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Visibility of the CryoSat mission in the scientific and technical literature: A bibliometric perspective

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Abstract

CryoSat is the first Earth observation mission launched by ESA with the purpose of observing the Earth's polar ice masses. Six years after the launching of the CryoSat-2 satellite, its outcomes have surpassed the objectives initially planned, and the mission has provided additional insights on aspects like sea level measurement. This paper makes an analysis of the visibility of the CryoSat mission in the scientific and technical literature. The analysis covers two aspects: (a) the quantitative description of the literature generated as a result of the mission's engineering and exploitation, and (b) the influence of this literature on the generation of additional scientific and technical knowledge. Although the generation of explicit, formal knowledge disseminated through journals, conferences and repositories is just one of the multiple benefits of space missions, the quantification of these outputs is relevant to assess the visibility of the mission in the scientific literature.

Keywords: CryoSat; Earth observation missions; Scientometric analysis; Bibliometrics; Collaboration in space research

1. Introduction

CryoSat is the first Earth observation mission launched by ESA with the purpose of observing the Earth's polar ice masses. After the failure in the launch of the original satellite in 2005, a second satellite – CryoSat-2 – was launched on April 2010 with the purpose of measuring the thickness of polar sea ice, monitoring its evolution and the consequences of the Earth global warming. Wingham (2005) summarized expected mission outcomes in two main objectives: building a detailed picture of natural variability in Arctic sea ice and observing the thinning rate of the ice sheets of Antarctica and Greenland.

Today, six years after its launching, CryoSat outcomes have surpassed those initially planned, and the mission has provided additional insights on aspects like sea level measurement.[1] One component of the CryoSat's payload is the SIRAL (Synthetic Aperture Interferometric Radar Altimeter) radar altimeter, an evolution of previous radars optimized for the purpose of the mission, which enables measurements to be made in areas of complex surface topography and in mixed sea ice, open sea areas, and thus accurate data about sea levels to be obtained and variations in ice thickness to be detected (Ratier and Zobl, 2005).

The purpose of this paper is to provide a descriptive analysis of the visibility of the mission in the scientific literature. This research is part of a general initiative aimed to carry out: (a) a quantitative description of the literature generated as a result of the mission's engineering and

[1] "CryoSat sets new standard for measuring sea levels". Available at: http://m.esa.int/Our_Activities/Observing_the_Earth/CryoSat/CryoSat_sets_new_standard_for_measur ing_sea_levels [27/08/2016].

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exploitation, and (b) an assessment of the visibility of this literature and its use in the generation of additional knowledge. The study also identifies the channels used to disseminate the knowledge derived from the space missions' outputs. Although the benefits of space missions go beyond the generation of explicit, formal knowledge disseminated through scientific journals, proceedings and repositories, the analysis of these outputs allows the assessment of the visibility of the mission in the scientific community. Although not covered in this study, the previous objectives are related to another aspect quite relevant to get a deeper understanding of the development of space activities: analyzing the knowledge needed for the development of complex mission and the effectiveness in presenting the mission findings to the wider scientific community.

The study uses scientometric techniques and methods to describe the visibility of CryoSat in the scientific and technical literature. The term scientometrics – coined by Vassily V. Nalimov in the 1960s (Hood and Wilson, 2001) - studies the rules that govern the generation and transfer of knowledge in scientific and technical domains, and covers "all quantitative aspects of the science of science, communication in science, and science policy" (Wilson, 2001). Its origins go back to the second half of the last century, with the initial application of statistical techniques for the analysis of the bibliographic production. Today, scientometrics is widely applied to assess the productivity and impact of personal researchers, research institutions and countries; it has also become a recognized tool for measuring the productivity of our R&D investments and policies, analyzing and understanding scientific domains. In space research, bibliometric studies have focused on the analysis of journals' outputs (Xia et al., 1999; Aswathy and Pal, 2015), specific topics like GPS technology (Wang et al., 2013) or aerodynamics (Rezadad and Maghami, 2014) and the bibliographic production of industries and institutions (Martin and Beaudry, 2014; Taskn et al., 2015; Eito-Brun and Ledesma-Rodríguez, 2016).

This paper is structured as follows: Section 1 presents the study objectives and context; Section 2 describes the methodology applied to conduct the study and the list of proposed bibliometric indicators; Section 3 provides the results of the analysis, with different subsections for each set of indicators; Section 4 reports the conclusions.

2. Methodology

The methodology applied in this study follows the guidelines proposed by Eito-Brun and Ledesma-Rodríguez (2016), which are based on the GQM (Goal-Question-Metric) approach developed by Basili and Weiss (1984) for analyzing software engineering data in the NASA Goddard Space Flight Center. Steps in GQM may be summarized as follows: (a) goal identification, (b) generation of questions to define goals in a quantifiable way, (c) identify the measures needed to answer the previous questions, (d) develop data collection methods, (e) proceed to data collection and validation, and (f) final analysis.

The first step is the definition of the research objectives. In this analysis, research objectives included:

1. Obtaining knowledge on the visibility of the mission in the scientific literature.
2. Identifying the topics covered by the mission-related scientific literature.
3. Analyzing the visibility in subsequent research of the literature that is derived from, or related to the mission.
4. Analyzing collaboration patterns between authors at the personal and institutional level.
5. Analyzing information consumption patterns: the documents used to generate mission-related literature.

In this study, a distinction is done between *the visibility of the mission in the scientific literature* (first objective), and *the visibility of the literature directly focused on the mission in later research* (third objective). This distinction is done to avoid mixing in the dataset those documents that are directly derived from the mission planning, engineering and exploitation, with other documents that just contain references to documents in the previous set. To articulate this distinction, the term "*Mission-Related Core Literature*" (MRCL) is used to refer to those papers that make direct reference to the mission in their title, abstract or keywords. MRCL represents the direct, explicit visibility of the mission in scientific literature. Papers in the MRCL have also an influence on later research; this influence is observed on the documents that contain citations to MRCL papers.

Table 1 shows the list of objectives, their related questions, and the scientometrics indicators proposed to answers to them.

Once the study objectives, questions and indicators are defined, the next steps are the selection of data sources and data collection. The main sources for scientometrics studies are the Web of Science (WoS) platform (recently sold by *Thomson Reuters* to *Onex and Baring*[2]) and the Elsevier Scopus database. The selection process led to the decision of using Scopus as the main data source, due to the availability of analysis tools that support the extraction of some indicators, its wider coverage and detailed indexing policy.[3] In the case of the CryoSat related literature, Scopus returned 298 documents that contain the mission name in their title, abstract or keywords, and 891 documents containing the mission name in the full record (list

[2] http://thomsonreuters.com/en/press-releases/2016/July/thomson-reuters-announces-definitive-agreement-to-sell-its-intellectual-property-science-business.html. Last visited on: 20/08/2016.

[3] Scopus indexes over 21,000 peer-reviewed journals and 360 trade publications from more than 5000 publishers around the world. Conference proceedings are also widely covered, with 6.8 million papers from 83,000 events. Since 2004, this multidisciplinary database gives access to more than 57 million records dating back to 1823.

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Table 1
Research objectives, questions and indicators.

Objective	Question	Indicator
Visibility of the Mission	How many documents have been published that are related to, or derived from, the mission preparation and results? Note: This set of documents constitutes the CryoSat MRCL	VI-1. Number of documents related to the mission (those making reference to the mission in their titles, abstracts or keywords)
	Which journals and conference proceedings have published mission- related content?	VI-2. Ranking of journals and conferences where mission- related contributions have been published
	What is the evolution of the mission- related contributions in time?	VI-3. Evolution in time of the number of published documents
	Who are the authors and entities writing documents related to the mission preparation/results?	VI-4. Ranking of the most productive authors VI-5. Ranking of the most productive entities (author affiliation)
	What entities and countries are generating content related to the mission?	VI-6. Ranking of the most productive affiliations grouped by country
Analysis of topics in MRCL	Which are the subjects covered by mission-related documents?	TA-1. Contributions by topic
Visbility of MRCL	How many citations has the MRCL received?	IM-1. Number of citations received by the MRCL
	To what extent have MRCL authors influenced subsequent research?	IM-2. Ranking of authors by citations received
	Which are the most influential papers?	IM-3. Ranking of MRCL documents by citations received
Collaboration in MRCL	What is the level of collaboration observed in the MRCL?	CO-1.Collaboration index (number of papers written by n authors)
	Who are the authors that collaborate?	CO-2. Co-authorship analysis
	Which institutions and entities have collaborated in writing the MRCL?	CO-3. Co-authorship analysis at the affiliation level
Information consumption in MRCL	Who are the mostly cited authors, by the authors of the MCRL?	IC-1. Ranking of the most-cited authors in MCRL documents IC-2. Co-citation analysis

Table 2
CryoSat related documents on different data sources.

Database	#Docs containing the mission name in key fields	#Docs containing the mission name in any fields	Documents after screening	Comments
SCOPUS	298 (dataset 1)	891 (dataset 2)	296	Dataset 1 contains the documents that contain the mission name on the title, keywords or abstract Dataset 2 contains the documents that contain the mission name in any field (title, keywords, abstract or references)
Web of Science	–	197	192	Most of the documents retrieved from WoS are part of the Scopus datasets. There are just 8 documents in WoS not present in Scopus, and 9 WoS documents that are present in SCOPUS dataset 2, but not in SCOPUS dataset 1
OpenAire	–	156	141	In addition to the documents, this repository contains two projects related to CryoSat: "Ocean application of the CryoSat-2 SAR mode: preparing for Sentinel-3 and Jason-CS (2300178169)" and "A Factor of 2 Improvement in Global Marine Gravity from Cryosat, Jason-1, and Envisat" 41 of the 141 documents in OpenAire are included in the SCOPUS' dataset 1
OCLC Oayster	–	170	149	40 of the 149 documents in OAYSTER are included in the SCOPUS' dataset 1

of references). The same search, conducted on the Web of Science, returned 197 documents. Although the purpose of this study is not to compare different Earth observation missions, it is interesting to note that Scopus includes 2440 documents related to the SMOS mission in the Earth and Planetary Sciences category, around 1840 for SENTINEL-1, -2 and- 3 and 261 for Proba-1 and – Proba-V.

Besides searching in Scopus and Web of Science, additional data sources were checked, to get a deeper understanding of the literature related to the mission. Two popular, open access repositories were searched: OpenAire

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Table 3
Journals and proceedings where Cryosat-related documents are published.

Journal	NDocs	%Docs	SJR	H index
International Geoscience and Remote Sensing Symposium (IGARSS)	40	13.51%	0.188	36
Cryosphere	15	5.07%	4.251	40
Geophysical Research Letters	15	5.07%	3.323	185
Advances in Space Research	13	4.39%	0.606	65
IEEE Geoscience and Remote Sensing Letters	10	3.38%	1.203	60
IEEE Transactions on Geoscience and Remote Sensing	10	3.38%	1.975	168
Journal of Geophysical Research	8	2.70%	2.310	263
Aviation Week and Space Technology	6	2.03%	0.100	7
European Space Agency Bulletin	6	2.03%	0.106	9
Proceedings of SPIE - The International Society for Optical Engineering	5	1.69%	0.216	109
Remote Sensing of Environment	5	1.69%	3.369	180
Journal of Glaciology	4	1.35%	2.330	71
Marine Geodesy	4	1.35%	0.753	31
Wuhan Daxue Xuebao (Xinxi Kexue Ban)/Geomatics and Information Science of Wuhan University	4	1.35%	0.246	18

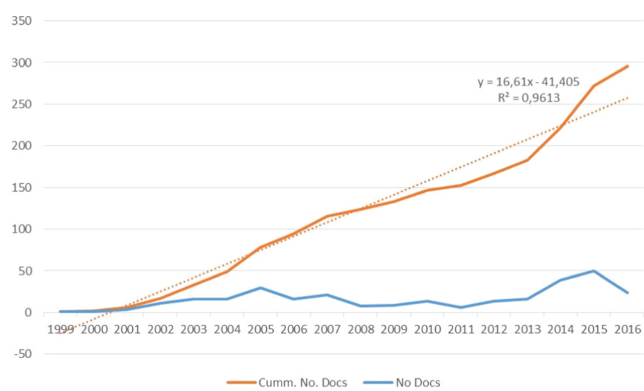

Fig. 1. Evolution in the number of documents.

and OCLC Oayster. These databases restrict their content to open, publicly available documents; due to this reason, their contents are expected to differ from those available in Scopus and Web of Science (that focus on peer-reviewed journals that are normally available through subscription). Table 2 shows the results obtained from the different databases, and the results of the analysis done to identify overlapping documents between the databases. A particular case is Google Scholar; although there are critics on its feasibility as a source for scientometrics studies, this tool is expected to have a wider use in the near future thanks to tools that automate Google Scholar data extraction and analysis (Harzing, 2007).[4]

The study focused on the first dataset retrieved from Scopus (298 documents), which constitutes the MRCL for the CryoSat mission. The screening of the documents' abstract was done to eliminate duplicates and ensure that all the documents were actually related to the mission, and just two documents were discarded.

Regarding data collection, some of the indicators in Table 1 can be obtained directly from Scopus using the analysis tool provided by this platform. In other cases, data pre-processing procedures were applied to normalize variants of names and misspelling data. After cleaning, data were processed with the BibExcel software tool (Persson et al., 2009) to obtain the relational indicators (co-authorship and co-citation), half-life of cited literature and some of the rankings. VosViewer software (Van Eck and Waltman, 2010) was used to visualize relationships between data and analyze collaboration networks.

3. Results

This section reports the results obtained for the indicators object of study. Results are presented in different subsections, grouped by objectives.

3.1. Visibility of the mission

3.1.1. Number of documents related to the mission (VI-1 in Table 1)

Scopus contains 893 documents that contains the CryoSat term in any field of the record (including references). By restricting the search to the Title, Abstract and Keywords fields, the result set is reduced to 296 documents.

3.1.2. Ranking of journals and conferences where mission-related contributions have been published (VI-2 in Table 1)

This section identifies the journals and conferences where Cryosat related documents have been published. The ranking was obtained with Scopus analysis tool and validated with BibExcel. Table 3 shows, for each journal/-conference, the number of documents related to CryoSat (Ndocs), the percentage that they represent with respect

[4] The search for CryoSat in Google Scholar returns around 4.500 hits. The big difference between this figure and the results obtained in other databases is because Google Scholar indexes different academic-related sites, not only content from archived, peer reviewed journals and conferences. In any case, this figure is of interest to get a deeper understanding of the visibility of the mission.

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Table 4
Ranking of authors by number of documents.

Author	Public. Dates	NDocs	NCit	NDocsDB[a]	NCitDB	h-index
Wingham, Duncan (UCL)	1984–2015	22	479	90	3351	28
Cullen, Robert A. (ESTEC)	1997–2014	17	373	22	400	7
Benvéniste, Jérôme (ESA)	1991–Present	14	35	80	232	8
Helm, Veit (Yanshan University, China)	2007–Present	13	111	24	170	7
Mavrocordatos, Constantin M. (ESA)	1993–2012	13	208	40	345	7
Francis, Richard C. (ESTEC)	1991–2014	12	108	21	109	4
Hendricks, Stefan (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung)	2005–Present	11	192	48	697	13
Haas, Christian (York University, Canada)	1997–Present	9	193	123	2074	26
Stenseng, Lars (Danmarks Tekniske Universitet)	2008–Present	9	21	19	176	6
Davidson, Malcolm W J (ESA)	1998–Present	9	182	93	1194	15
Andersen, Ole Baltazar (Danmarks Tekniske Universitet)	1994–Present	8	11	93	1196	17
Ricker, Robert (Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung)	2013–Present	8	23	9	23	2
Mardle, Nic (ESOC)	1993–2014	7	–	10	–	–
Smith, Walter H F (National Oceanic and Atmospheric Administration, US)	1989–2015	7	133	69	9520	26
Shepherd, Andrew P. (University of Leeds)	2001–Present	7	111	59	2885	25
Laxon, Seymour William (UCL)	1986–2015	7	355	69	1861	23

[a] The values for the Public.dates, NDoc (total) NCit(total) and h-index have been taken directly from Scopus. Differences between the values of NDoc in dataset and NDoc (total) may be due to changes in the affiliations of the authors.

Table 5
Ranking of entities by number of documents.

Institution/Entity	NDocs	% Docs
ESTEC - European Space Research and Technology Centre	49	16.55
UCL	31	10.47
Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung	23	7.77
ESRIN - ESA Centre for Earth Observation	21	7.09
ESOC - European Space Operations Centre	19	6.42
CNES - Centre National d'Etudes Spatiales	18	6.08
CLS (France)	13	4.39
Astrium GmbH	12	4.05
Danmarks Tekniske Universitet	11	3.72
Thales Alenia Space	11	3.72
National Oceanic and Atmospheric Administration	11	3.72
European Space Agency – ESA	11	3.72
NASA Goddard Space Flight Center	8	2.7
Jet Propulsion Laboratory, California Institute of Technology	8	2.7
Nansen Environmental and Remote Sensing Center (Norway)	8	2.7
University of Alberta	8	2.7
Scripps Institution of Oceanography (US)	7	2.36
National Oceanography Centre Southampton (UK)	6	2.03
Wuhan University (China)	6	2.03
Universite de Toulouse	6	2.03
Universitat Hamburg	5	1.69
Scott Polar Research Institute (UK)	5	1.69

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Table 6
Ranking of countries by number of documents.

Country	NDocs	% Docs
Germany	71	23.99
Netherlands	59	19.93
United Kingdom	55	18.58
United States	47	15.88
France	42	14.19
Undefined	36	12.16
Italy	35	11.82
Denmark	20	6.76
China	17	5.74
Canada	14	4.73
Norway	12	4.05
Spain	10	3.38

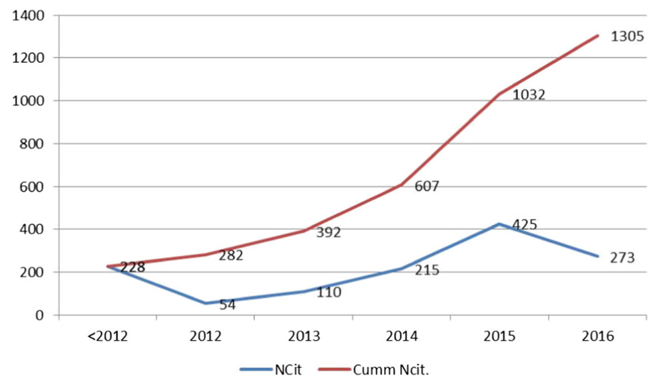

Fig. 3. Number of Citations received by MRCL.

Table 7
Keywords extracted from documents.

Keywords	Freq.	Keywords	Freq.	Keywords	Freq.
Cryosat	74	Radar Altimetry	33	Arctic Ocean	21
Synthetic Aperture Radar	64	Geodetic Satellites	33	Ice Sheet	21
Cryosat-2	63	Remote Sensing	31	Earth (Planet)	20
Sea Ice	63	Altimetry	29	Space Research	18
Aneroid Altimeters	59	Interferometry	28	Snow	18
Satellites	58	Ice Thickness	27	Sea Level	17
Radar	45	Radio Altimeters	27	Oceanography	17
Satellite Altimetry	43	Radar Measurement	25	Antarctica	16
Meteorological Instruments	36	Orbits	22	Satellite Data	16
Ice	33	Radar Altimeters	21	Glaciers	16

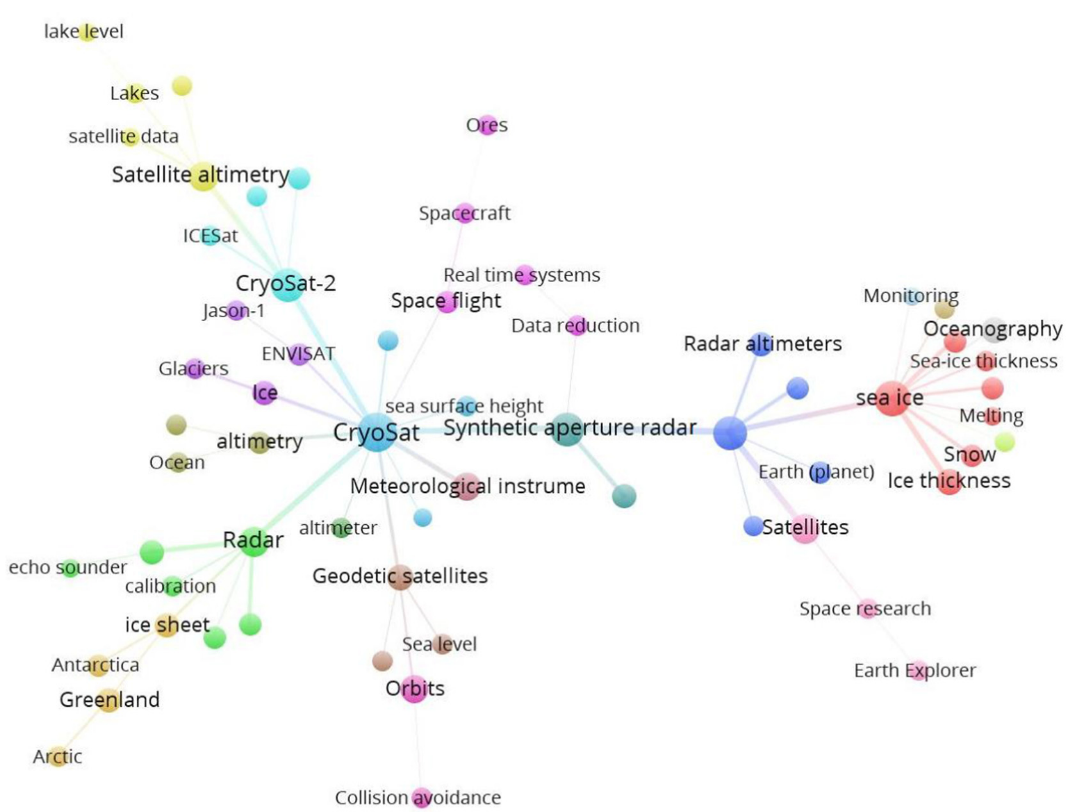

Fig. 2. Visual representation of keywords based on co-occurrence.

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Table 8
Ranking of Authors by number of citations.

Author	Public. dates	NDoc	NCit	NCitDB	h-index
Wingham, Duncan (UCL)	1984–2015	22	479	3351	28
Cullen, Robert A. (ESTEC)	1997–2014	17	373	400	7
Laxon, Seymour William (UCL)	1986–2015	7	355	1861	23
Mavrocordatos, Constantin M. (ESA)	1993–2012	13	208	345	7
Phalippou, Laurent (Business Unit Observation Systems and Radars, Toulouse)	1990–2011	8	197	298	6
Haas, Christian (York University)	1997–Present	9	193	2074	26
Hendricks, Stefan (Alfred-Wegener-Institut)	2005–Present	11	193	694	13
Davidson, Malcolm W J (ESA)	1998–Present	9	170	1198	15
Giles, Katharine Anne (UCL)	2006–2013	3	168	527	10
Kwok, Ron (Jet Propulsion Laboratory)	1987–Present	5	162	7121	46
Willatt, Rosemary C. (UCL)	2010–2013	2	162	181	3
Ratier, Guy (ESTEC)	1986–2006	6	151	172	3
Ridout, Andy L. (UCL)	2001–Present	8	146	488	9
Kurtz, Nathan T. (NASA Goddart)	2008–Present	3	144	466	13
Rey, Laurent (Thales Alenia Space)	1995–2011	7	144	229	5
Farrell, Sinéad Louise (National Oceanic and Atmospheric Administration)	2004–Present	1	143	511	11
Krishfield, Richard A. (University of Montana)	1993–Present	1	143	1504	23
Schweiger, Axel J.(University of Washington)	1987–2015	1	143	1769	22

Table 9
Ranking of Documents by number of citations.

Document	NCit.
Laxon, S. W., Giles, K. A., Ridout, A. L., Wingham, D. J., Willatt, R., Cullen, R., … Davidson, M. (2013). CryoSat-2 estimates of arctic sea ice thickness and volume. Geophysical Research Letters, 40(4), 732–737. doi:10.1002/grl.50193	143
Wingham, D. J., Francis, C. R., Baker, S., Bouzinac, C., Brockley, D., Cullen, R.,… Wallis, D. W. (2006). CryoSat: A mission to determine the fluctuations in earth’s land and marine ice fields. Advances in Space Research, 37(4), 841–871. doi:10.1016/j.asr.2005.07.027	133
Sandwell, D.T., Müller, R. D., Smith, W. H. F., Garcia, E., & Francis, R. (2014). New global marine gravity model from CryoSat- 2 and jason-1 reveals buried tectonic structure. Science, 346(6205), 65–67. doi:10.1126/science.1258213	72
Wingham, D. J., Phalippou, L., Mavrocordatos, C., & Wallis, D. (2004). The mean echo and echo cross product from a beamforming interferometric altimeter and their application to elevation measurement. IEEE Transactions on Geoscience and Remote Sensing, 42(10), 2305–2323. doi:10.1109/TGRS.2004.834352	47
McMillan, M., Shepherd, A., Sundal, A., Briggs, K., Muir, A., Ridout, A.,… Wingham, D. (2014). Increased ice losses from antarctica detected by CryoSat-2. Geophysical Research Letters, 41(11), 3899–3905. doi:10.1002/2014GL060111	46
Helm, V., Humbert, A., & Miller, H. (2014). Elevation and elevation change of greenland and antarctica derived from CryoSat-2. Cryosphere, 8 (4), 1539–1559. doi:10.5194/tc-8-1539-2014	44
Hawley, R. L., Morris, E. M., Cullen, R., Nixdorf, U., Shepherd, A. P., & Wingham, D. J. (2006). ASIRAS airborne radar resolves internal annual layers in the dry-snow zone of greenland. Geophysical Research Letters, 33(4) doi:10.1029/2005GL025147	37
Sandwell, D., Garcia, E., Soofi, K., Wessel, P., Chandler, M., & Smith, W. H. F. (2013). Toward 1-mGal accuracy in global marine gravity from CryoSat-2, envisat, and jason-1. Leading Edge, 32(8), 892–899. doi:10.1190/tle32080892.1	33
Alexandrov, V., Sandven, S., Wahlin, J., & Johannessen, O. M. (2010). The relation between sea ice thickness and freeboard in the arctic. Cryosphere, 4(3), 373–380. doi:10.5194/tc-4-373-2010	30
Recommendations for the collection and synthesis of antarctic ice sheet mass balance data. (2004). Global and Planetary Change, 42(1 −4), 1–15. doi:10.1016/j.gloplacha.2003.11.008	27
Giles, K. A., Laxon, S. W., & Worby, A. P. (2008). Antarctic sea ice elevation from satellite radar altimetry. Geophysical Research Letters, 35 (3) doi:10.1029/2007GL031572	25
Kaleschke, L., Maaß, N., Haas, C., Hendricks, S., Heygster, G., & Tonboe, R. T. (2010). A sea-ice thickness retrieval model for 1.4 GHz radiometry and application to airborne measurements over low salinity sea-ice. Cryosphere, 4(4), 583–592. doi:10.5194/tc-4-583-2010	20
Willatt, R., Laxon, S., Giles, K., Cullen, R., Haas, C., & Helm, V. (2011). Ku-band radar penetration into snow cover on arctic sea ice using airborne data. Annals of Glaciology, 52(57 PART 2), 197–205. doi:10.3189/172756411795931589	19
Lisæter, K. A., Evensen, G., & Laxon, S. W. (2007). Assimilating synthetic CryoSat sea ice thickness in a coupled ice-ocean model. Journal of Geophysical Research: Oceans, 112(7) doi:10.1029/2006JC003786	19
Zygmuntowska, M., Rampal, P., Ivanova, N., & Smedsrud, L. H. (2014). Uncertainties in arctic sea ice thickness and volume: New estimates and implications for trends. Cryosphere, 8(2), 705–720. doi:10.5194/tc-8-705-2014	17
Siegfried, M. R., Fricker, H. A., Roberts, M., Scambos, T. A., & Tulaczyk, S. (2014). A decade of west antarctic subglacial lake interactions from combined ICESat and CryoSat-2 altimetry. Geophysical Research Letters, 41(3), 891–898. doi:10.1002/2013GL058616	17
Boon, S., Burgess, D. O., Koerner, R. M., & Sharp, M. J. (2010). Forty-seven years of research on the devon island ice cap, arctic canada. Arctic, 63(1), 13–29. Retrieved from www.scopus.com	17
Drinkwater, M. R., Francis, R., Ratier, G., & Wingham, D. J. (2004). The european space agency’s earth explorer mission CryoSat: Measuring variability in the cryosphere. Annals of Glaciology, 39, 313–320. Retrieved from www.scopus.com	17
Ricker, R., Hendricks, S., Helm, V., Skourup, H., & Davidson, M. (2014). Sensitivity of CryoSat-2 arctic sea-ice freeboard and thickness on radar-waveform interpretation. Cryosphere, 8(4), 1607–1622. doi:10.5194/tc-8-1607-2014	16
Labroue, S., Boy, F., Picot, N., Urvoy, M., & Ablain, M. (2012). First quality assessment of the cryosat-2 altimetric system over ocean. Advances in Space Research, 50(8), 1030–1045. doi:10.1016/j.asr.2011.11.018	16

N.Auth	N.docs	%Docs
1	**33**	**11.15**
2	**36**	**12.16**
3	**55**	**18.58**
4	**59**	**19.93**
5	**37**	**12.5**
6	**18**	**6.08**
7	11	3.72
8	6	2.03
9	8	2.7
10	5	1.69
11	2	0.68
12	1	0.34
15	2	0.68
16	2	0.68

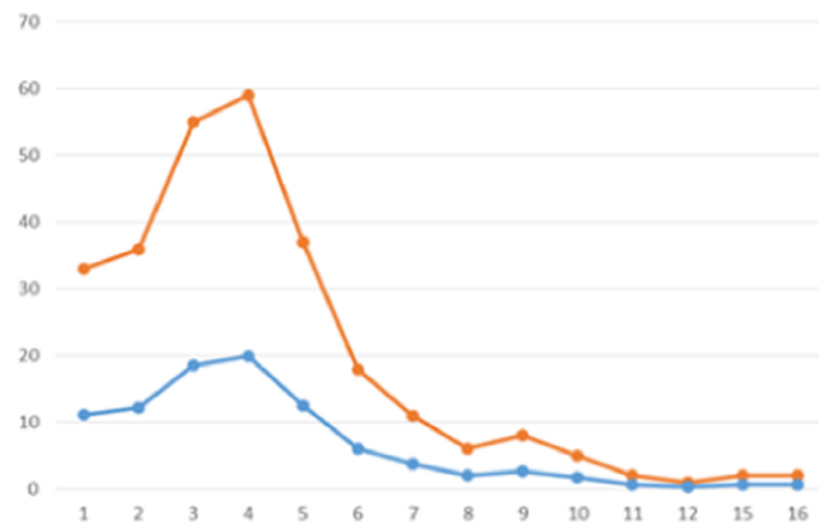

Fig. 4. Collaboration Index.

Table 10
Co-authorship analysis.

Co-authors		NDocs	Co-authors		NDocs
Cullen, R.	Wingham, D.J.	10	Mavrocordatos, C.	Rey, L.	5
Andersen, O.B.	Stenseng, L.	8	Andersen, O.B.	Knudsen, P.	5
Hendricks, S.	Ricker, R.	8	Francis, R.	Mavrocordatos, C.	5
Helm, V.	Hendricks, S.	7	Halimi, A.	Tourneret, J.-Y.	5
Mavrocordatos, C.	Phalippou, L.	7	Mallow, U.	Rostan, F.	5
Helm, V.	Ricker, R.	6	De Château-Thierry, P.	Phalippou, L.	5
Mailhes, C.	Tourneret, J.-Y.	5	Haas, C.	Hendricks, S.	5
Cullen, R.	Viau, P.	5	Phalippou, L.	Rey, L.	5
Halimi, A.	Mailhes, C.	5	Boy, F.	Halimi, A.	4
De Château-Thierry, P.	Mavrocordatos, C.	5	Boy, F.	Tourneret, J.-Y.	4

to the total number of documents in the dataset (%Docs), and the SJR and h index of the journals.[5]

[5] SJR and h-index are two indicators used to measure the impact of scientific journals.SCImago Journal Rank (SJR) "expresses the average number of weighted citations received in the selected year by the documents published in the selected journal in the three previous years, --i.e. weighted citations received in year X to documents published in the journal in years X-1, X-2 and X-3". SJR is considered an alternative to the popular Journal Citation Report (JCR). Both indexes have the same purpose, but they are based on different input data and slightly different algorithms: JCR is calculated with data from the Web of Science database, and SJR is calculated with data from Scopus. The h-index quantifies the cumulative impact and relevance of the scientific output of an individual, entity or journal. It takes into account the quantity of papers published and the citations that they have received. A particular entity has an index x if x of his N papers have received at least x citations each, and the other (N-h) papers have received less than x citations.

3.1.3. Evolution in time of the published number of documents (VI-3 in Table 1)

This section reports the growth of the literature related to the mission. Fig. 1 shows the cumulated number of documents per year, with an average growth rate of 48%.

3.1.4. Ranking of the most productive authors (VI-4 in Table 1)

Scopus' analysis tool provides a ranking of the authors by number of co-authored papers using the complete count method.[6] Table 4 shows the partial ranking of authors by number of documents. It also provides the authors' affiliation, the time period when they have published documents (Public.Dates), the number of documents the mission data-set (NDocs), the number of citations received by these doc-

[6] Each occurrence of an author receives equal treatment regardless of the number of co-authors associated with the document (Andrés 2009, p. 25).

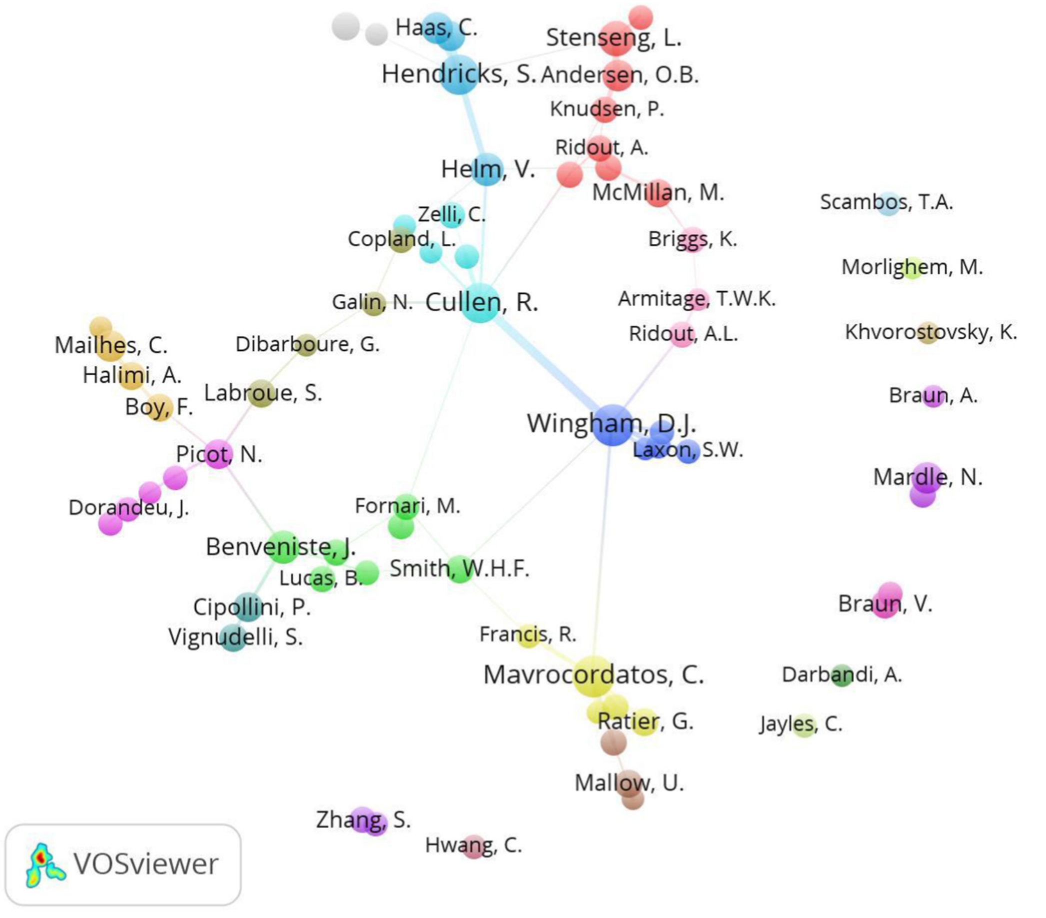

Fig. 5. Network and clusters of co-authorship.

uments (NCit), the total number of documents in Scopus (NDocsDB) and the total number of citations received by all his/her documents (NCitDB). The information about authors is completed with their Hirsch Index (h-index), that quantifies the cumulative visibility of the scientific output of an individual (Norris and Oppenheim, 2010).[7]

3.1.5. *Ranking of the most productive entities (author affiliation) (VI-5 in Table 1)*

This ranking is also provided by Scopus analysis tool. Table 5 reports the entities that have written most of the papers related to the mission – according to the data in Scopus -, the number of documents in the mission (NDocs) and the percentage with respect to the number of documents in the dataset (%Docs).[8]

3.1.6. *Ranking of the most productive affiliations grouped by country (VI-6 in Table 1)*

This section shows the ranking of countries by number of papers (countries are taken from the authors' affiliations). 77% of the signatures correspond to authors affiliated at European centers, 15% to authors affiliated at American centers, 28% to Asia and 6% to Australia (see Table 6).[9]

[7] If, instead of using as the dataset the MRCL, we use all the documents in Scopus containing CryoSat in any field, the ranking changes: Wingham (27 docs.), is followed by Haas and Helm (20 docs.), Cullen (19), Benvéniste (18), Hendricks (16), Mavrocordatos (15), Raney (14), Kwok (13) and Francis and Kurtz (12), etc.

[8] If, instead of using MRCL as the dataset, we use all the documents in Scopus containing CryoSat, the ranking changes: Alfred-Wegener-Institut (69 docs.), ESTEC (64), UCL (49), NASA Goddard Space Flight Center (37), Jet Propulsion Laboratory (34), CNES (31), NOAA and ESRIN (30), University of Colorado (27), ESOC (25), etc.

[9] The ranking of countries also differs if we use all the documents in Scopus containing CryoSat instead of those in the MRCL: USA (292), Germany and UK (177), France (108), Netherlands (105), China (88), Norway (67), Canada (64), Italy (63), etc.

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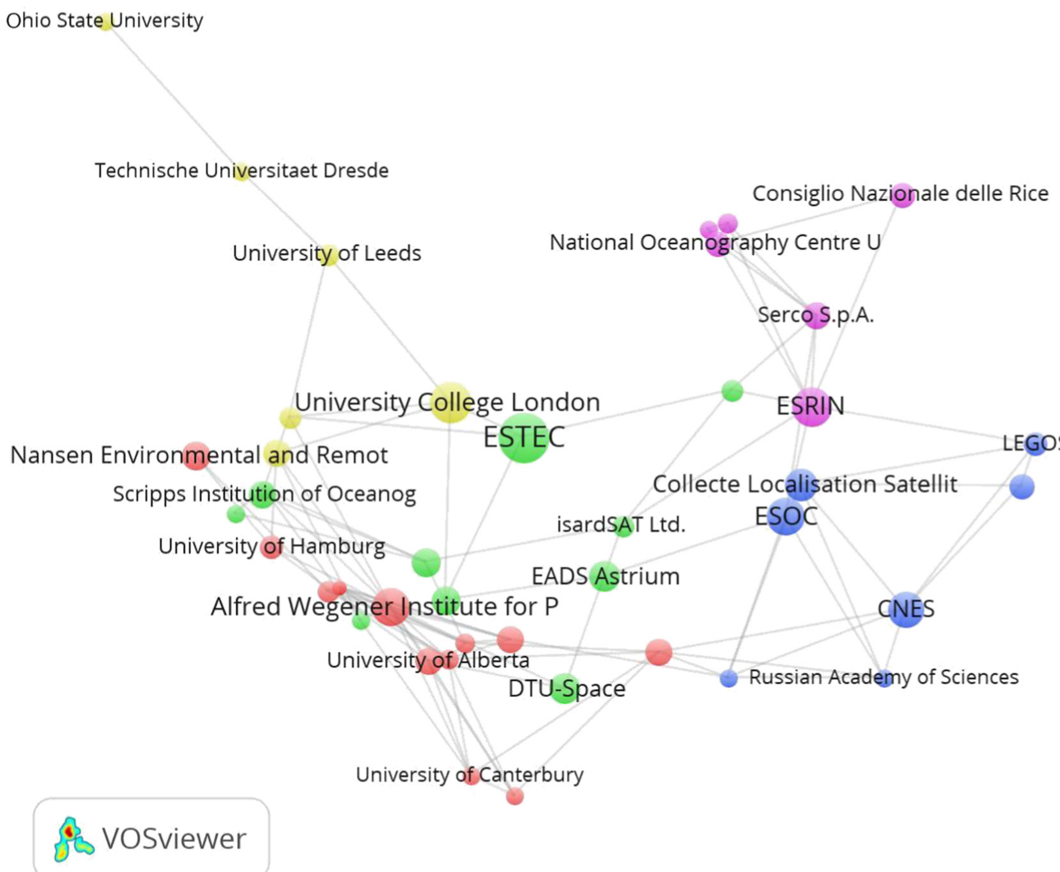

Fig. 6. Network and clusters of collaborating entities.

Table 11
Ranking of most-cited authors in MRCL.

Author	Public. dates	NCit	NCitDB	h-index
Wingham, Duncan (UCL)	1984–2015	310	3351	28
Laxon, Seymour William (UCL)	1986–2015	202	1861	23
Zwally, H. Jay (NASA Goddard Space Flight Center)	1978–2013	141	7359	36
Kwok, Ron (Jet Propulsion Laboratory)	1987–Present[a]	123	7121	46
Raney, Russell Keith (2kR, LLC)	1977–Present	120	1761	20
Cullen, Robert A. (ESTEC)	1997–2014	117	400	7
Smith, Walter H F (National Oceanic and Atmospheric Administration, US)	1989–2015	84	9520	26
Phalippou, Laurent (Business Unit Observation Systems and Radars, Toulouse)	1990–2011	76	298	6
Haas, Christian (York University)	1997–Present	75	2074	26
Mavrocordatos, Constantin M. (ESA)	1993–2012	74	345	7
Helm, Veit (Yanshan University, China)	2007–Present	69	170	7
Giles, Katharine Anne (UCL)	2006–2013	62	527	10
Rignot, Eric J M (UC Irvine)	1987–Present	61	10,566	50
Francis, Richard C. (ESTEC)	1991–2014	59	109	4
Shepherd, Andrew P. (University of Leeds)	2001–Present	58	2885	25
Yi, Donghui (NASA Goddard Space Flight Center)	1994–2015	57	2294	18
Fricker, Helen Amanda (Scripps Institution of Oceanography)	2000–Present	56	2187	26
Hendricks, Stefan (Alfred-Wegener-Institut)	2005–Present	56	694	13
Scharroo, Remko (EUMETSAT)	1991–Present	56	488	10
Bamber, Jonathan L. (University of Bristol)	1988–Present	55	5389	38
Baker, Stephen H.(Imperial College London)	1992–Present	55	14,079	54
Bouzinac, Catherine (ESTEC)	1997–2013	55	259	6
Krabill, William B. (NASA)	1973–2014	54	4973	41
Picot, Nicolas (CNES)	2001–2015	52	300	10
De Château-Thierry, P. (Thales Alenia Space)	1987–2006	52	145	3
Wallis, Dave W. (UCL)	2000–2012	51	396	6
Benvéniste, Jérôme (ESA)	1991– Present	50	232	8

[a] Scopus data uses the word "present" to indicate that the database contains papers from the author published in the current year. As the data used for this study were collected in 2016, "present" means that the author published papers during 2016.

3.2. Analysis of topics in MRCL

3.2.1. TA-1. Contributions by topic

This indicator uses the keywords assigned to the documents to identify the topics covered by the MRCL. Keywords have been extracted and ranked with BibExcel. A total of 1886 different, non-normalized keywords were extracted; those with the highest frequency are shown in Table 7.

Raw keyword extraction and ranking does not provide enough clues to identify specific topics within the document set. Keyword co-occurrence and clustering was run with BibExcel; this analysis identified 17.174 pairs of keywords clustered as depicted in Fig. 2.

These figures – generated with the VosViewer tool and that are used in other sections of the paper with different purposes - show a map of clusters. Clusters group together the items that co-occur in the same documents a number of times above a specific threshold; they are drawn with the same color. The size of the font represents how many times the item appears in the set of documents under analysis (Van Eck and Waltman, 2011, 2014).

3.3. Visibility of MRCL

3.3.1. Number of citations received by the MRCL (IM-1 in Table 1)

The number of received citations is used as the main indicator of the visibility that authors, institutions or individual documents have on subsequent research. The documents in the MRCL have received a total of 1307 citations (4.41 as an average). This represents the overall impact of CryoSat-related documents on future studies. Fig. 3 shows the evolution in time of the number of citations.

3.3.2. Ranking of authors by citations received (IM-2 in Table 1)

This section shows the partial list of authors of MRCL papers sorted by number of citations. Table 8 contains the authors' name and affiliation, dates when they have documents in the database, number of documents in the MRCL dataset (NDoc), number of citations received by these documents (NCit), and the total number of citations received by all the authors' papers in the Scopus database (NCitDB).

3.3.3. Ranking of MRCL documents by citations received (IM-3 in Table 1)

With Scopus, it is possible to identify those documents that have received the highest number of citations. These are the documents with the highest visibility on subsequent research (of course, we need to avoid making equivalent visibility with scientific impact). Table 9 shows the top 20, mostly cited documents. It is remarked that two of the documents in the dataset have received a significantly larger number of citations than the remaining documents: 143 and 133.[10]

3.4. Collaboration in MRCL

3.4.1. Collaboration index (CO-1 in Table 1)

Analysis of collaboration between researchers is one of the objectives of bibliometric studies. The collaboration index measures the average number of co-authors per document. Fig. 4 shows the number of documents (NDocs) having a specific number of signatories (NAuth), and the percentage that these documents represent in the dataset.

3.4.2. Co-authorship analysis (CO-2 in Table 1)

Co-authorship analysis identifies the authors who have worked together. Pairs of co-authors are used as an input to create collaboration networks using clustering techniques. The analysis of co-authorship run with BibExcel identified 1.426 pairs of co-authors (see Table 10 and Fig. 5 for the authors' clusters).

3.4.3. Co-authorship analysis at the affiliation level (CO-3 in Table 1)

At the institutional level, collaboration data patterns can reveal the results of strategically planned policies to strength and capitalize on the knowledge acquired by institutions leading complementary areas. Using the authors' affiliations, it is possible to build the network of collaborating entities (see Fig. 6).

[10] The ranking is built on data collected the 3Q2016. It changed if we took as a reference all the documents containing CryoSat. In this case, the first and second position remained the same, but in between Wingham et al. (2006) and Sandwell et al. (2014), we found these documents:

- Overland, J. E. and Wang, M. (2013). When will the summer arctic be nearly sea ice free? Geophysical Research Letters, 40(10), 2097–2101 (105 citations).
- Font, J., Lagerloef, G. S. E., Le Vine, D. M., et al. (2004). The determination of surface salinity with the european SMOS space mission. IEEE Transactions on Geoscience and Remote Sensing, 42(10), 2196–2205 (105 citations).
- Kwok, R. and Cunningham, G. F. (2008). ICESat over arctic sea ice: Estimation of snow depth and ice thickness. Journal of Geophysical Research: Oceans, 113(8) (99 citations).
- Abdalati, W., Zwally, H. J., Bindschadler, R., et al. (2010). The ICESat-2 laser altimetry mission. Proceedings of the IEEE, 98(5), 735–751. (97 citations).
- Moholdt, G., Nuth, C., Hagen, J. O., et al. (2010). Recent elevation changes of svalbard glaciers derived from ICESat laser altimetry. Remote Sensing of Environment, 114(11), 2756–2767. (87 citations).
- Donlon, C., Berruti, B., Buongiorno, A., et al. (2012). The global monitoring for environment and security (GMES) sentinel-3 mission. Remote Sensing of Environment, 120, 37–57. (83 citations)Other changes may be observed in other intermediate positions of the list.

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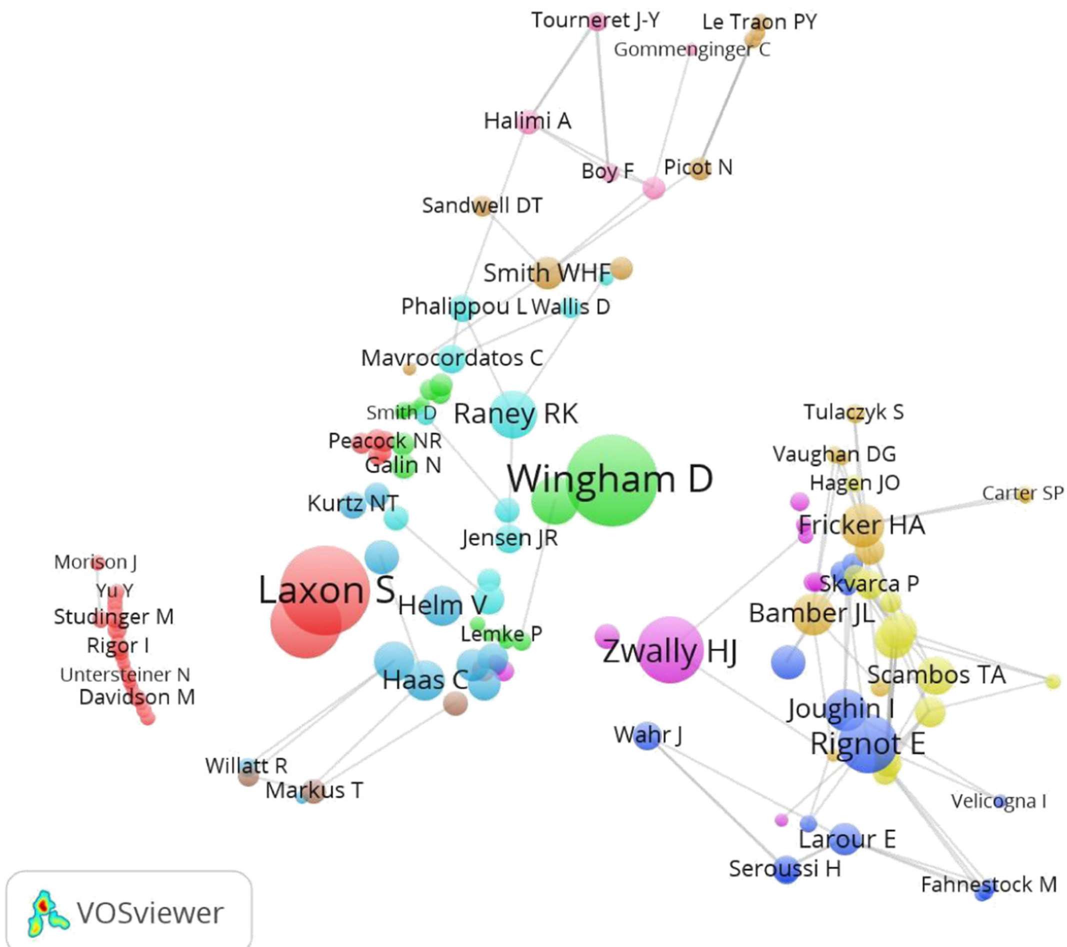

Fig. 7. Network of most cited authors.

3.5. Information consumption in MRCL

3.5.1. Ranking of the most-cited authors in MCRL documents (IC-1 in Table 1)

The purpose of this indicator is to identify those authors that are cited in the MRCL documents. These are the researchers whose previous research has had a significant impact on the documents related to the CryoSat mission. This is one of the most relevant aspects of bibliometric research, as it provides clues to know about the knowledge behind the design, engineering and exploitation of space missions. Table 11 shows the sorted list of authors who have received at least 50 citations in the MRCL papers (see Fig. 7).

3.5.2. Co-citation analysis (IC-2 in Table 1)

Information consumption data permits the identification of authors that are cited together in the same documents. Co-citation and co-word analysis are the most relevant methods to visualize a scientific domain (Chen et al., 2010). The result is a network with different clusters of co-cited authors (see Fig. 6, where the size of the nodes corresponds to the number of received citations, and the links indicate the relationships established by co-citation).

4. Conclusions

Space missions are complex endeavours that require the application of the previously accumulated, scientific and technical knowledge, and the establishment of collaboration networks and partnerships between experts and entities owning different skills and competences. Space missions make also possible the generation of new knowledge during the different phases of their design, development and exploitation. In the case of Earth observation, mission products constitute the basis to conduct scientific analysis and obtain new knowledge.

This paper analyzes the feasibility of applying scientometric techniques to assess the visibility of the CryoSat mission in the scientific community through the literature published the journals indexed in the Scopus database. Two main conclusions are identified through this study. First of all, scientometric analysis are useful tools to identify knowledge consumption trends through chains of bibliographic citations and to give visibility to the knowledge

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acquired with the mission. Indicators like IM-1 and VI-1 help identify the visibility of the mission in the scientific production and research; other indicators like VI-4, VI-5, co-2 and CO-3 help identify the researchers and entities doing related and collaborating with the mission outputs. The methods and tools used by scientometric analysis give us an overview of the scientific literature produced around the outputs of the space missions and can be used as an input to conduct additional studies on collaboration, trends and topics of research. Specific conclusions of the study include the highly increasing number of citations received by the MRCL (see Fig. 3) and the role of different universities and companies in the research networks established around the data collected by the mission (see Fig. 6). The figures attached to this study give only a clue on the possibilities offered by the applied tools to explore this collaboration landscape and identify further collaboration opportunities.

The approach also shows some limitations. It must be understood that these analysis are conducted on data sets that represent the status of the scientific literature in a specific database at a given time. This is especially relevant when considering the number of citations received by the articles, which is subject to continuous change as additional contributions to the scientific literature are created. This means that the data reported at a specific time will evolve and be different in the future, until the exploitation of the mission data reaches its maturity (this challenge opens an interesting line of research). It is possible to conclude that although the approach is useful and offers benefits, the analysis must be done with caution and conclusions should be given a preliminary value as they are subject to change. In fact, scientometric studies in highly dynamic areas should be conducted on a continuous basis, to monitor the evolution of the scientific and technical landscape.

Another limitation of these studies - in the case of space missions - is due to the fact that the databases that provide citation information in a way that supports its exploitation (Scopus and Web of Science) do not support searching in the document full text, but only in the fields that compose the bibliographic record. This means that some documents that refer to the mission can be overlooked as they do not contain explicit references to the mission's name in their title, abstract or citations. Regardless of these constraints, scientometric analysis provides a tool that may be useful to gain insights on the knowledge generated by space missions, assess their visibility in the scientific literature and identify collaboration patterns between scientists and institutions. Of course, the application of these techniques in the area of the space missions is a novel area of study that requires further development, with promising areas like comparing different missions or characterizing the life cycle of the missions from a scientometric perspective.

Finally, it must be remarked that the impact of space research and, in particular, Earth observation missions, goes far beyond the generation of explicit knowledge disseminated through traditional channels (peer-reviewed journals and conferences), and it may take years to assess the actual impact of Earth observations missions in all its facets. Scientometric analysis just offers complementary possibilities to achieve a deeper understanding of the visibility of these complex projects.

References

Andrés, A., 2009. Measuring Academic Research: How to Undertake a Bibliometric Study. Chandos, Great Abington, Ca, p. 168.

Aswathy, S., Pal, S., 2015. A scientometric analysis of AIAA journals. In: Handbook of Research on Inventive Digital Tools for Collection Management and Development in Modern Libraries. Hershey, PA, IGI Global, pp. 115–132.

Basili, R., Weiss, D.M., 1984. A methodology for collecting valid software engineering data. IEEE Trans. Softw. Eng., SE-10: 6, 728–738.

Chen, Ch., Ibekwe-SanJuan, F., Hou, J., 2010. The structure and dynamics of cocitation clusters: a multiple-perspective cocitation analysis. J. Am. Soc. Inform. Sci. Technol. 61 (7), 1386–1409.

Eito-Brun, R., Ledesma-Rodríguez, M., 2016. 50 years of space research in Europe: a bibliometric profile of the European Space Agency (ESA). Scientometrics 109 (1), 551–576. https://doi.org/10.1007/s11192-016-2053-8.

Harzing, A.W., 2007. Publish or Perish, available from <http://www.harzing.com/pop.htm>.

Hood, W., Wilson, C., 2001. The literature of bibliometrics, scientometrics, and informetrics. Scientometrics 52 (2), 291–314.

Martin, A., Beaudry, C., 2014. Measuring collaboration mechanisms in the Canadian space sector. In: Proceedings of the International Astronautical Congress, IAC, vol. 13, pp. 9237–9244.

Norris, M., Oppenheim, C., 2010. The h-index: a broad review of a new bibliometric in-dicator. J. Doc. 66 (5), 681–705.

Persson, O., Danell, R.J., Schneider, S., 2009. How to use Bibexcel for various types of bibliometric analysis. In: Åström, F., Danell, R., Larsen, B., Schneider, J. (Eds.), Celebrating scholarly communication studies: A Festschrift for Olle Persson at his 60th Birthday. International Society for Scientometrics and Informetrics, Leuven, Belgium, pp. 9–24.

Ratier, G., Zobl, R., 2005. The CryoSat system -the satellite and its radar altimeter. ESA Bull. 122, 18–26.

Rezadad, M., Maghami, M., 2014. Quantitative and qualitative analysis on trend of literature on flapping wing (2004–2014) by bibliometric analysis. Int. Rev. Aerospace Eng. 7 (6), 177–186.

Taskn, Z., Arsev, Aydinoglu, U., 2015. Collaborative interdisciplinary astrobiology research: a bibliometric study of the NASA Astrobiology Institute. Scientometrics 103, 1003–1022.

Van Eck, N.J., Waltman, L., 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84 (2), 523–538.

Van Eck, N.J., Waltman, L., 2011. Text mining and visualization using VOSviewer. ISSI Newslett. 7 (3), 50–54.

Van Eck, N.J., Waltman, L., 2014. Visualizing bibliometric networks. In: Ding, Y., Rousseau, R., Wolfram, D. (Eds.), Measuring Scholarly Impact: Methods and Practice. Springer, Heidelberg, pp. 285–320.

Wang, H., Liu, M., Hong, S., Zhuang, Y., 2013. A historical review and bibliometric analysis of GPS research from 1991–2010. Scientometrics 95 (1), 35–44.

Wilson, C.S., 2001. Informetrics. In: Williams, M.E., (Ed.), Annual Review of Information Science and Technology, Vol. 34, Medford, NJ: Information Today, Inc. for the American Society for Information Science, pp. 3–143.

Wingham, D., 2005. CryoSat: a mission to the ice fields of Earth. ESA Bull. 122, 10–17.

Xia, X., Li, M., Xiao, C.F., 1999. Author analysis of papers published in "Space Medicine & Medical Engineering" from 1988 to 1998. Space Med. Med. Eng. 12 (6), 431–435.

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