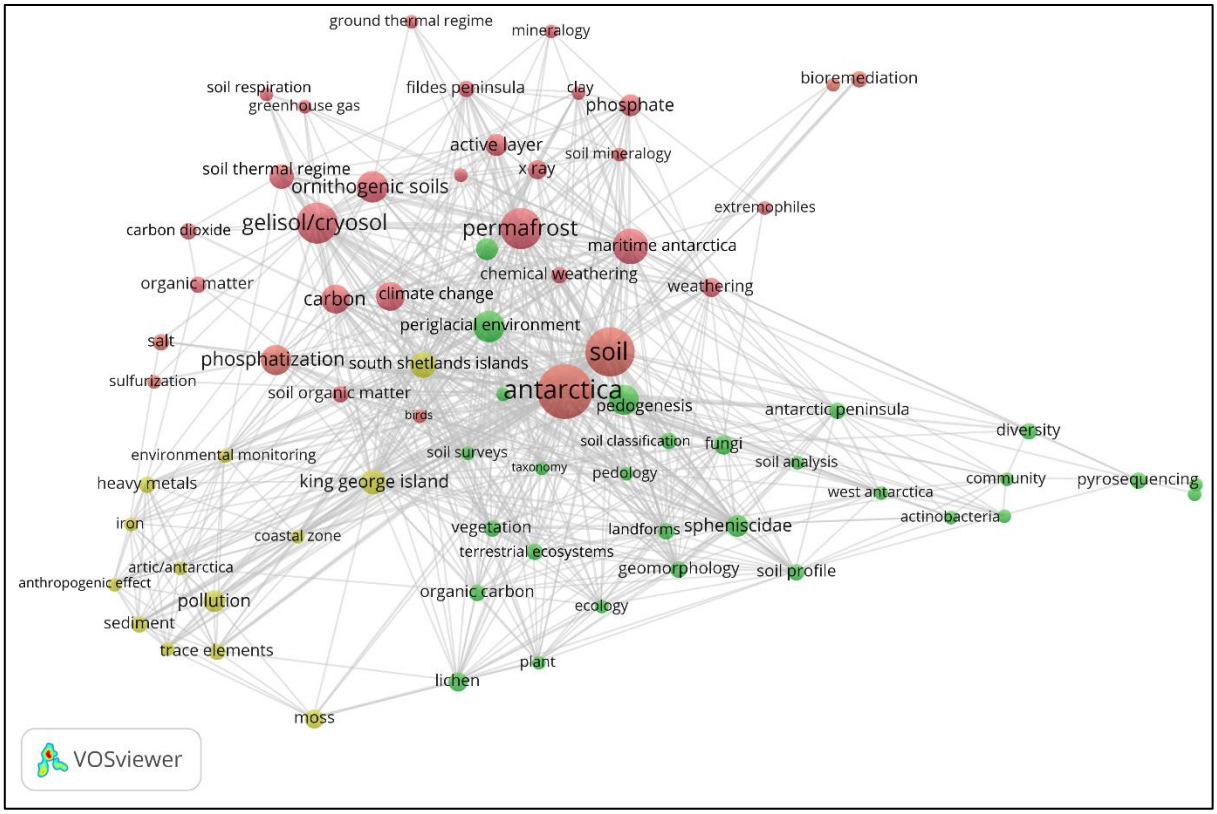
De uma forma ou de outra, a maior parte dos trabalhos também se atentaram para os efeitos das mudanças climáticas na Antártica através tanto do monitoramento térmico e hídrico da camada ativa dos solos e do *permafrost* (MICHEL et al., 2012; SCHAEFER et al., 2017a) quanto dos padrões espaciais da colonização das áreas livres de gelo pelas plantas, líquens e invertebrados (ALMEIDA et al., 2014).

A ciência do solo combina procedimentos clássicos com instrumentos mais modernos, enfatizando a importância de integrar ambas as abordagens para obter uma compreensão abrangente dos conceitos básicos do solo e suas aplicações práticas. A combinação de métodos tradicionais, como observações de campo e amostragem de solo, com tecnologias avançadas como biologia molecular e sensoriamento remoto, permite aos pesquisadores explorar as intrincadas complexidades dos ecossistemas terrestres. Ao combinar sinergicamente essas abordagens, os cientistas podem descobrir informações valiosas sobre a composição do solo, comunidades microbianas, dinâmica de nutrientes e seus impactos em processos ecológicos mais amplos.

A partir do mapa de visualização de palavras-chave (Figura 20) é possível observá-las de acordo com a frequência de ocorrência específica (tamanho do círculo) e conjunta (conexões entre as palavras), além da proximidade entre elas, formando diferentes *clusters*. Os três principais campos de pesquisa também se veem representados aqui nas cores verde, amarelo e vermelho e apresentam forte entrelaçamento.

A área das Geociências se destaca com termos como “permafrost”, “criossolo/gelissolo” indicando foco em temas de monitoramento do permafrost, além de levantamento, classificação e gênese dos solos, temas mais próximos da pedologia clássica. A perspectiva ecossistêmica da biologia do solo relaciona a influência da biota nos processos pedológicos, com especial atenção às aves e plantas. Palavras como “poluição”, “efeitos antropogênicos” e “biorremediação” mostra um ramo de pesquisa que conecta as anteriores sob uma perspectiva ambiental atrelada aos impactos humanos. Os termos referentes à Antártica Marítima como “peninsula fildes” e “king george island” e se devem ao fato de serem o local onde ocorreram a maioria dos estudos brasileiros sobre os solos antárticos.

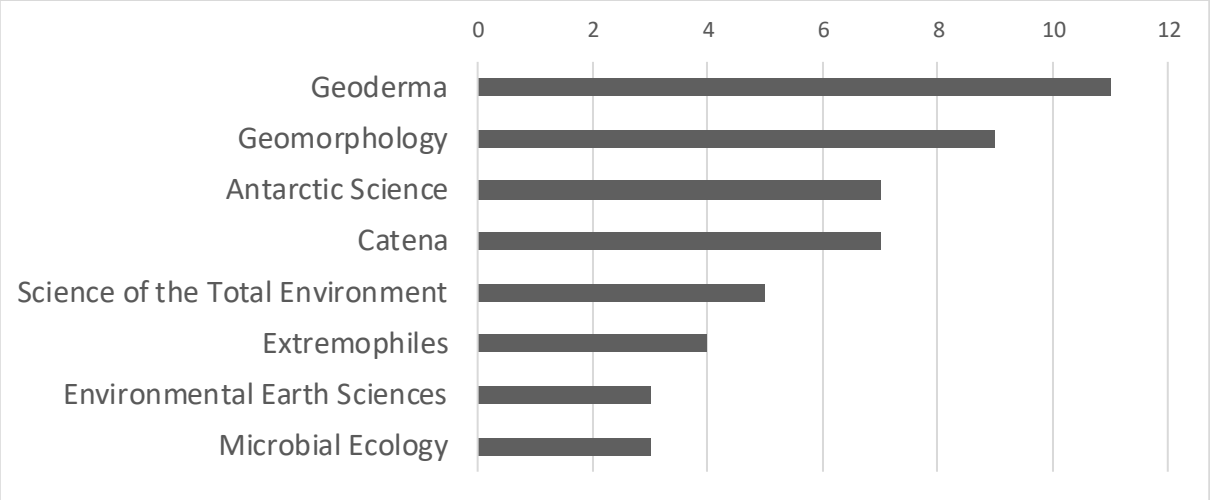
Figura 20 - Mapa de visualização de palavras-chave



Fonte: Elaborado pelo autor.

Geoderma (fator de impacto - FI de 7,422) e Geomorphology (FI de 4,406) despontaram como os principais periódicos em termos de publicação de artigos relacionados à pesquisa sobre os solos antárticos, com 11 e 9 artigos, respectivamente (Figura 21). Essas revistas são conhecidas por seu foco na ciência do solo e geomorfologia, que se alinha com os campos de geociências predominantes na pesquisa do solo da Antártica. No entanto, é importante notar que outros periódicos, como Antarctic Science (FI de 2.104) e Catena (FI de 6.367), também fizeram contribuições notáveis para o campo. Esses periódicos demonstram a natureza interdisciplinar da pesquisa do solo antártico, com uma representação das ciências biológicas e ambientais, mostrando a abordagem holística adotada no estudo dos ecossistemas únicos do solo antártico. A diversidade de periódicos destaca a colaboração entre pesquisadores de várias disciplinas científicas que trabalham juntos para aprimorar nossa compreensão da paisagem antártica.

Figura 21 - Principais periódicos de publicação das pesquisas brasileiras

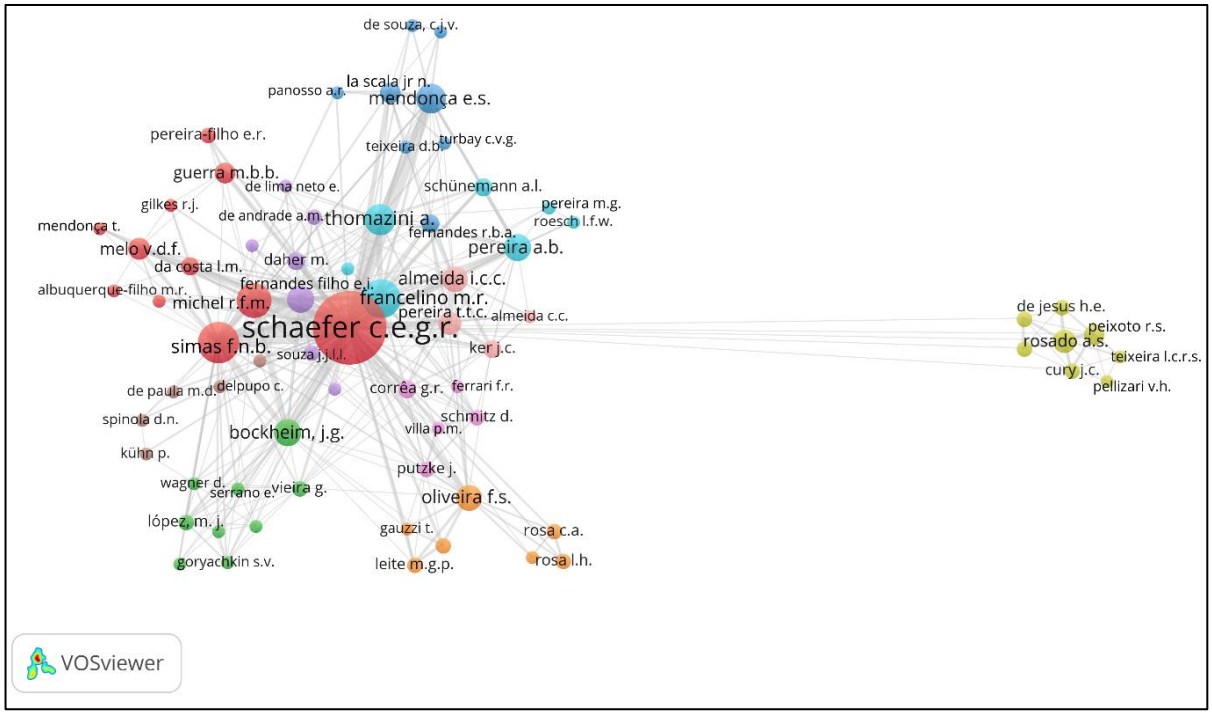


Fonte: Elaborado pelo autor.

A partir das redes de coautoria de autores e instituições identificou-se os principais grupos de pesquisa. O Núcleo Terrantar, sediado na Universidade Federal de Viçosa (UFV), destaca-se como o principal grupo de pesquisadores brasileiros a estudar os solos antárticos. Outro grupo de trabalho de destaque é o MycoAntar, da UFMG, sob coordenação do Prof. Luiz Rosa (ROSA, 2019). Esse Grupo se concentrou nos estudos relacionados à microbiologia antártica com destaque para os grupos de fungos. Não apenas analisaram a riqueza de diversidade de espécies, mas também em bioprospecção (GODINHO et al., 2015) e seu uso potencial na biorremediação e auxiliar na mitigação dos impactos antrópicos no ambiente antártico (SAMPAIO et al., 2017). Igualmente merecem atenção os trabalhos desenvolvidos pelo Núcleo de Estudos da Vegetação Antártica (NEVA), coordenador pelo Prof. Antonio Pereira (UniPampa) especializado na diversidade biológica terrestre (Figuras 22 e 23).

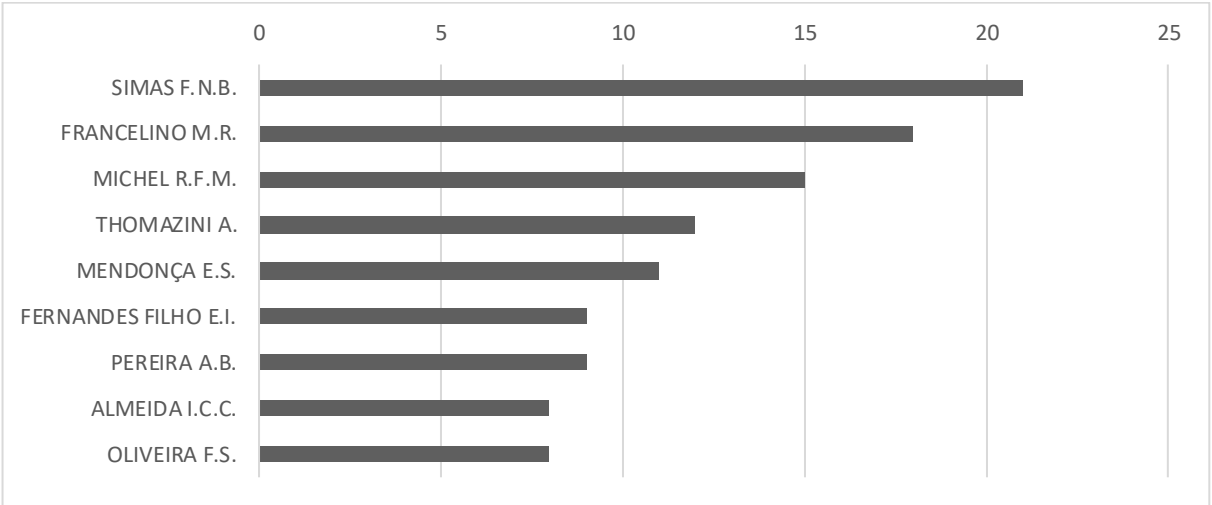
Tendo como principal autor o Prof. Carlos Schaefer, da UFV, os demais autores encontram-se orbitando-o e são altamente interconectados entre si. Dentre os autores destacam-se os Profs. Márcio Francelino (UFV), Felipe Simas (UFV), Elpídio Fernandes Filho (UFV) André Thomazini (UFSJ) e Roberto Michel (UESC), todos colaboradores do Núcleo Terrantar (Figura 6).

Figura 22 - Rede de autores das publicações brasileiras



Fonte: Elaborado pelo autor.

Figura 23 - Principais autores de acordo com número de publicações



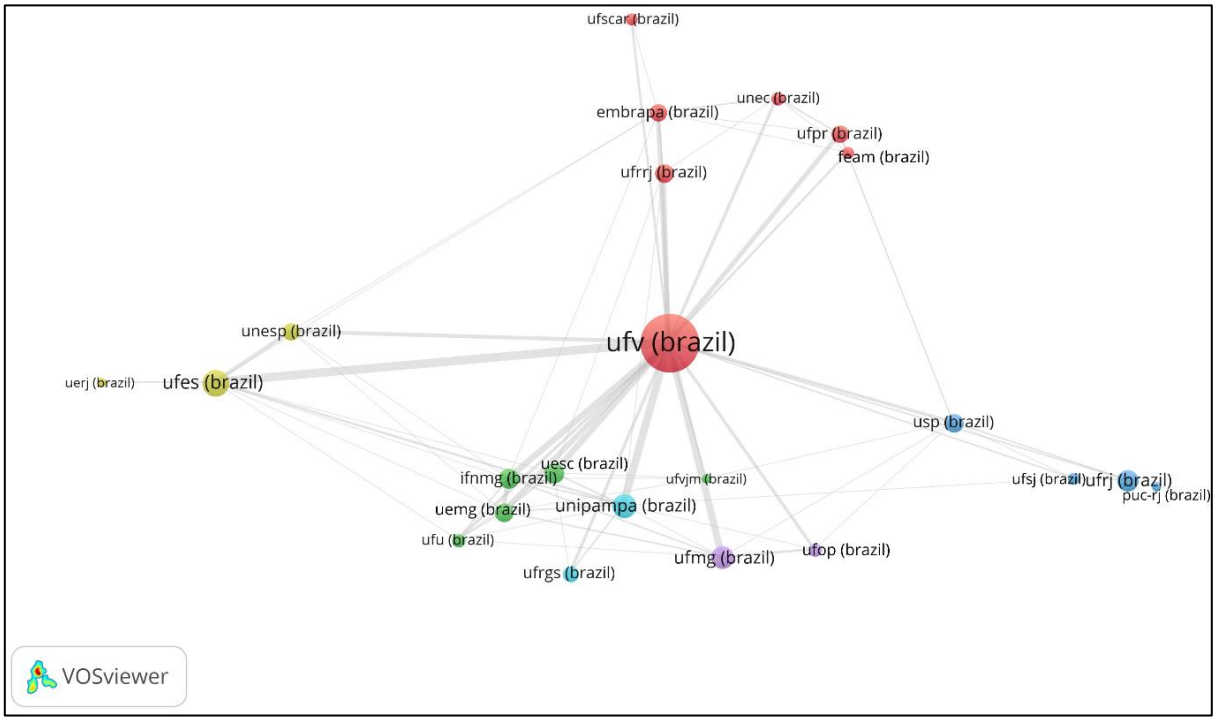
Fonte: Elaborado pelo autor.

Boa parte da produção de Thomazini (UFSJ) e Michel (UESC) foi contabilizada para a UFV, visto que se refere ao período em que cursaram suas pós-graduações nesta instituição. Essa situação colaborou para que a UFV concentrasse o maior número de autores e publicações (Figuras 24 e 25), tornando-se a instituição central na produção científica sobre os solos antárticos.

Os trabalhos da UFES e parte da UFMG também estão vinculados ao Terrantar, através do Prof. Eduardo de Sá Mendonça (UFES) e o Prof. Fábio Oliveira (UFMG). O grupo também agrega outras instituições mineiras, como a Universidade Federal de Uberlândia, através do

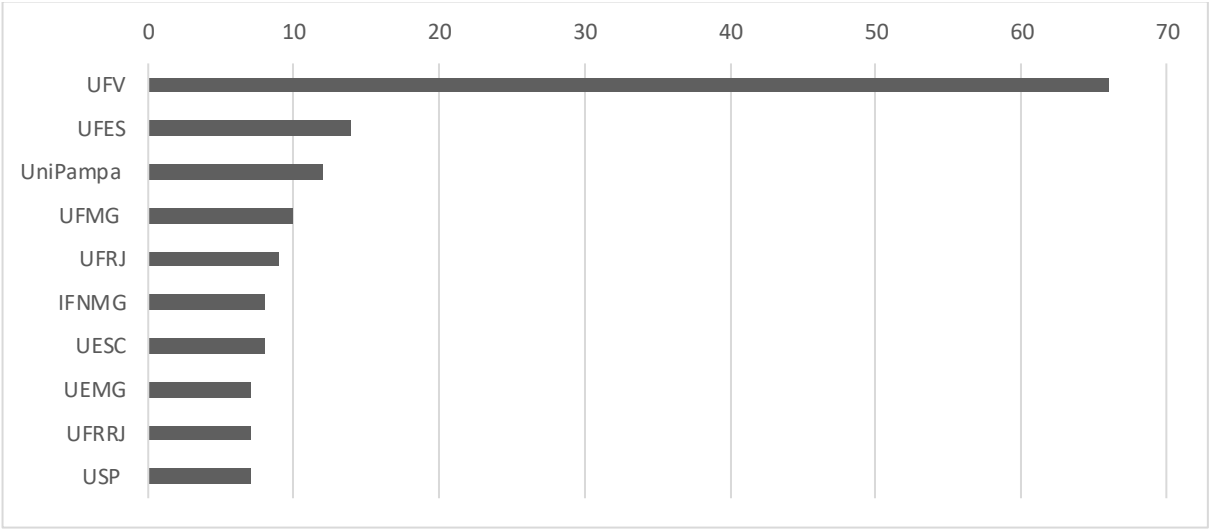
Prof. Guilherme Rezende (UFU), e com o Instituto Federal de Minas Gerais, através da Profa Caroline Delpupo (IFMG), além da Universidade Federal do Rio Grande do Sul (UFRGS).

Figura 24 - Rede de instituições das publicações brasileiras



Fonte: Elaborado pelo autor.

Figura 25 - Principais instituições de acordo com número de publicações

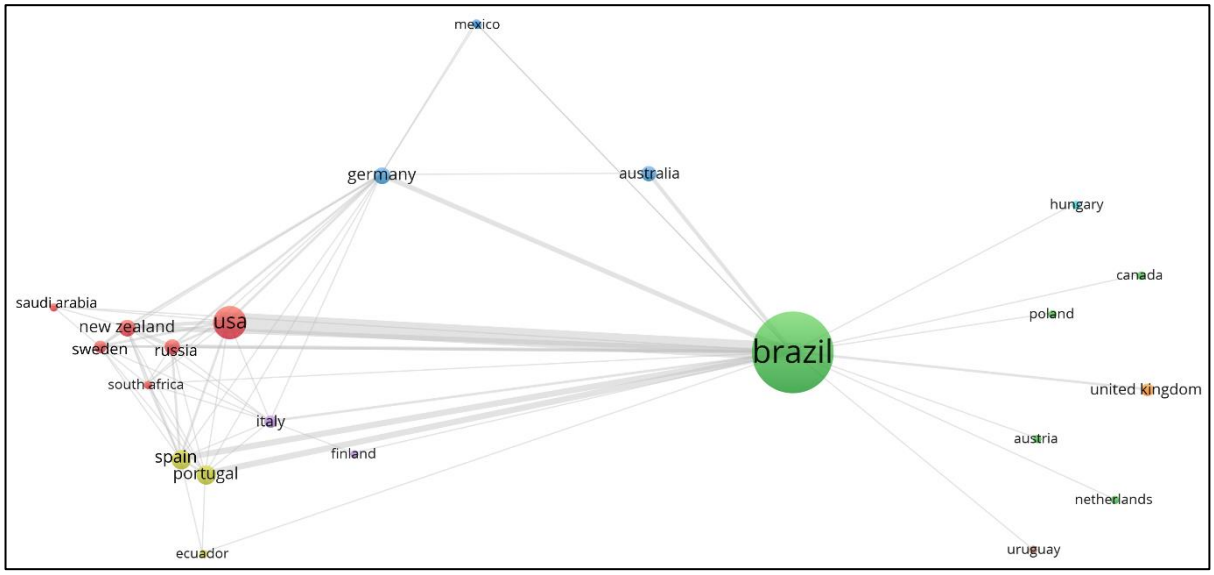


Fonte: Elaborado pelo autor.

Os pesquisadores brasileiros estabeleceram parcerias com instituições de mais de 20 países, com destaque para os Estados Unidos através de publicações com o Prof. James Bockheim (VIEIRA et al., 2010; MICHEL et al., 2014b; GJORUP et al., 2020). Outros importantes parceiros foram Portugal (VIEIRA et al., 2014) , Espanha (MICHEL et al., 2014a)

e Alemanha (MEIER et al., 2019), países também relevantes na pesquisa sobre os solos antárticos (Figura 26).

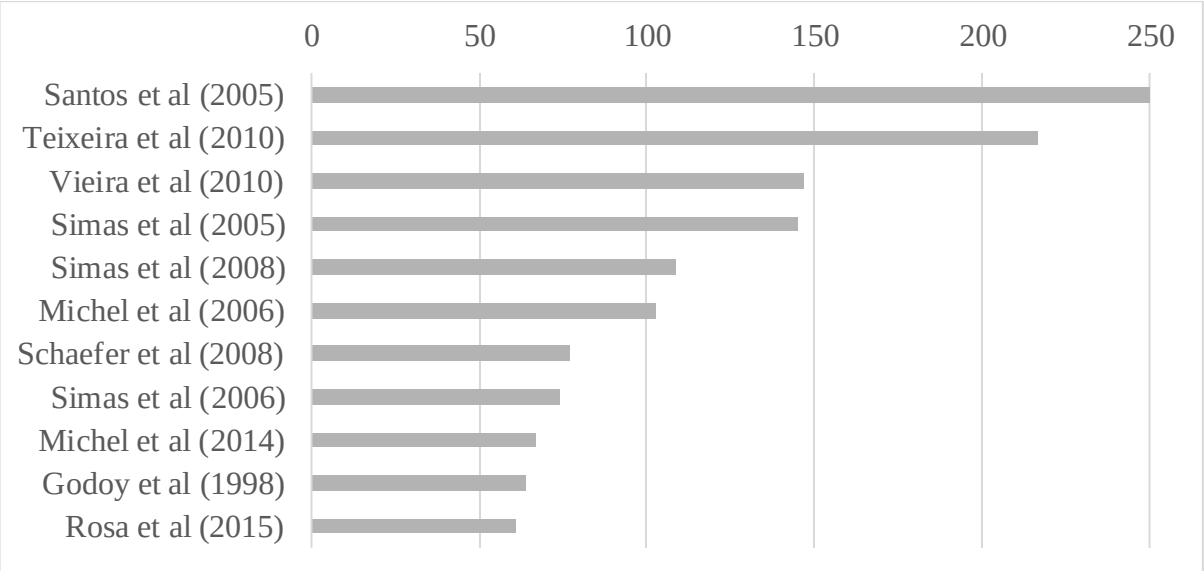
Figura 26 - Rede de países das publicações brasileiras



Fonte: Elaborado pelo autor.

A quantidade de citações de uma publicação é uma das medidas de impacto que um texto tem na literatura, e reflete o número de citações que uma publicação recebeu de outras publicações contidas nas bases de dados consultadas. Considerados os valores da base Scopus, as publicações mais citadas são apresentadas na Figura 27.

Figura 27 - Publicações de maior impacto de acordo com número de citações



Fonte: Elaborado pelo autor.

O artigo de maior impacto foi o de Santos *et al.*, (2005), que investigaram a química de diferentes solos na Península Keller, onde está localizada a estação científica brasileira. Em seguida aparece o artigo de Teixeira *et al.*, (2010), que estudaram o DNA da comunidade

microbiana associada às rizosferas de *Deschampsia antarctica* Desv (Poaceae) e *Colobanthus quitensis* (Kunth) Bart I (Caryophyllaceae), as duas únicas plantas vasculares nativas dos ecossistemas antárticos. As demais publicações são comentadas ao longo deste trabalho. O fato de as publicações mais citadas abordarem temas relacionados às geociências, biologia e monitoramento ambiental revela que os pesquisadores brasileiros publicam trabalhos de impacto nos principais campos de estudo sobre os solos antárticos sendo referência global no assunto.

3.2 Aspectos espaciais

Apenas em 6 (7,05%) publicações não foi possível obter informações de localização dos estudos, o que permitiu realizar as análises espaciais com grau de cobertura considerável dos dados. Mais da metade dos pontos catalogados são de publicações de autoria exclusivamente brasileira, revelando grau considerável de autonomia e expertise destes cientistas (Tabela 21).

Tabela 21 - Síntese dos dados de localização de publicações brasileiras

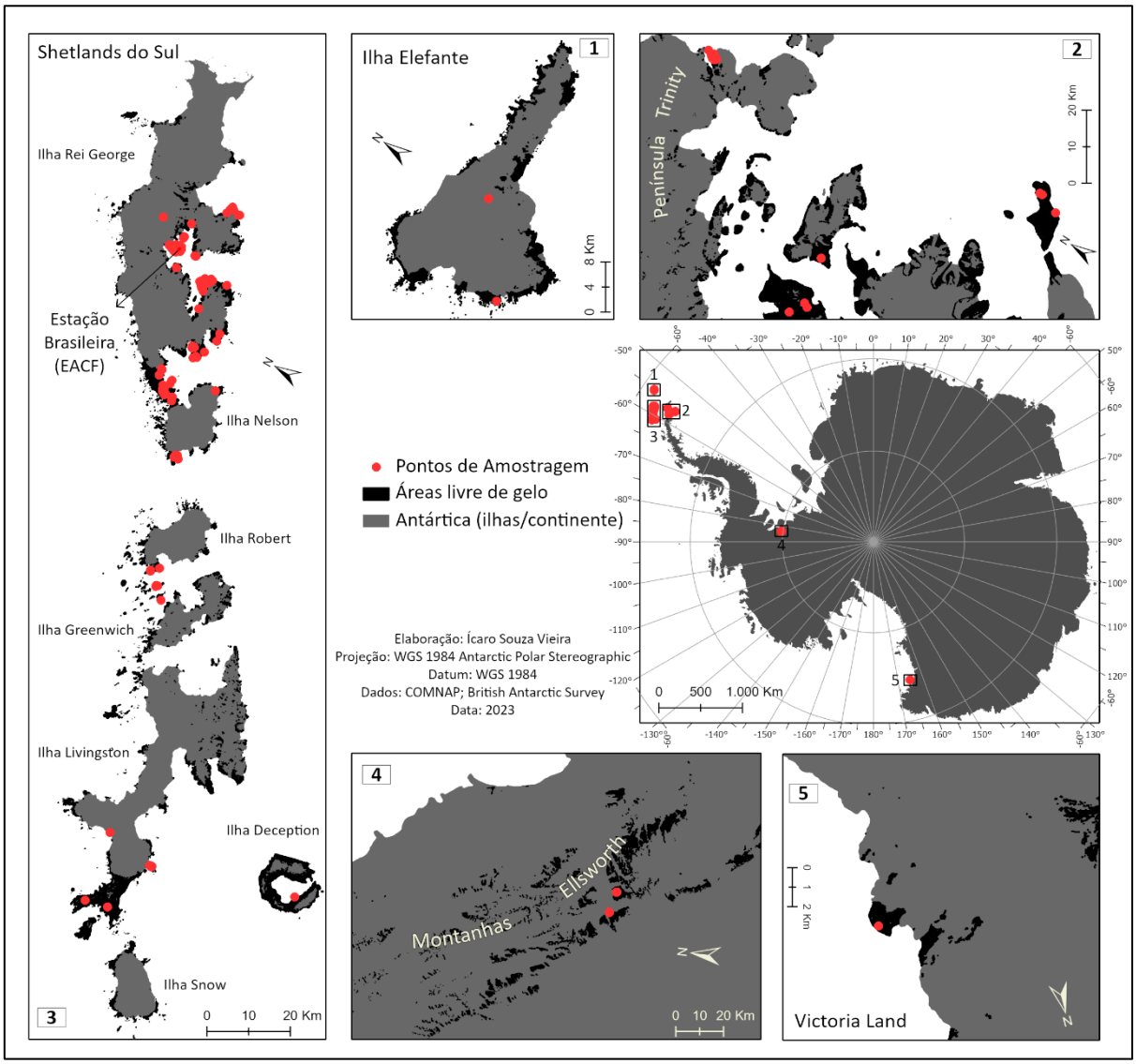
Pontos de Amostragem	
Documentos com Informação de Localização	79
Documentos sem Informação de Localização	6
Total de Pontos de Localização	301
Pontos exclusivos (% do total)	164 (54,48%)
Distância média dos pontos à estação de pesquisa	108,38 km
Infraestrutura Geral	
Estações de Pesquisa	1

Fonte: Elaborado pelo autor.

É importante pontuar que os 70 pontos de localização do artigo "*Thermal state of permafrost and active-layer monitoring in the antarctic: Advances during the international polar year 2007-2009*" não foram levados em consideração nas análises que se seguem, pois foi uma iniciativa global da *International Permafrost Association* e que poderiam enviesar o comportamento e a interpretação da pesquisa brasileira.

Foi identificada ampla abrangência espacial das pesquisas da comunidade científica brasileira, uma vez que não se limitaram apenas às áreas próximas à estação científica brasileira Comandante Ferraz - EACF (Península Keller, Ilha Rei George) (Figura 28). As pesquisas cobrem áreas da Baía do Almirantado, se estendem pelo arquipélago das Shetlands do Sul, Ilha Elefante áreas a leste da Península Trinity, além de localidades nas Montanhas Ellsworth e em Victoria Land nas Montanhas Transantárticas.

Figura 28 - Mapa dos pontos de localização das publicações brasileiras



Fonte: Elaborado pelo autor.

Ao agrupar os dados a partir do ano de publicação pelo método de quebras naturais (Tabela 22), foi possível identificar que a Química do Solo é o assunto ou subtema no qual os pesquisadores brasileiros possuem maior expertise dentre os demais (OLIVEIRA et al., 2013), mas também se destacam em pesquisas sobre gênese e morfologia do solo (MICHEL et al., 2006; SIMAS et al., 2007, 2008) e biologia do solo (SILVA et al., 2020).

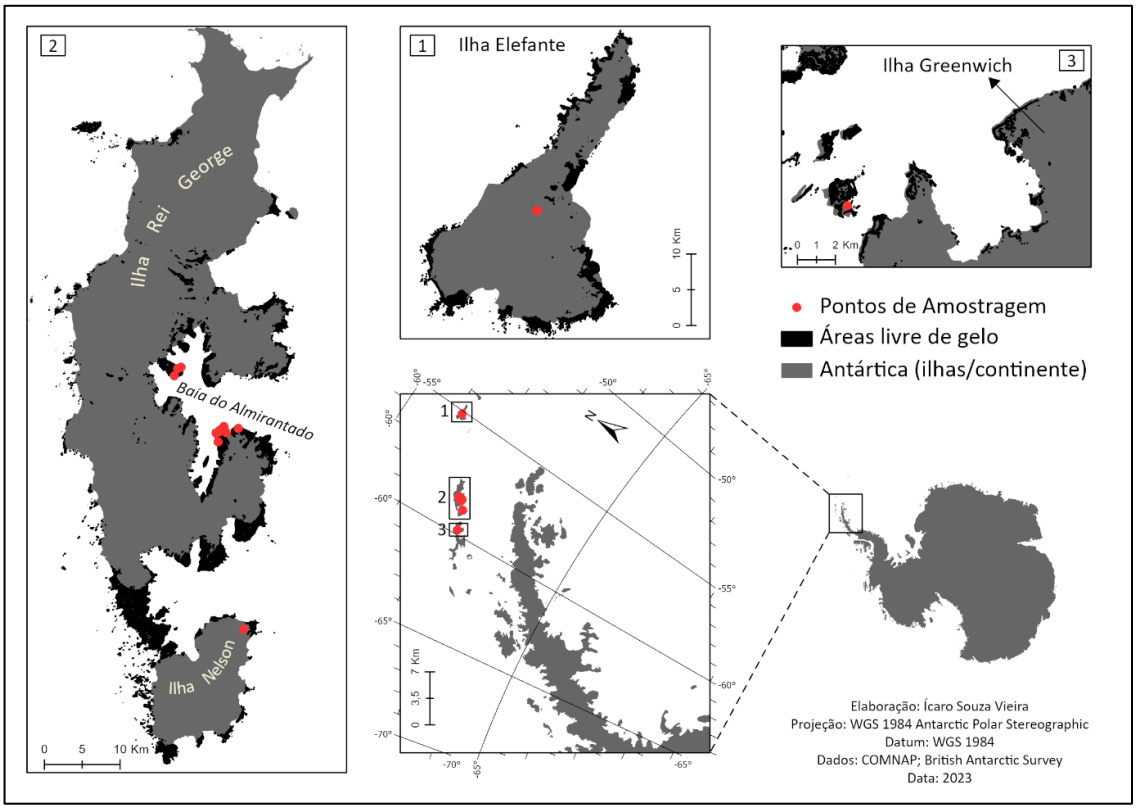
Tabela 22 - Dados das publicações por intervalos de tempo

Intervalo	Pub.	N. de pontos	Pub. exclusivas (% do período)	Assuntos Principais (frequência)
1998-2007	7	19	4 (57,14%)	Química do Solo (3); GMS (2); PRR (2)
2008-2011	10	32	9 (90%)	Química do Solo (6); Biologia do Solo (2); GMS (2)
2012-2015	28	54	15 (53,57%)	Química do Solo (9); Biologia do Solo (6); GMS (4); Física do Solo (3)
2016-2018	21	68	13 (61,9%)	Química do Solo (6); Pedometria (5); Biologia do Solo (3); GMS (3); PRR (3); LCS (3)
2019-2021	19	52	15 (78,94%)	Química do Solo (5); GMS (5); Biologia do Solo (5); LCS (4); Pedometria (3)

Fonte: Elaborado pelo autor.

Apesar da publicação mais antiga ter estudado amostras da Ilha Nelson, Ilha Elefante e ilhotas próximas a Ilha Greenwich (GODOY et al., 1998), nos primeiros 10 anos as pesquisas brasileiras concentram-se nas áreas livres de gelo da Baía do Almirantado (Figura 29) abordando principalmente a gênese, morfologia e mineralogia do solo (SIMAS et al., 2006), e também há estudos iniciais sobre o seu potencial de biorremediação (LUZ et al., 2006).

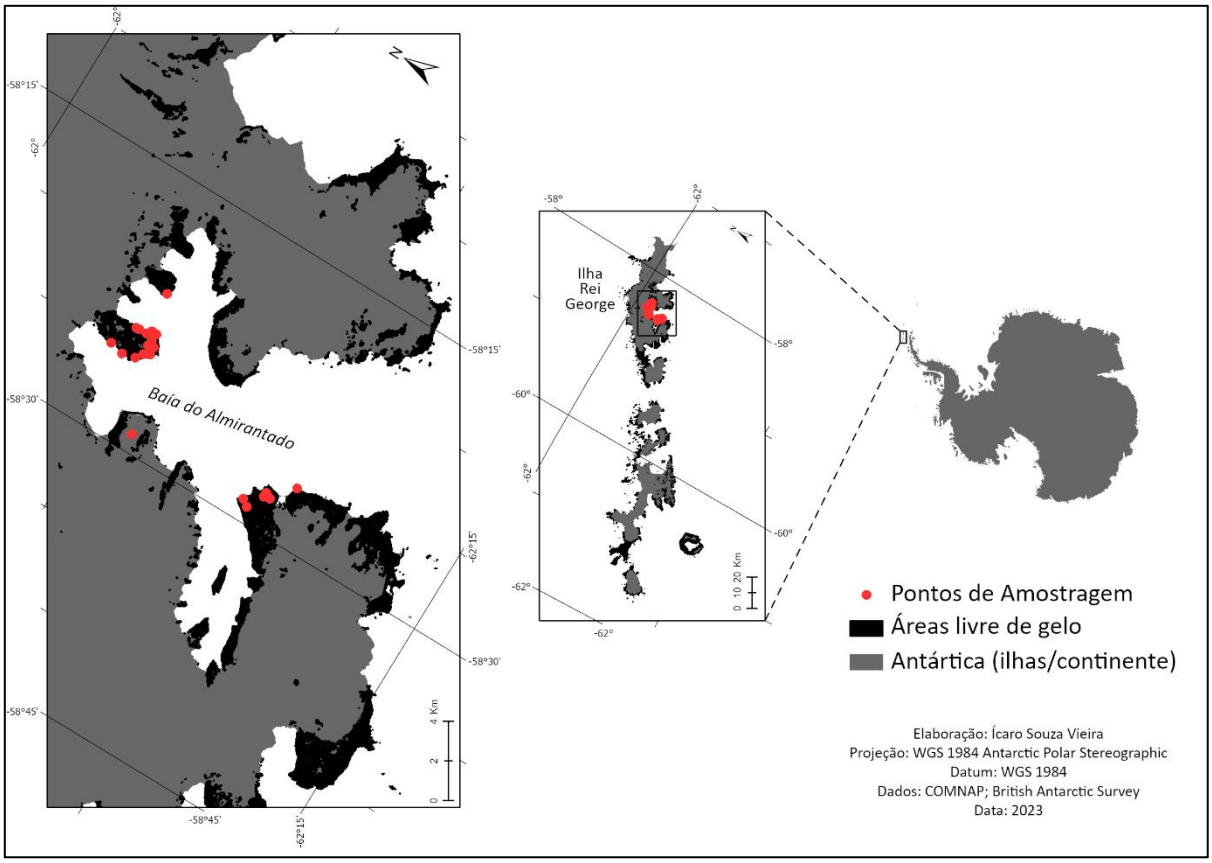
Figura 29 - Mapa dos pontos de localização no intervalo 1998-2007



Fonte: Elaborado pelo autor.

Durante o período de 2008 a 2011 as pesquisas continuaram concentradas na Baía do Almirantado, com 90% delas exclusivamente com pesquisadores filiados a instituições brasileiras (Figura 30). Investigaram principalmente a pedogênese sob abordagens micromorfológica (SCHAEFER et al., 2008) e pedogeomorfológica (FRANCELINO et al., 2011), além de estudos sobre o impacto das mudanças climáticas na mineralização de carbono (CARVALHO et al., 2010) e de comparação de métodos de análise química de criossolos (GUERRA et al., 2010).

Figura 30 - Mapa dos pontos de localização no intervalo 2008-2011

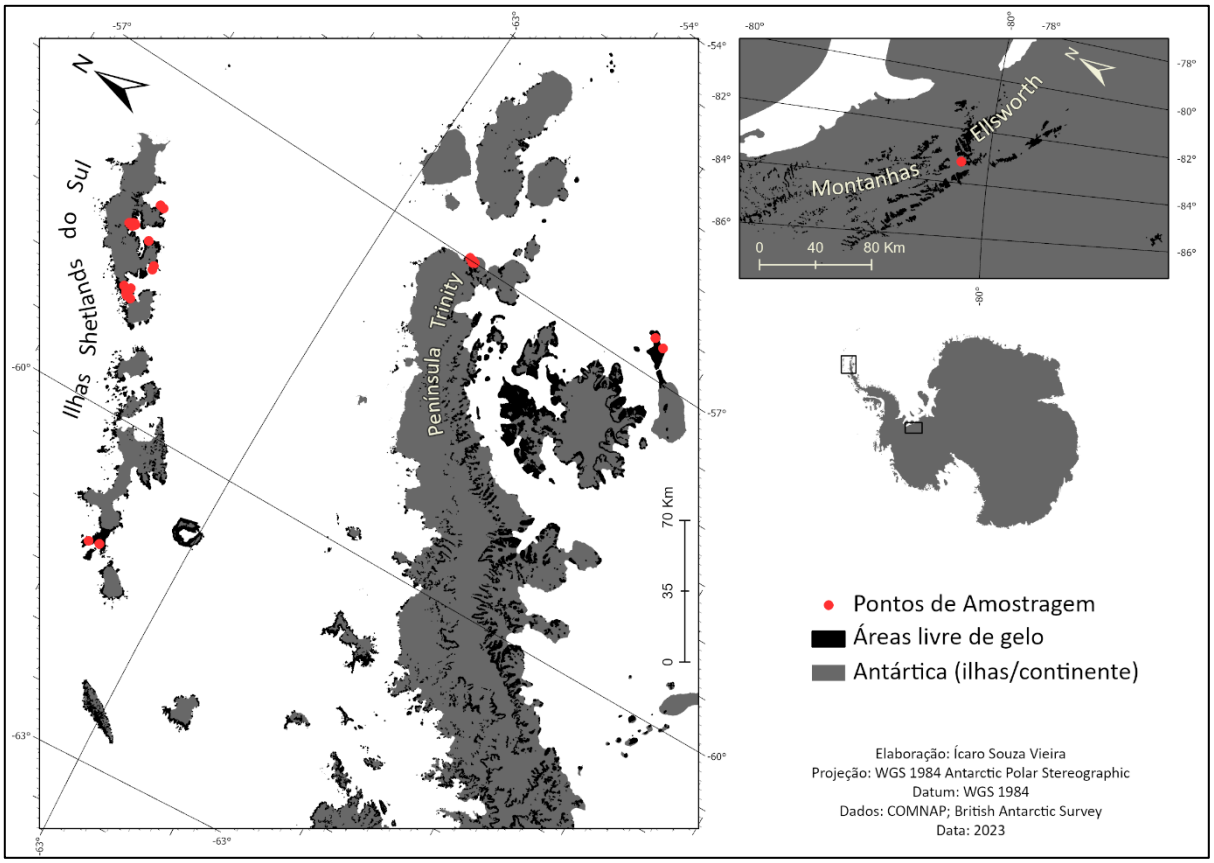


Fonte: Elaborado pelo autor.

De 2012 a 2015 (Figura 31) as pesquisas ainda ocorrem na Baía do Almirantado, destacando-se estudos de quantificação de emissão de gás carbônico de solos em áreas de retração de geleiras (THOMAZINI et al., 2014, 2015), além de caracterizar a diversidade bacteriana dos solos próximos à estação brasileira (ROESCH et al., 2012).

A criopedologia brasileira possui expertise em abordagens pedogeomorfológicas do estudo da paisagem. Neste intervalo de tempo específico, investigações relacionando os solos e o relevo expandiram-se para outras localidades da região, como a Península Fildes (MICHEL et al., 2014a), Ilha Livingston (MOURA et al., 2012), Hope Bay (Península Trinity) (PEREIRA et al., 2013) e Península Potter (POELKING et al., 2015). A realização de estudos em outras regiões da Antártica tem alto valor agregado no que diz respeito à autonomia e estratégia na produção de conhecimento científico. Nesse sentido, destaca-se o trabalho de bioprospecção de fungos em solos das Montanhas Ellsworth (GODINHO et al., 2015).

Figura 31 - Mapa dos pontos de localização no intervalo 2012-2015

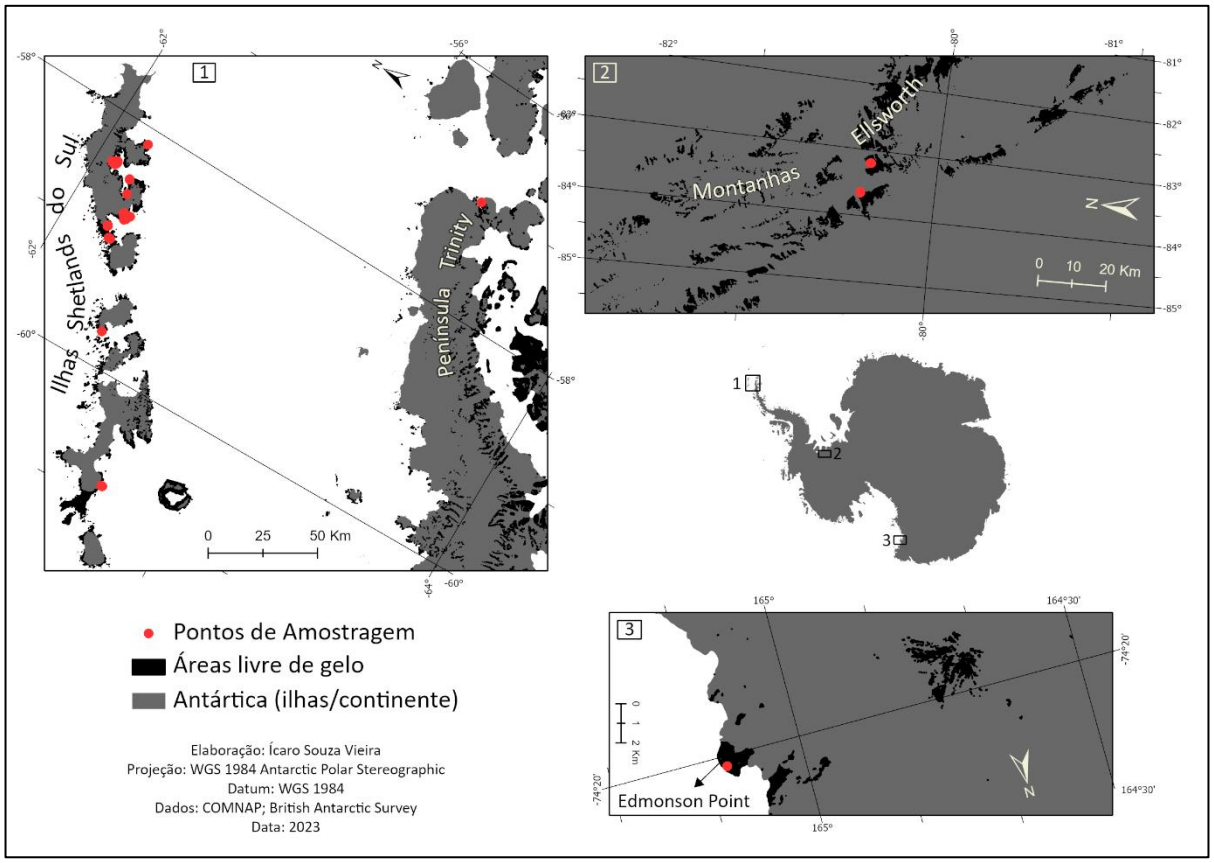


Fonte: Elaborado pelo autor.

De 2016 a 2018 (Figura 32) o padrão de distribuição dos pontos na Antártica Marítima é semelhante ao anterior. No entanto, em termos de enfoque temático, as pesquisas se concentraram no monitoramento da camada ativa na Ilha Rei George (THOMAZINI et al., 2016; CHAVES et al., 2017), e na compreensão da atividade biológica ne solos da Península Trinity (SCHAEFER et al., 2017b). Estudos que abarcaram os processos bio-geo-químicos da paisagem se destacam como o de Pires *et al.* (2017) sobre como o nitrogênio e o carbono orgânico influenciam na emissão de gás carbônico em solos às margens da Baía do Almirantado, e o de Thomazini *et al.* (2018) no qual estudaram a estrutura da variabilidade espacial dos atributos do solo no entorno da EACF.

Além disso, houveram trabalhos que estudaram os solos nos vales das Montanhas Ellsworth numa abordagem pedogeomorfológica (DELPUPO et al., 2017; SCHAEFER et al., 2017a) e a ecologia da camada ativa em Edmonson Point, nas Montanhas Transantárticas numa parceria com pesquisadores italianos (PAPALE et al., 2018).

Figura 32 - Mapa dos pontos de localização no intervalo 2016-2018

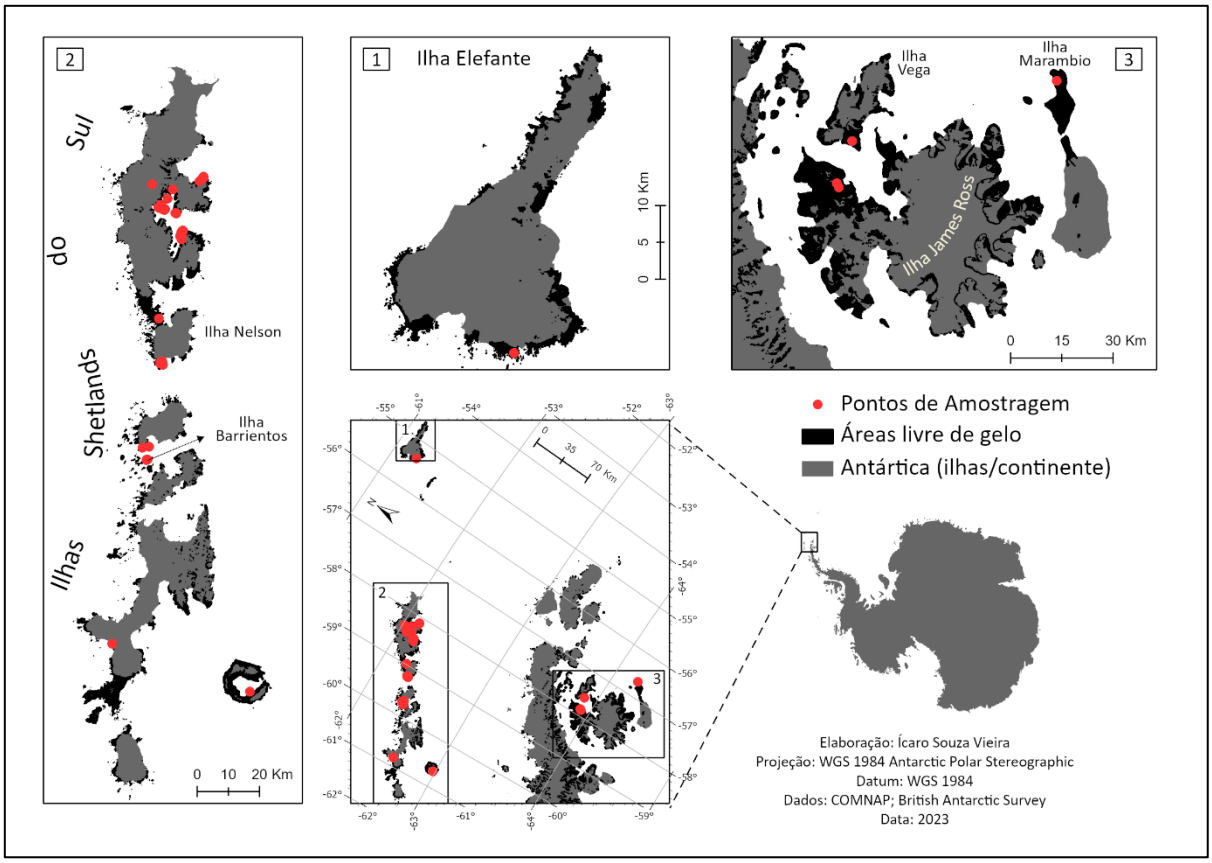


Fonte: Elaborado pelo autor.

No período mais recente, de 2019 a 2021 (Figura 33), houve um enfoque numa abordagem mais ecológica do solo sob a perspectiva ecossistêmica a partir dos "pedoambientes" (SCHMITZ et al., 2020a) e das "soilscapes" (RODRIGUES et al., 2021) na Ilha Nelson e suas relações com a vegetação na Ilha Elefante (SCHMITZ et al., 2020b). Neste mesmo paradigma, também se desenvolvem estudos pedobiogeográficos da Baía do Almirantado (RAMOS et al., 2019; PORTO et al., 2020) e de diferentes ilhas das Shetlands do Sul (SILVA et al., 2020).

As pesquisas de levantamento, classificação e formação de solos sob a perspectiva da dinâmica da paisagem é uma das vertentes consolidadas da pedologia brasileira e que nos últimos anos produziram notáveis trabalhos realizados na Ilha Barrientos (DAHER et al., 2019a) e na porção ocidental da Antártica Marítima, em especial nas Ilhas James Ross (DAHER et al., 2019b; MEIER et al., 2019), Marambio (GJORUP et al., 2020) e Vega (SIQUEIRA et al., 2021).

Figura 33 - Mapa dos pontos de localização no intervalo 2019-2021



Fonte: Elaborado pelo autor.

O comportamento espaço-temporal das pesquisas indica que os cientistas brasileiros têm buscado expandir, ao longo do tempo, o alcance geográfico das investigações tanto dentro da região da Península Antártica quanto para outras regiões do continente, seja através de iniciativas próprias ou em parcerias com outros países. A distância média dos pontos até a estação brasileira foi em torno de 100 km, o que indica a Antártica Marítima como a região-foco das pesquisas brasileiras.

Abordagens holísticas que integram diferentes elementos da paisagem a fim de compreender sua dinâmica têm aparecido como uma forte tendência da pesquisa brasileira sobre os solos antárticos. Estudos relacionados à bioprospecção e biorremediação dos ecossistemas terrestres também surgem como um dos *hotspots* de investigação. Assim, é possível considerar que ainda há muitas localidades com potencial para futuras pesquisas e a consequente expansão do conhecimento brasileiro sobre a paisagem pedológica da Antártica Marítima.

4 Conclusões

Apesar de possíveis limitações dos métodos utilizados, esta pesquisa demonstrou consideráveis contribuições dos estudos brasileiros na compreensão dos solos e da paisagem da região antártica. Ao concentrar os estudos em dados de apenas um país, foi possível caracterizar o perfil da produção científica brasileira como produtiva, internacionalizada e de impacto na literatura sobre os solos antárticos. É uma conquista notória que demonstra a tenacidade destes cientistas a despeito das dificuldades de orçamento do Programa Antártico Brasileiro (GANDRA, 2013; ANDRADE et al., 2018).

Além disso, a abrangência espacial das pesquisas demonstrou um notável conhecimento produzido e acumulado do Brasil acerca da temática não só do ponto de vista puramente pedológico, mas também geológico, climático, biológico, antrópico e geográfico da Antártica Marítima e de outras regiões do continente. Tal conhecimento é crucial para entender não só o andamento das mudanças climáticas, seus efeitos na Antártica e sua influência no território brasileiro, mas também na geração de patentes biotecnológicas com enorme potencial de aplicação em áreas como agricultura, alimentícia, farmacêutica, etc.

As pesquisas também chamam a atenção para um dos principais desafios da ciência antártica brasileira: a logística. A acessibilidade às áreas de pesquisa desejadas continua sendo uma preocupação significativa. Para avançar, é fundamental contemplar a expansão da malha logística. Ao enfrentar essa questão, os cientistas brasileiros teriam maiores oportunidades de explorar novos locais de pesquisa, coletar dados cruciais e aprimorar ainda mais suas contribuições para a compreensão dos ambientes antárticos e suas conexões multiescalares.

O principal grupo de pesquisa sobre os solos antárticos do mundo (Núcleo Terrantar) é sediado no Brasil e possui importante contribuições nas áreas de gênese, morfologia e classificação dos solos, pedogeomorfologia, bio-geo-química e pedometria. Outros grupos contribuem nas áreas da bioprospecção e biorremediação. Esses cientistas têm o desafio de fortalecer a pesquisa em tais áreas cuja relevância é crescente no contexto científico internacional atual e futuro.

A internacionalização da atividade científica por meio de diferentes tipos de parcerias entre países traz vantagens para a construção do conhecimento científico e é característica marcante da ciência antártica como um todo (BRASIL, 1975). Tendo isso vista, outro desafio que se coloca é buscar manter as atuais e estabelecer novas parcerias internacionais com cientistas de países como Rússia, China, Alemanha, Austrália e Coreia do Sul.

Ademais, os resultados desta pesquisa permitiram considerar os comportamentos estatístico e geográfico da atividade científica ao longo do tempo. Tal metodologia pode ser utilizada em diferentes escalas espaciais desde que haja quantidade e cobertura suficiente de

dados. Os mapas forneceram novos insights sobre localidades-foco de pesquisa e detecção de novos locais potenciais de pesquisa.

CONSIDERAÇÕES FINAIS

Os solos da Antártica assistiram o conhecimento a respeito de si desenvolver-se e se tornar vital na compreensão do comportamento dos ecossistemas terrestres e da paisagem num planeta em mudança. Atentando-se a isso, esta dissertação procurou fornecer uma análise cienciométrica do *status* e das tendências da pesquisa global e brasileira sobre os solos antárticos. Os principais acadêmicos, países e instituições, temáticas e tópicos "aquecidos" da pesquisa foram identificados e discutidos. Este estudo permitirá que os profissionais e novos pesquisadores conheçam os principais aspectos do campo a fim de aprimorar sua atividade e orientar suas decisões de pesquisa.

Fazendo uso de informações de coautoria, co-ocorrência de palavras, citação e temas de pesquisa foi possível observar que a comunidade científica envolvida no assunto se expandiu ao longo do tempo bem como a sua internacionalização com cada vez mais instituições de todo mundo se interessando pelos solos antárticos. Os países que se destacaram em termos de contribuição ao campo foram os EUA, Nova Zelândia, Brasil, Espanha e Rússia.

As temáticas ligadas à biologia do solo, geociências e relações humano-ambiente despontam como os as áreas de pesquisa concentradoras da criopedologia antártica. Acredita-se que o caráter científico-ambiental do Sistema do Tratado da Antártica influencia a atividade científica atraindo os pesquisadores para temas como poluição e remediação do solo, monitoramento dos regimes térmico e hídrico do solo, entre outros.

Ademais, esta pesquisa se esforçou em produzir um mapeamento e a análise espacial das pesquisas no assunto a partir dos locais de amostragem, pesquisadores (país de filiação) e temáticas de pesquisa. Dessa forma foi possível analisar a atividade científica do ponto de vista geográfico ao longo do tempo através de softwares de informação geográfica.

Os mapas gerados forneceram insights sobre a geografia do campo científico estudado. Foram úteis para analisar e entender a dinâmica espacial de pesquisa comparando mapas em intervalo de tempo longos, diferentes temáticas de pesquisa e diferentes regiões. Além disso identificou o potencial dos resultados serem utilizados para a detecção de novos locais potenciais de pesquisa.

Ao concentrar os estudos em dados de apenas um país (Brasil) no último capítulo, foi possível aprofundar a análise e caracterizar o perfil da produção científica brasileira como produtiva, internacionalizada e de impacto na literatura sobre os solos antárticos. Além disso, a abrangência espacial das pesquisas demonstrou um notável conhecimento produzido e acumulado do Brasil acerca da temática não só do ponto de vista puramente pedológico, mas

também geológico, climático, biológico, antrópico e geográfico da Antártica Marítima e de outras regiões do continente.

O principal grupo de pesquisa sobre os solos antárticos do mundo (Núcleo Terrantar) é sediado no Brasil e possui importante contribuições nas áreas de gênese, morfologia e classificação dos solos, pedogeomorfologia, bio-geo-química e pedometria. É importante destacar que o grupo possui um dos maiores bancos de solos daquela região, além de implementar uma das maiores redes de monitoramento do permafrost e da camada ativa em funcionamento, com 29 sítios distribuídos em diferentes locais da Antártica.

Considerando os resultados alcançados e discussões levantadas pela presente dissertação, defende-se que a inclusão do aspecto temporal em conjunto com o espacial potencializa a compreensão da atividade científica em estudos de natureza cienciométrica. Além de trazer novas percepções para o público alvo (cientistas e gestores), fortalece a noção multifacetada da atividade científica bem como o senso comunitário que a Ciência, em especial as geociências, requer.

Em termos de sugestões e encaminhamentos futuros identificou-se que novas análises podem ser realizadas a partir do banco de dados e mapas construídos neste trabalho. Distribuição geográfica pormenorizada de temáticas de pesquisa, necessidades de enfoques específicos em determinadas localidades, compreensão das relações entre paisagem-cientista-pesquisa, entre outras abordagens são passíveis de execução e podem trazer resultados e percepções inovadoras sobre a atividade científica.

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