INFACT

INNOVATIVE NON-INVASIVE & FULLY ACCEPTABLE EXPLORATION TECHNOLOGIES

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TECHNOLOGY WATCH REPORT

Summary:

This report presents a bibliometric study on patents and scientific publications related to the following technologies involved in INFACT: airborne electromagnetic methods, airborne gravity gradiometry, airborne magnetometry and drone-borne hyperspectral imaging. A statistical analysis of the documents reveals the main players, technology trends and collaboration patterns via bibliometric techniques.

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EXECUTIVE SUMMARY

The Agency of Innovation and Development of Andalucía (IDEA), as a participant of the INFACT project and in its function as regional patent information centre and European PATent LIBrary (PATLIB) node, has key competences in Intellectual Property and Competitive Intelligence / Technology Watch.

Technology watch is a methodology for organisations to systematically analyse technical information and it is based mainly on statistical analysis of patents and scientific publications. Patents are publicly available documents that describe, in a structured and unified way, a technical invention that, once granted by a government or regional patent office, gives the owner the monopoly to commercially exploit the invention in a specific country.

By analysing this information via distinctive techniques the technology watch can reveal technology trends and can identify players (companies, research institutions, etc.) that are potential INFACT reference sites users.

The working methodology of IDEA for elaborating the present technology watch report is based on the general competitive intelligence workflow (as outlined in the full report). In order to detect the technology watch needs a survey was sent out to the INFACT partners.

Based on the responses the following four technology groups were established as the key intelligence topics (KITs) to be analysed in this present study:

Key Intelligence Topics	Technologies
AIRBORNE ELECTROMAGNETIC METHODS	*Airborne electromagnetics ; Airborne transient electromagnetic*
AIRBORNE GRAVITY GRADIOMETRY	*Full Tensor Gravity Gradiometry*
AIRBORNE MAGNETOMETRY	*Full Tensor Magnetic Gradiometry*
DRONE-BORNE HYPERSPECTRAL IMAGING	*long-wave/thermal infrared, near infrared, short-wave infrared*

For each of the key intelligence topics relevant keywords and patent classifications were identified and search queries established for the data retrieval. Expert commercial patent databases were used with worldwide coverage and advanced searching and analysis tools. The search queries yielded a total of 669 patent families and 2019 scientific publications.

Technology comparison

Especially in the fields of Electromagnetic (EM) methods and gravity gradiometry considerably more scientific publications were retrieved than patents. This can show us that these INFACT technologies still involve a considerable amount of basic research. Drone Borne hyperspectral imaging technologies seem to be more applied to the market with more patents than scientific works. Airborne magnetometry has yielded similar number of documents on patents and scientific publications.

Airborne electromagnetic methods

- Key players in patent filings are the Canadian GEOTECH (INFACT partner) being the leading company in patenting activity. Other important players in the field are the French Geoscience company CGG and the Dutch Geo-data specialist FUGRO. As for the public research institutions the Chinese JILIN UNIVERSITY seems to play an important role, followed by the Chinese CHENGDU UNIVERSITY OF TECHNOLOGY and the Korean INSTITUTE OF GEOSCIENCE & MINERAL RESOURCES. As for the scientific output the Danish Aarhus University plays an important role being the institution that publishes the most in the field of airborne electromagnetic methods, followed by the Chinese Jilin University.
- Regarding the evolution in patent publications over the last 10 years we can see a light increase over the years (with a trough in 2013 and a peak in 2016) with an average of 10 patents published a year. As for the evolution in scientific publications we identify a similar development as in patenting, only slightly earlier, with a peak in the years 2015 and 2016. Contrary to the patent filing behaviour we do not detect such a trough in 2013 as in patenting.
- When looking at the patenting evolution of the top 10 main players over the last 20 years we see that the Dutch FUGRO patenting activity has stalled with no patent published since 2012. GEOTECH and CGG have published patents in the field of airborne electromagnetic methods since 2013 till 2017 but nothing since then. The Asian organisations (JILIN UNIVERSITY, CHENGDU UNIVERSITY OF TECHNOLOGY and especially the KOREAN INSTITUTE OF GEOSCIENCE) seem to be the ones that generate innovations and protect them in most recent time (2017-2019).
- The number of patents protected in the various national Offices can give us information on the patent strategies of the actors in the sector studied, as the national filings are a good indicator of the markets that need to be protected. For airborne electromagnetic methods the main countries where patent protection was sought were China, the US, Canada and Australia. As for the applicants, both GEOTECH and CGG, showed to have the most internationalised patent portfolio. When analysing the country of origin of scientific publications (by country of residence of the corresponding authors institution) we see a similar picture, with the difference that Canada and the US are leading, Australia and Denmark following and China is on 5th rank.
- When analysing patent citations of applicants a strong relation of patents from GEOTECH and CGG become evident, with 11 patents of CGG citing patents from GEOTECH. Also worth noting is the connection between CGG and FUGRO with 5 patents from CGG citing patents from FUGROs portfolio.
- When analysing the co-authorship of patents few collaborations were detected, mostly only a single invention of the patent portfolios of the companies was co-authored with another company and nearly all of the collaborations were between applicants of the same country, with exception of the French CGG that co-authored one patent with the Dutch FUGRO.

Airborne gravity gradiometry

- Regarding the key players in patent filings two Chinese military organisations are leading in patenting, the CHINESE ARMY and the NATIONAL UNIVERSITY OF DEFENCE[1]. As for the

[1] It has to be noted that the patents of both defence organisations are domestic (Chinese) applications only and no patent has been extended to other countries

companies, we identified ARKEX, a former Cambridge-based geophysical service company (closed since 2015), the US specialist BELL GEOSPACE, the French CGG and the American GEDEX SYSTEMS, acquired by FCMI Geo Corporation. When analysing the scientific output, the US and Canadian institutions are leading, with aerospace institution NASA, followed by Natural Resources Canada, the US Geological Survey and the Geological Survey of Canada.

- Regarding the evolution in patent publications we can see over the last 10 years a continuous increase (with a trough in 2015/16) with an average of 7 patents published a year. As for the evolution in scientific publications we identify a peak in 2018 similar to the patenting behaviour.
- Regarding the patenting evolution of the top 10 main players over the last 20 years we detected recent patenting activity of the Chinese Defense research (Chinese Army & National University of Defense) and the Chinese AERO GEOPHYSICAL SURVEY REMOTE SENSING CENTRE have, with all of its patents published over the last 6 years, whereas the non-Chinese companies like BELL GEOSPACE or GEDEX have not published related patents in recent years, with the exception of French CGG that published its latest patent in the field of airborne gravity gradiometry in 2016.
- As for the jurisdictions where patent protection was sought in this technology field China, the US, Canada, and Australia were the main countries, in scientific output the US is leading followed by Canada then China and Germany on 4th position.
- As for the applicants of related patents the Chinese applicants only file in China (domestic filing), whereas CGG, GEODEX, BELL GEOSPACE and ARKEX have patented in multiple countries, with CGG having the most international patent portfolio.
- When analysing patent citations of applicants the patents from Gedex seem to have the biggest citation impact, with 11 citing patents from 5 different applicants. Furthermore it is worth mentioning that most of the related patents from Arkex are citing patents from Bell Geospace, which is citing patents from CGG.
- When analysing co-authorship patterns, some company-company collaborations become evident, and also some university-company partnerships such as the University of Western Australia that co-owns 2 patents with RTZ Mining & Exploration.

Airborne magnetometry

- Regarding the key players in patent filings we detected several patents from the French atomic agency CEA, but all of them expired (+30 years old). As with granted and/or pending patents we have identified the French CGG, the Swiss based HEXAGON TECHNOLOGY CENTRE and the Brazilian mining company VALE.
- As for the public research institutions the Russian VERNADSKY INSTITUTE OF GEOCHEMISTRY, the Chinese INSTITUTE OF ELECTRONICS (part of the Chinese Academy of Science) and the Korean INSTITUTE OF GEOSCIENCE & MINERAL RESOURCES have related patents, but all of them domestic patents only, with the exception of the Korean Institute that has extended their patent protection internationally.
- As for the institutions that published scientific articles it is interesting to see that the Iranian university of Teheran is leading the ranking, closely followed by the US research intensive NASA and the University of California.
- Analysing the patent publications over the last 10 years we can detect a slight increase with peaks in 2012 and 2018 and an average of 9 patents published a year since 2010. In scientific

research output of airborne magnetometry related scientific publications the evolution is not very clear with a light peak in 2017.

- When looking at the patenting evolution of the top 10 main players over the last 20 years we see that HEXAGON has published all its patents in 2012 and the latest one to publish was the KOREAN INSTITUTE OF GEOSCIENCE in 2018.
- As for the research intensive countries in airborne magnetometry the US and Canada are the countries with most related scientific publications, followed by Germany, Brazil and Italy. As for the jurisdictions where patent protection has been sought, most of the inventions have patent filings in China, the US and Canada and Australia, with the difference that, on fourth position the European patent system (EP) was chosen for protection which leads to the assumption that the European market seems to be of certain importance for airborne magnetometry related technologies. As for the applicants CGG, HEXAGON and VALE have the most internationalised patent portfolio.
- The patent citation analyses of airborne magnetometry related patents reveal a knowledge network between the applicants, e.g. CGG patents have cited patents from GEOTECH, VALE and SHIFT GEOPHYSICS and BARRINGER RESEARCH. The co-authorship analysis reveals several small collaborations between 2 applicants, mainly between applicants from China.

Drone-borne hyperspectral imaging

- Regarding the key players in patent filings it showed to be a relatively new and innovative field in terms of patenting activity, with many patents still pending and with the Chinese ZHEJIANG UNIVERSITY having the biggest related patent portfolio, followed by the Chinese technology company MAIFEI TECHNOLOGY (now: McFly). Furthermore the US aviation company BOEING and the US e-commerce giant AMAZON also are active in the field with several granted patents. Few scientific publications have been identified in this field, with the Chinese Academy of Science and the Italian National Research Centre leading with 4 publications each.
- Regarding the patent publications over the last 10 years we detect a strong increase in publications with a peak in 2018 with 49 patents. In scientific publications we see a similar evolution, with a steady increase in the last years, being 2018 the most productive year so far, with 19 publications. This technology field is the only of the analysed ones where more patents have been filed than scientific works being published.
- Analysing the evolution of key players, reveals that most companies have recent patenting activity with most publications occurring since 2016, especially the Chinese MAIFEI TECHNOLOGY and ZHEJIANG UNIVERSITY.
- Most patents have been filed in China, followed by the US and Europe. As for the internationalisation of the applicant's portfolio, the main Chinese applicants only file in China, whereas BOEING and AMAZON have the most internationalised patent portfolio. We encounter a similar picture when analysing the scientific publications, with the difference that China and US are not that accentuated. Italy is on third position with nearly the same amount of publications, but far less patent filings.
- Drone-borne hyperspectral imaging related patent citations shows a more scattered landscape, with few citation networks that include more than two applicants.
- Patent co-authorship analysis reveals some company-university partnerships as the Japanese Fujifilm and Hiroshima University. Most collaboration is on domestic level only and with maximum 2 partners.

1 INTRODUCTION

1.1 Background

The Agency of Innovation and Development of Andalucía (IDEA), as a participant of the INFACT project and in its function as regional patent information centre and European Patent Library (PATLIB) node, has key competences in Intellectual Property and Competitive Intelligence / Technology Watch, providing these services to Andalusian SMEs since 2007 (Jürgens 2011).

Technology-watch is a systematic approach to analyse publicly available technological information such patents, R&D project results and technology offers and scientific publications. By analysing this information via distinctive techniques this methodology can reveal technology trends and can identify players (companies, research institutions, etc.) and technology trends.

With the present report it is therefore envisaged from IDEA to provide to the stakeholders and the interested public the state of the art of technologies related to INFACT.

1.2 Technology Watch & Competitive Intelligence

Technology watch, also known as “technology intelligence”, “technology monitoring” or “patent intelligence”, is a methodology for organisations to systematically analyse technical information in order to gain insights and competitive advantage in a specific technical domain. Technology watch is a part of the broader concept of “Competitive Intelligence” (CI) which can be defined as a methodology for gathering, analysing, and managing external information that can affect the organisations plans, decisions, and operations (Negash 2004, Miller 2001). Especially research-intensive organisations need to be able to anticipate the technology trends, since a wrong choice can result in obsolete products and can have a major impact on the financial performance for many years (Hodgson et al. 2008).

Technology watch is based on statistical analysis of patent information and scientific literature. Patents are publicly available documents that describe, a technical invention that was once granted by a government or regional patent office, gives the owner the monopoly to commercially exploit the invention in a specific country, in a structured and unified way. Translating patent information into competitive intelligence allows an organisation to determine its current technical competitiveness, to forecast technological trends, and to plan for potential competition based on new technologies (Fleisher 2003).

Although in the literature different technology watch methodologies are discussed (Escorsa et al. 2001, Palop & Vicente 1999, Lichtenthaler 2004, Savioz 2003), they all have in common that they describe an iterative process that involves the basic steps shown in the following figure:

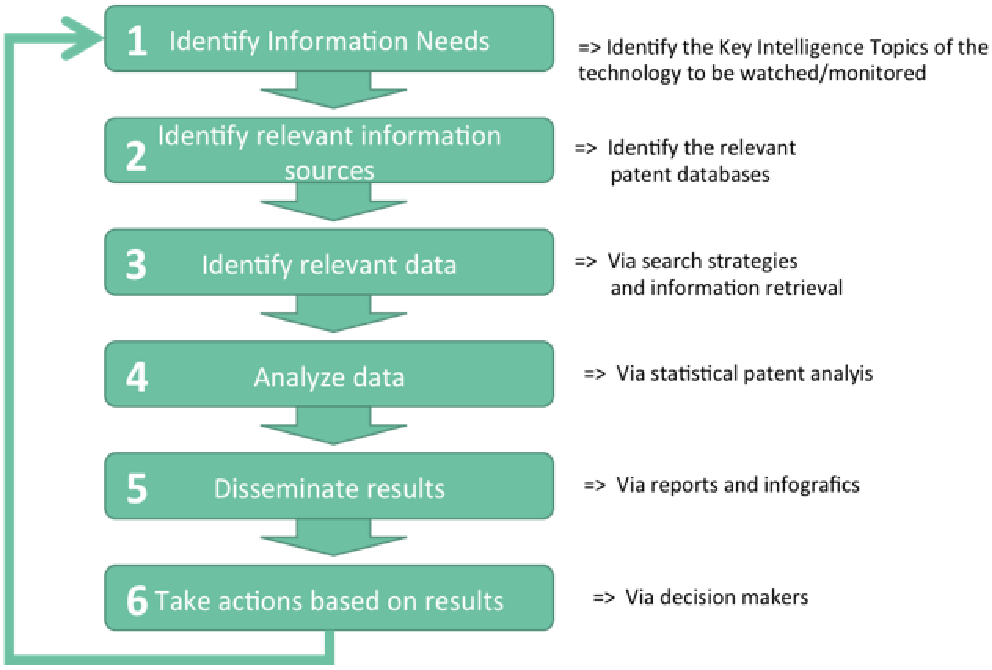


Fig. 1 General competitive intelligence cycle and its application to technology watch

- The process begins with determining the information needed and the identification of key intelligence topics (KIT). Key intelligence topics, first introduced by Herring (1999), identify and prioritize the key intelligence/information needs of the organization. In the case of INFACT the KIT are defined by the needs analysis as outlined in the methodology chapter of the present study.
- Once the KITs are agreed, the second step involves the identification of the most suitable information sources in order to gather the most meaningful data related to the KIT. For the present study worldwide patent and scientific publication was to be analysed, so information sources (databases) with the adequate coverage were chosen (as outlined in chapter 2.3).
- With information sources identified and selected, the third step is the data collection that involves the compilation of a comprehensive search strategy, which is can collect the most relevant data. The quality of the further analysis is related to the retrieved information it is crucial to give high attention to the reliability of the data sources and the gathering process.
- Once the information is retrieved (in our case bibliographic patent and scientific literature records) it is decisive to analyse and process it, gaining indicators etc. and therefore converts data into meaningful information aka "technical intelligence" (step 4). This will be presented in chapter 3 of the present study.
- In step 5 of the technology watch process the information or technical intelligence has to be transmitted to the decision makers so that they can take actions based on the indicators and conclusions (Step 6) in order to generate competitive advantage. In most cases this is done by drafting a comprehensive report, including an executive summary, as it is the case with the present INFACT technology watch report.

1.2.1 Patent information

Patents describe technologies in an objective and exhaustive manner. With currently more than 110 million publicly available patent documents (Epo-A 2019), patent information is a powerful source to conduct technology watch for specific technological domains. As patents cover mainly technical inventions, they are a rich source of data reflecting technical change and an indicator for the research and development intensity in technology fields. Especially in emerging technology sectors, patent data can reveal the intermediate stages of innovation activities and offers a basis for analysis where other data is lacking (Zuniga et al. 2009).

Patents are nowadays searchable via web based patent databases, some of them free to use and offering worldwide coverage (Jürgens & Herrero-Solana 2015). When it comes to search patent data, a combination of searching via keywords and patent classification is used. Patents classifications are assigned by subject matter experts of the patent office (the patent examiners) in order to classify the patents according to their technology field. Several different classification schemes were introduced by the patent offices over time, whereas the most important are the International Patent Classification (IPC) and the Cooperative Patent Classification (CPC). Hence, both IPC and CPC were employed for the present study.

1.2.2 Bibliometrics

Taking advantage of its structured format, patent statistics are commonly based on bibliographic data and therefore generated with bibliometric techniques (Pavitt 1985). This is why it is also known as “patent bibliometrics”, a term introduced by Narin (1994). The term Bibliometrics, was first mentioned in 1969 as "the application of mathematical and statistical methods to books and other media of communication" (Pritchard, 1969) and nowadays typically analyses scientific publications. Patents differ from scientific publications, as outlined in the following table.

	Scientific publications	Patent publications
Content	Mainly basic research findings	Technical solutions to a problem
Access	Paid access or open access or depending on the journal	Open access via public patent databases
Quality filter	Peer review	Patent examination process
Indexing	Scientific papers can have inconsistent bibliographical details, meaning that they can be hard to index.	Patent publications have a (more or less) standardised numbering system, meaning that it is possible to fully index them.
Subject categorization	Core journals by subject field	Patent classifications by technology field
Reason to publish	Scientific recognition	Economic (gain commercial monopoly, licensing, etc.)
Who publishes	Research entities (mainly Universities)	Companies and to a lesser degree research entities and private persons (inventors)
Cost	Sometimes fee based and others for free (depending on journal prestige)	Fee based (depending on patent office and coverage)
Content duplicity	No (the article can only be published in one single journal)	Yes (as patents are territorial, the same invention can generate several different patent documents for each country)
Timeliness	Article publishing depends on the efficiency of the peer review process of the journal	Patent is not published before 18 months after filing

Table 1 Scientific literature vs. patent literature[2]

[2] From: Lloyd (2015) and own research

1.3 Analysed Technologies - Key Intelligence Topics

In the present study patents and scientific publications were analysed of the following four INFACT relevant technologies:

- Airborne electromagnetics (AEM): transient electromagnetics (TEM)
- Airborne gravity gradiometry (AGG): Full Tensor Gravity Gradiometry (FTG)
- Airborne magnetometry: Full Tensor Magnetic Gradiometry (FTMG)
- Drone-borne hyperspectral imaging (HSI): long-wave/thermal infrared, near infrared, short-wave infrared

1.3.1 Airborne electromagnetics (AEM): transient electromagnetics (TEM)

Transient electromagnetics, also time-domain electromagnetics (TDEM), is an active geophysical exploration technique in which electric and magnetic fields are induced by transient pulses of electric current and the subsequent decay response is measured, which relates to the conductivity distribution in the subsurface. Depending on subsurface resistivity, the current induced, receiver sensitivity and transmitter-receiver geometry, TEM/TDEM measurements allow geophysical exploration from a few metres below the surface to several hundred metres of depth.

TEM/TDEM surveys are a very common surface EM technique for mineral exploration, groundwater exploration, and for environmental mapping, used throughout the world in both onshore and offshore applications. Other applications are mapping contamination (pathways and fracture systems), and engineering (mapping of aggregate resources for highway construction, pipeline route mapping). There are several TEM/TDEM systems on the market today, e.g. Geotech VTEM, SkyTEM, CGG HeliTEM, Nuvia NuTEM, New Resolution Geophysics Xcite. These systems are continuously modified to improve the effectiveness of AEM in light of the modern challenges of exploration. Some of the current developments include lowering the base frequency and building more powerful transmitters for increased depth of penetration, enabling full waveform recording, improving calibration, multiple receiver configurations (e.g. ground-floor EM), and direct measurement of the B-field.

In INFACT, several TDEM systems have been employed: the Geotech VTEM-ET was flown at Sakatti and Geyer, and the VTEM-Max was flown at Rio Tinto and Las Cruces. In addition, the SkyTEM and CGG HeliTEM systems were flown at Las Cruces.

Further information & references:

- Dentith, M., and Mudge, S.T., 2014, Geophysics for the mineral exploration geoscientist: Cambridge University Press, 454 pp.
- Legault, J., 2015, Airborne electromagnetic systems–state of the art and future directions: CSEG Recorder, v. June, p. 38–49.
- McNeill, J.D., 1980, Applications of transient electromagnetic techniques: Geonics Limited, 15 pp.
- Sattel, D., 2009, An overview of Helicopter Time-Domain EM systems: ASEG Extended Abstracts, v. 2009, p. 1–7, doi: 10.1071/ASEG2009ab049.
- Sørense, K.I., and Auken, E., 2004, SkyTEM – a new high-resolution helicopter transient electromagnetic system: Exploration Geophysics, v. 35, p. 194–202, doi: 10.1071/eg04194.
- Witherly, K., Irvine, R., and Morrison, E., 2004, The geotech VTEM time domain helicopter em system: ASEG Extended Abstracts, v. 2004, p. 1–4, doi: 10.1071/ASEG2004ab162.

1.3.2 Airborne gravity gradiometry (AGG): Full Tensor Gravity Gradiometry (FTG)

Gravity gradiometer technology uses a spatially separated pair of accelerometers mounted on a common base to measure minute differences in the Earth's density field, yielding information on subsurface geologic structures. Airborne gravity gradiometry provides rapid acquisition of accurate gravity data at high spatial resolution with complete coverage over large areas. Compared to airborne or ground gravity measurements, airborne gradiometry provides higher density data with higher signal-to-noise ratio. FTG measures the full gravity field in all directions and thus provides more accurate information on depth, shape, and orientation of the target of interest.

Three oil and mineral exploration contractors currently fly AGG equipment: CGG with Falcon-AGG, HeliFalcon and Falcon Plus; Bell Geospace with FTG; and AustinBridgeporth with FTG.

Gravity gradiometry is an excellent tool to map geological features, such as faults, weathering profiles and lithologies, particularly under cover. The technology was initially commercialised for the petroleum exploration industry to assist with defining complex salt structure/geometry. In mineral exploration, the original motivation for using gravity gradiometers was centred on diamond exploration, but the technique has proved useful for the exploration of other high-density targets such as iron oxide copper gold (IOCG) deposits, massive sulphide nickel–copper deposits, volcanogenic massive sulphide (VMS) copper and gold deposits, iron ore deposits, and silver–lead–zinc deposits. Conversely, it is also suitable for the exploration of low density deposits such as coal and alluvial diamonds.

Apart from oil, gas and mineral exploration, gravity gradiometer technology finds application in aquifer detection, geothermal exploration, underwater navigation and collision avoidance, underground tunnel and void detection, at ports and airports for static density signature monitoring of container cargo imports (to detect hazardous substances such as explosives).

AGG has not yet been applied in the INFACT project.

Further information & references:

- Dransfield, M.H., and Christensen, A.N., 2013, Performance of airborne gravity gradiometers: Leading Edge, v. 32, p. 908–922, doi: 10.1190/tle32080908.1.
- Fairhead, J.D., Cooper, G., and Sander, S., 2017, Advances in Airborne Gravity and Magnetics, In "Proceedings of Exploration 17: Sixth Decennial International Conference on Mineral Exploration" edited by V. Tschirhart and M.D. Thomas, 2017, p. 113–127.
- Pilkington, M., 2013, Evaluating the utility of gravity gradient tensor components: Geophysics, v. 79, p. G1–G14, doi: 10.1190/GEO2013-0130.1.
- Veryaskin, A.V., 2018, Gravity, Magnetic and Electromagnetic Gradiometry: Strategic Technologies in the 21st Century: Chapter 1: Gravity gradiometry, doi: https://doi.org/10.1088/978-1-6817-4700-2ch1.

1.3.3 Airborne magnetometry: Full Tensor Magnetic Gradiometry (FTMG)

Magnetic surveying is a passive technique that measures the direction, strength, or relative change of a magnetic field at a particular location. Magnetometers can be used to study anomalies in the geomagnetic field resulting from the magnetic properties of the underlying rocks (magnetic susceptibility and remanence). Magnetic data can be used to directly detect magnetically anomalous mineral deposits, and indirectly to identify geologically favourable sites for potential mineralization. If the magnetic properties of rock units are known, then forward and inverse modelling techniques can be applied to gain insight into the three-dimensional geological structure.

Full tensor magnetic gradiometer (FTMG) systems are based on liquid helium or nitrogen cooled Superconducting Quantum Interference Devices (SQUIDs) providing measurements of the full magnetic gradient tensor of the Earth's magnetic field. SQUIDs have a higher sensitivity compared to traditional magnetometers which means they provide data at higher resolution. SQUIDs measure the changes of the magnetic field in all directions, which make them great edge detectors and allow the reconstruction of the complete magnetisation vector to estimate both direction and intensity of induced and remanent magnetization for more robust geological interpretation in mineral exploration scenarios.

Non-geological applications of magnetics (including FTMG) include military applications (including mine detection, vehicle detection, and target recognition), archaeological investigations, and engineering/construction site investigations.

In the INFACT project, a magnetic gradiometry survey was performed over the Sakatti and Geyer reference sites using a Superconducting Quantum Interference Device (SQUID) by Supracon.

Further information & references:

- Beiki, M., Clark, D.A., Austin, J.R., and Foss, C.A., 2012, Estimating source location using normalized magnetic source strength calculated from magnetic gradient tensor data: Geophysics, v. 77, p. J23–J37, doi: 10.1190/geo2011-0437.1.
- Pedersen, L.B., and Rasmussen, T.M., 1990, The Gradient Tensor of Potential-Field Anomalies - Some Implications on Data-Collection and Data-Processing of Maps: Geophysics, v. 55, p. 1558–1566, doi: 10.1190/1.1442807.
- Queitsch, M., Schiffler, M., Stolz, R., Rolf, C., Meyer, M., and Kukowski, N., 2019, Investigation of three-dimensional magnetization of a dolerite intrusion using airborne full tensor magnetic gradiometry (FTMG) data: Geophysical Journal International, v. 217, p. 1643–1655, doi: 10.1093/gji/ggz104.
- Schmidt, P.W., and Clark, D.A., 2006, The magnetic gradient tensor: Its properties and uses in source characterization: Leading Edge (Tulsa, OK), v. 25, p. 75–78, doi: 10.1190/1.2164759.
- Schneider, M., Stolz, R., Linzen, S., Schiffler, M., Chwala, A., Schulz, M., Dunkel, S., and Meyer, H.G., 2013, Inversion of geo-magnetic full-tensor gradiometer data: Journal of Applied Geophysics, v. 92, p. 57–67, doi: 10.1016/j.jappgeo.2013.02.007.
- Stolz, R., Schiffler, M., Queitsch, M., Schönau, T., Schmelz, M., Goepel, A., Meyer, U., Kukowski, N., and Meyer, H.G., 2015, Why bother about gradients?-a SQUID based full tensor magnetic gradiometer for mineral exploration, in Netherlands, EAGE Publications BV, doi: 10.3997/2214-4609.201411992.

1.3.4 Drone-borne hyperspectral imaging (HSI): long-wave/thermal infrared, near infrared, short-wave infrared

In hyperspectral imaging, the spectral reflectance and emission properties of materials are recorded with high precision across certain regions of the electromagnetic spectrum. Absorptions and emissions in the infrared range occur due to different optico-physical phenomena causing characteristic spectral signatures for a variety of common geologic materials, including iron oxides, iron hydroxides, and iron sulfates as well as rare earth elements in the visible to near-infrared (VNIR, 0.4–0.9 µm); "alteration minerals", such as phyllosilicates, hydroxylated silicates, sulphates, carbonates, and ammonium minerals in the shortwave infrared (SWIR, 0.9–2.5 µm); and rock-forming minerals including silicates (notably tectosilicates like quartz and feldspar), oxides, carbonates, hydroxides, sulfates, and phosphates in the long-wave infrared range (LWIR, 7.7–11.8 µm). Hyperspectral images can thus be used in mineral exploration to identify and map minerals and rocks exposed at the surface.

Hyperspectral sensors are being deployed on unmanned aerial vehicles (UAVs) as emerging tools for exploration targeting because they present an accessible, cost- and time-efficient means for acquiring high-resolution, multi-sensor, multi-temporal and multi-perspective data. There are UAV-mountable hyperspectral cameras in the VNIR, SWIR and LWIR range of the electromagnetic spectrum. For LWIR, there are only prototypes of UAV sensors, whereas both VNIR (e.g. Senop Optronics Hyperspectral Imager; Cubert UHD 185-Firefly) and SWIR UAV sensors (e.g. HySpex Mjolnir

VS-620; Headwall co-aligned) are commercially available. However, to date, only geologic case studies based on UAV VNIR have been published, and none based on SWIR sensors, which are relatively new sensors on the market.

Apart from geological applications, hyperspectral imagery acquired from drones may also be useful in natural hazard assessment (slope stability, seismic risk, volcanic hazard), military (camouflage, gas detection), civil engineering (building material strength analysis, concrete crack detection, heritage preservation), environmental (detection of methane emissions), archeology, and industrial (gas leak detection, combustion analysis) applications.

In the INFACT project, drone-borne hyperspectral imaging has been employed in the Rio Tinto reference area.

Further information & references:

- Booysen, Zimmermann, Lorenz, Gloaguen, Nex, Andreani, and Möckel, 2019, Towards Multiscale and Multisource Remote Sensing Mineral Exploration Using RPAS: A Case study in the Lofdal Carbonatite-Hosted REE Deposit, Namibia: Remote Sensing, v. 11, p. 2500–28, doi: 10.3390/rs11212500.
- Jackisch, R., Lorenz, S., Zimmermann, R., Möckel, R., and Gloaguen, R., 2018, Drone-borne hyperspectral monitoring of acid mine drainage: An example from the Sokolov lignite district: Remote Sensing, v. 10, doi: 10.3390/rs10030385.
- Jackisch, R., Madriz, Y., Zimmermann, R., Pirttijärvi, M., Saartenoja, A., Heincke, B.H., Salmirinne, H., Kujasalo, J.P., Andreani, L., and Gloaguen, R., 2019, Drone-borne hyperspectral and magnetic data integration: Otanmäki Fe-Ti-V deposit in Finland: Remote Sensing, v. 11, doi: 10.3390/rs11182084.
- Jakob, S., Zimmermann, R., and Gloaguen, R., 2017, The Need for Accurate Geometric and Radiometric Corrections of Drone-Borne Hyperspectral Data for Mineral Exploration: MEPHySTo—A Toolbox for Pre-Processing Drone-Borne Hyperspectral Data: Remote Sensing, v. 9, p. 88–17, doi: 10.3390/rs9010088.
- Kirsch, M., Lorenz, S., Zimmermann, R., Tusa, L., Möckel, R., Hödl, P., Booysen, R., Khodadadzadeh, M., and Gloaguen, R., 2018, Integration of Terrestrial and Drone-Borne Hyperspectral and Photogrammetric Sensing Methods for Exploration Mapping and Mining Monitoring: Remote Sensing, v. 10, p. 1366–30, doi: 10.3390/rs10091366.

2 METHODOLOGY

2.1 Workflow

The working methodology of IDEA for elaborating the present technology watch report (Fig. 2) is based on the established and recognized general competitive intelligence workflow (as outlined in chapter 1.2) and includes three roles:

- Technology Watch / Information specialist from IDEA who is coordinating the work and who is in charge of executing most of the steps
- Collaborators are persons from INFACT that have participated in the technology needs survey (see next chapter).
- The Validator/Expert is the main scientific coordinator of the INFACT project.

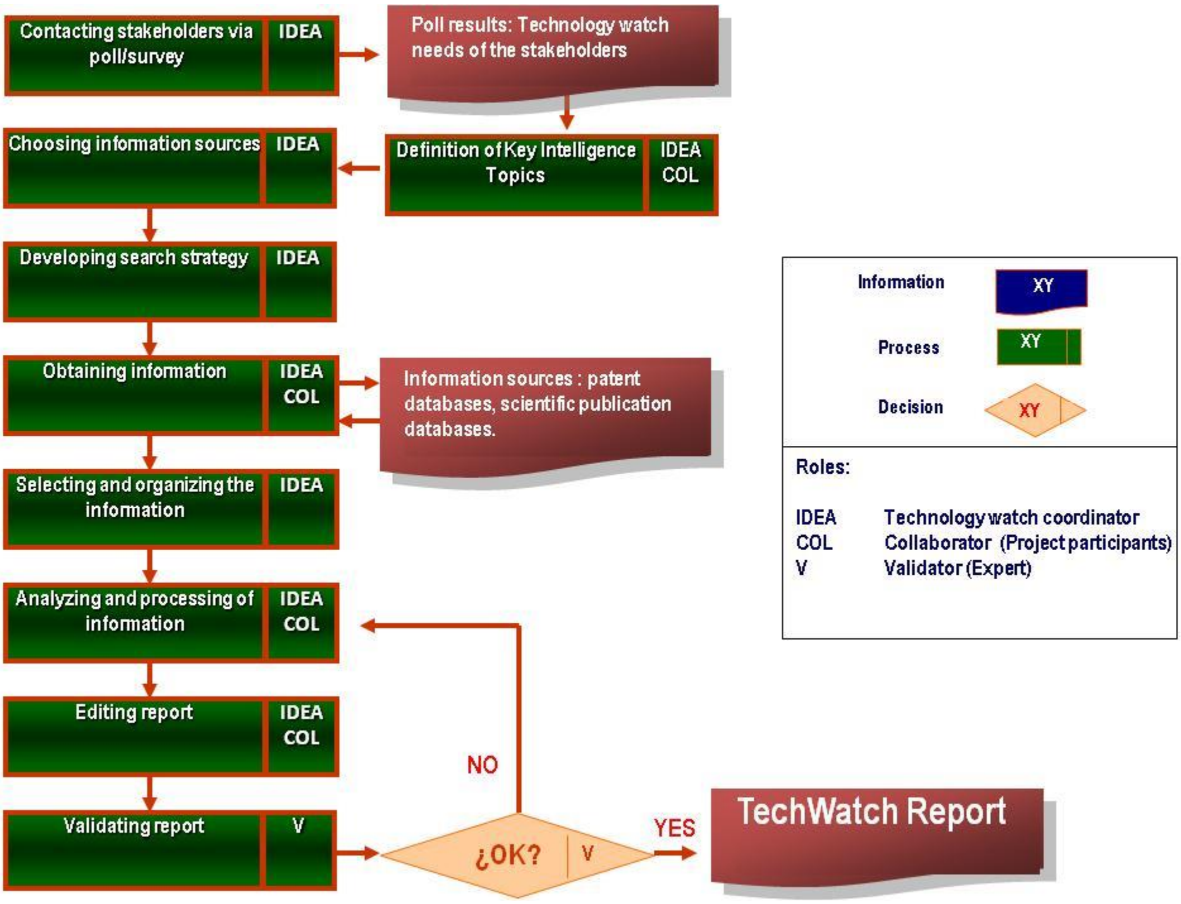


Fig. 2 IDEA workflow of technology watch

2.2 Needs analysis

Mid April 2019 the technology needs survey was sent out to the INFACT partners. The full questionnaire can be found in Annex A. As of 20th May 2019, 11 responses had been received from the project partners. A sum up of all responses can be found in Annex B.

Based on the survey results (see Annex B) four relevant technologies for INFACT that most participants mentioned were identified (Table 2). These four technology groups (further explained in chapter 1.3) thus were established as the key intelligence topics (KITs) to be analysed in this present study.

Key Intelligence Topics	Technologies
AIRBORNE ELECTROMAGNETIC METHODS	*Airborne electromagnetics (AEM) ; Airborne transient electromagnetic (ATEM)*
AIRBORNE GRAVITY GRADIOMETRY	*Full Tensor Gravity Gradiometry (FTG)*
AIRBORNE MAGNETOMETRY	*Full Tensor Magnetic Gradiometry (FTMG)*
DRONE-BORNE HYPERSPECTRAL IMAGING	*long-wave/thermal infrared, near infrared, short-wave infrared*

Table 2 Technology watch survey results – key intelligence topics

2.3 Data sources

Patent data and scientific publication data were retrieved using the following databases:

- Patents documents: Questel Orbit Intelligence (ORBIT)[3]
- Scientific publications: Clarivative Web of Science - Core Collection (WOS)[4]

Both sources provide worldwide coverage and are recognised expert commercial databases with advanced searching and analysis tools. They are available to the authors since they are licensed at their organisations.

2.4 Development of search strategy and data set generation

For each of the four key intelligence topics relevant keywords were identified. The keywords were then grouped in 3 concept categories as shown in the following table, and were searched in the title, abstract or claims section of the patent documents and title, abstract, keyword section of the scientific publications. Truncation (+ or * symbol) was used when needed in order to broaden the search and to include keyword variants.

Key Intelligence Topic	AIRBORNE ELECTROMAGNETIC METHODS	AIRBORNE GRAVITY GRADIOMETRY	AIRBORNE MAGNETOMETRY	DRONE-BORNE HYPERSPECTRAL IMAGING
KEYWORDS concept 1 (TI/AB/CLMS)	*AERIAL OR AERO OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER*	*AERIAL OR AERO OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER*	*AERIAL OR AERO OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER*	*DRONE OR UAV OR ((UNMANNED OR UNCREWED) AND (AIR+ OR AERIAL))*
KEYWORDS concept 2 (TI/AB/CLMS)	*ELECTROMAGNETIC+*	*GRAVIT+ OR GRADIOMET+ OR FULL_TENSOR_GRAVI+ OR EFTG OR FTG*	*FULL_TENSOR_MAGNET+ OR MAGNETOMET+ OR SQUID OR FTMG OR NITROGEN_VACANC+*	*HYPER_SPECTR+ OR MULTI_SPECTR+*
KEYWORDS concept 3 (TI/AB/CLMS)	*SURVEY+ OR MAPPING OR PROSPECT+ OR EXPLOR+*	*SURVEY+ OR MAPPING OR PROSPECT+ OR EXPLOR+*	*SURVEY+ OR MAPPING OR PROSPECT+ OR EXPLOR+*	*None*

Table 3 Keyword concept groups of key intelligence topics

For the patent documents retrieval the keyword concepts furthermore were combined with several patent classifications that were also grouped in concepts (Table 4, for the detailed search strategy see Annex C). The classification codes were searched in the two most important patent classification schemes, the Cooperative Patent Classification (CPC) and the International Patent Classification (IPC), both alphanumerical classification schemes with similar structure[5].

Key Intelligence Topic	AIRBORNE ELECTROMAGNETIC METHODS	AIRBORNE GRAVITY GRADIOMETRY	AIRBORNE MAGNETOMETRY	DRONE-BORNE HYPERSPECTRAL IMAGING
CPC/IPC concept 1	*none*	*none*	*none*	*B64C2201 Unmanned aerial vehicles;*

[3] www.orbit.com
[4] www.webofknowledge.com
[5] see Glossary

CPC/IPC concept 2	*none*	*G01V7 Measuring gravitational fields or waves; Gravimetric prospecting or detecting*	*G01V3/175 ...operating with electron or nuclear magnetic resonance*	*G01J3 (Spectrometry) G06K2009/00644 using hyperspectral data, i.e. more or other wavelengths than RGB*
CPC/IPC concept 3	*G01V3 Electric or magnetic prospecting or detecting*	*G01V7 Measuring gravitational fields or waves; Gravimetric prospecting or detecting*	*G01V3 Electric or magnetic prospecting or detecting*	*G01N21/35 Investigating or analysing materials by the use of optical means... using infra-red light*

Table 4 CPC/IPC concept groups of key intelligence topics

For the scientific publications retrieval the keyword concepts were combined and with subject categories offered by the database. The following categories were chosen to refine the results:

- GEOSCIENCES MULTIDISCIPLINARY
- GEOCHEMISTRY GEOPHYSICS
- REMOTE SENSING

2.5 Types of Analysis

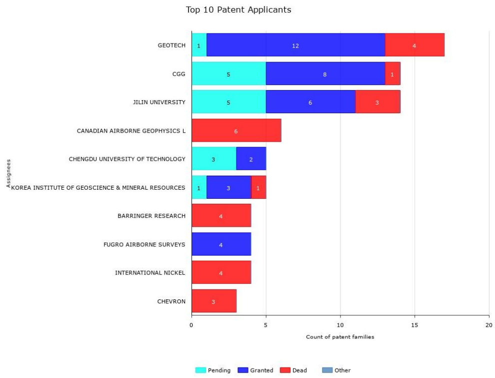
The following analysis and visualizations were applied to all four INFACT technologies:

KEY PLAYERS – Patents

This analysis shows the size of the patent applicants' portfolios in the technology field and is an indicator of the level of inventiveness of the active players. The analysis not only presents the top applicants in the group of patents analysed, but also their legal status. This information makes it possible to identify applicants who have already withdrawn from the sector (abandonment, lapse and/or expiration of their patents) and those who are still active (applications and patents granted still in force).

Furthermore the granted and pending (to be granted) patents of the most important players are listed, and the patent that is active in most jurisdictions is marked in bold. For jurisdiction country code description see Glossary => Country Codes. The number of countries where an invention is protected by a patent (patent family size) can be considered as an indicator of the importance of the invention.

Source: Questel Orbit and own research



Patent title and reference number	Jurisdictions	
	in force	pending
Airborne electromagnetic (em) survey system (AU2012204041)	AU	
Airborne electromagnetic (em) survey system (MX2008008390)	MX	
Airborne electromagnetic (em) survey system 10 (US20080246484)	**CA, US, AU, ZA**	
Unmanned airborne vehicle for geophysical surveying (WO2006/037237)	ZA	

KEY PLAYERS – Scientific publications

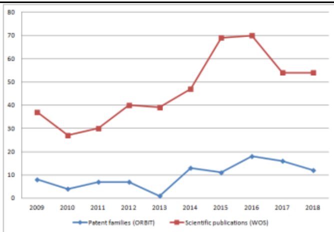
This analysis shows the research effort of institutions in the technology field, how many scientific publications have been published (articles & conference proceedings). It helps us to detect the organizations that are researching in the field (mainly basic research).

Source: Web of Science and own research

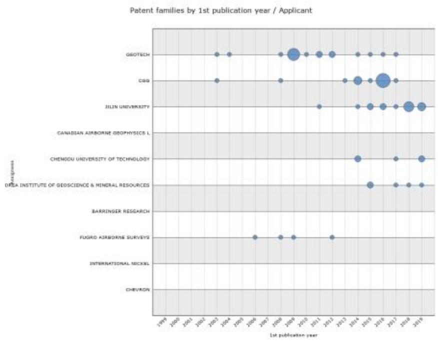
Research institution	# papers
AARHUS UNIVERSITY (DK)	64
JILIN UNIVERSITY (CN)	46
GEOLOGICAL SURVEY OF DENMARK AND GREENLAND (DK)	33
FUGRO (NL)	26
GEOLOGICAL SURVEY OF CANADA (CA)	26
COMMONWEALTH SCIENTIFIC INDUSTRIAL RESEARCH ORGANISATION (AU)	23
UNITED STATES GEOLOGICAL SURVEY (US)	23
CHINESE ACADEMY OF SCIENCES (CN)	21
UNIVERSITY OF BRITISH COLUMBIA (CA)	21
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (FR)	20
ROYAL MELBOURNE INSTITUTE OF TECHNOLOGY (AU)	19
LEIBNIZ INSTITUT FUR ANGEWANDTE GEOPHYSIK (DE)	17
UNITED STATES DEPARTMENT OF ENERGY (US)	17
HELMHOLTZ ASSOCIATION (DE)	16
LAURENTIAN UNIVERSITY (CA)	16

EVOLUTION

This line chart graph shows the evolution in total of patent and scientific publications and illustrates the evolution of the technology and the top applicants /institutions over time, indicating the dynamics of inventiveness of the portfolio studied. The first line chart graph shows the evolution in total, comparing patenting and scientific publications.



The bubble chart shows the patenting behaviour of the top applicants (bubble size corresponds to number of filed patents in that year).



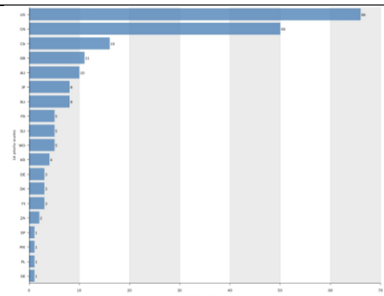
On both maps different types of profiles can be observed. Thus, a sector with linear growth shows actors' continued interest in the field without their needing to construct massive portfolios. Conversely, a sector with exponential growth is indicative of a race for a patent. When the number of applications filed decreases, it is indicative of the disengagement of the actors of the field, while a stable profile is a sign of sector maturity. It is also possible to distinguish peaks or troughs in the number of applications filed, depending on R&D budgets or broader economic or even strategic changes. Important: There will always be a gap in current patent information due to the 18-month delay between the filing of an application and its publication.

Source: Questel Orbit, Web of Science and own research

INNOVATION ORIGIN - Patents

This analysis illustrates the countries where a patent was filed for the first time (the priority patent). These are usually the countries where the invention originates and thus can give us information about the geographical origin of innovations.

Source: Questel Orbit and own research



INNOVATION ORIGIN – Scientific publications

This analysis illustrates the countries of residence of the corresponding authors institution and can give us insight into the country where the research originated

Source: Web of Science and own research

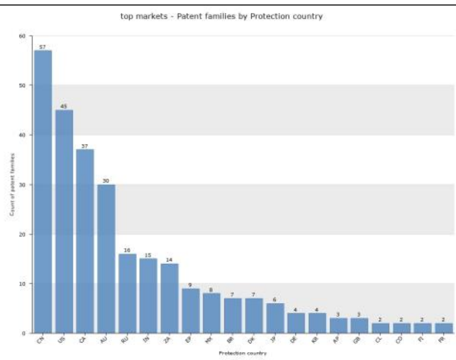
Institution country	# papers
CANADA	153
USA	150
AUSTRALIA	114
DENMARK	98
CHINA	88
GERMANY	62
ITALY	36
ENGLAND	32
FRANCE	29
NORWAY	24
JAPAN	23
SWEDEN	18
FINLAND	17
NETHERLANDS	15
AUSTRIA	12

MARKETS

This analysis illustrates the number of published patents in the various national Offices.

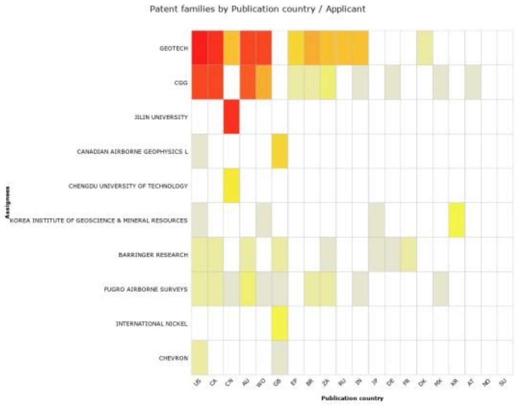
The first bar graph provide the number of alive patents protected in the various national Offices ("protection country") and thus can give us information on the patent strategies of the actors in the sector studied, as the national filings are a good indicator of the markets that need to be protected.

Note: Some players protect the geographical areas where the manufacturing sites of their competitors are located.



The second visualization is a heat map that provides information about countries where the top 10 applicants of each INFACT technology field protect their inventions the most. Patent families with more than one member in a specific country will only be counted once for that country. However, you can find the same family in several portions of the chart if members of that family have been published in different countries or are co-owned. The intensity of the colour (heat graph) reflects the number of families in the intersection.

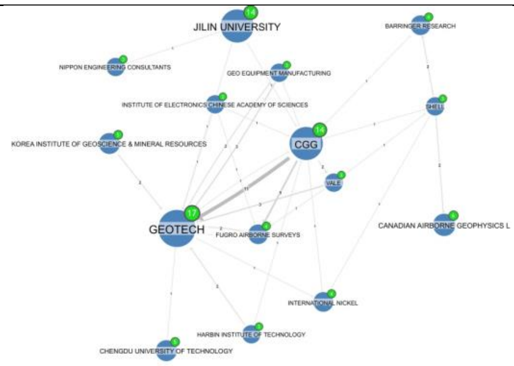
Source: Questel Orbit and own research



PATENT CITATION & COLLABORATION MAPS

This analysis shows via node maps connections between applicants. Patent citation maps visualise connections via citations (citation direction via arrow). A portfolio that is strongly cited by most players is likely to be a pioneering or a blocking portfolio. Patent collaboration maps visualise connections via co-authorship (inventorship) and reveals cooperation between applicants since they are co-filing a patent (co-authorship via line).

Source: Questel Orbit and own research



TOP PATENTS

This analysis lists the top inventions of each of the 4 analysed INFACT technologies with its title, abstract and representative image. For evaluating the quality or importance of a patent the following four established patent value indicators were taken into account:

- Number of citations received
- Number of jurisdictions where the patent is pending or granted
- Number of litigated inventions
- Number of opposed inventions

A detailed list with the corresponding indicator values and patent reference numbers is shown in the Annex of the present study.

Source: Questel Orbit and own research

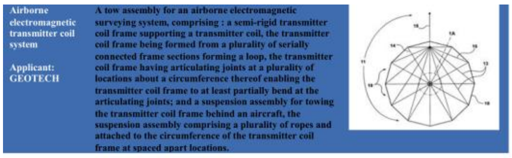


Table 5 Types of analysis

3 TECHNOLOGY WATCH RESULTS

The search queries that were established for each Key Intelligence Topic yielded a total of 669 patent families[6] and 2019 scientific publications, distributed in the following manner (Table 6):

Key Intelligence Topic	AIRBORNE ELECTROMAGNETIC METHODS	AIRBORNE GRAVITY GRADIOMETRY	AIRBORNE MAGNETOMETRY	DRONE-BORNE HYPERSPECTRAL IMAGING	Total Documents
Patent families (ORBIT)	**203**	**134**	**156**	**176**	**669**
Scientific publications (WOS)	**772**	**1002**	**168**	**77**	**2019**

Table 6 Query results

The patent document numbers are low for a patent analysis exercise (which usually deals with big data, e.g. 10.000+ documents), but this is due to the fact that the INFACT technologies seem to be niche technologies.

Especially in the fields of EM methods and gravity gradiometry considerably more scientific publications were retrieved than patents. This can show us that these INFACT technologies still involve a considerable amount of basic research. Drone-borne hyperspectral imaging technologies seem to be more applied to the market with more patents than scientific works. Airborne magnetometry has yielded similar number of documents on patents and scientific publications.

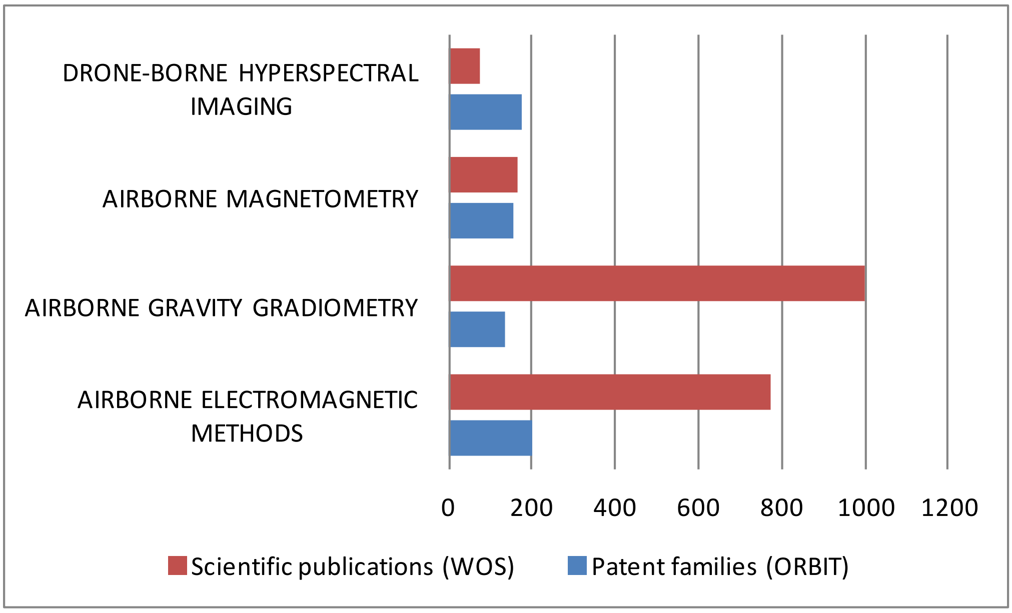


Fig. 3 INFACT technology fields retrieved documents

As for the distribution, all technologies seem to have a similar amount of patents, whereas in scientific publications half of the documents deal with airborne gravity gradiometry (Fig. 4).

[6] Patent families are used in patent statistics to count per invention and not per document since the same invention disclosed by a common inventor(s) due to the territoriality of the patent system can be patented in more than one country and thus generates a patent document in every country where protection is sought (see also glossary)

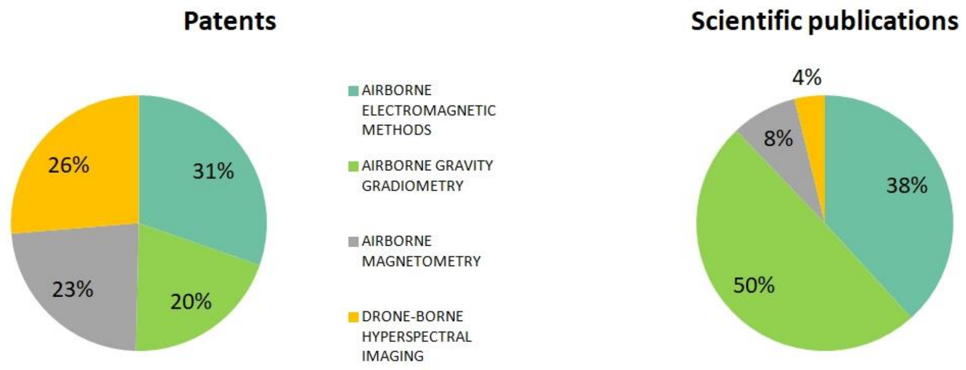


Fig. 4 Distribution of retrieved patents (left) and scientific publications (right)

To indicate trends the patenting and the scientific publishing activities of the four KITs were mapped over a timespan of ten years (Fig. 5 & Fig. 6).

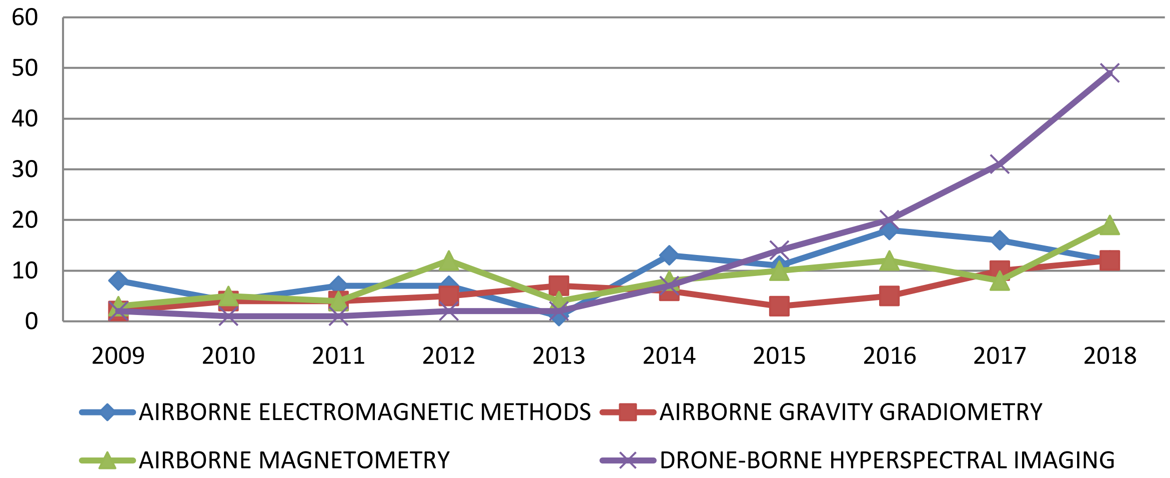


Fig. 5 Patenting of less-invasive technologies

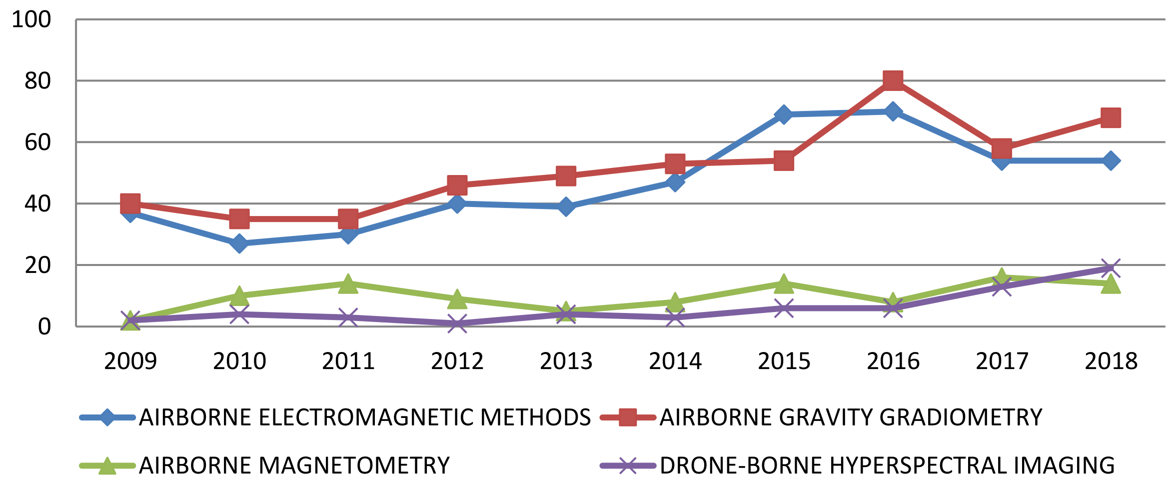


Fig. 6 Scientific publishing of less-invasive technologies

It is apparent that over the last ten years all four KIT's show an increase in patenting activity. Closer inspection shows that drone-borne hyperspectral imaging show highest patenting activity. Despite the strategic importance of airborne electro-magnetics indicated by the experts, in airborne electro-magnetics no heightened patenting activities can be recorded. The peak of patenting activity in 2016 is consequently somewhat counterintuitive.

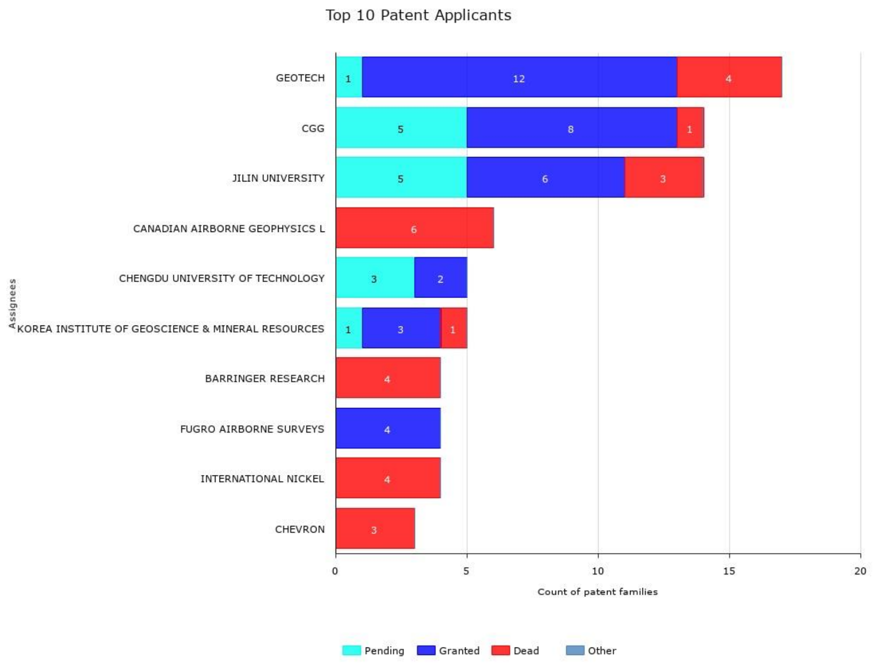
Regarding scientific publications it can be seen that by far the greatest publishing activity is in airborne gravity gradiometry and airborne electromagnetic methods. There is a clear difference between the publishing activity in airborne electromagnetic methods and airborne gravity gradiometry compared to airborne magnetometry and drone-borne hyperspectral imaging. The discrepancy is especially apparent in 2016.

Comparing the patenting and the scientific publishing activities the results are somewhat surprising. For three out of four KIT's patent activity show clear upwards trends throughout the years, while publishing activity for airborne electromagnetic and airborne gravity gradiometry, show an upwards trends over the years with airborne magnetometry and drone-borne hyperspectral remaining somewhat stable over the years. Interestingly, the peak in airborne electromagnetic patenting in 2016 is also shown in the publishing activities in this KIT. Taken together, these results suggest that hyperspectral imaging receives most recent attention in patenting activities, while airborne gravity gradiometry is most popular in publishing.

3.1 AIRBORNE ELECTROMAGNETIC METHODS

3.1.1 Top key players - Patents

In airborne electromagnetic methods the Canadian GEOTECH[7] (INFACT partner) is the leading company in patenting activity with a total of 17 patent applications: 12 of them granted and 1 pending (Fig. 7 and Table 7).



[7] http://geotech.ca

Fig. 7 Airborne electromagnetic methods top key players – Patents (Source: Questel Orbit)

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions [8]	
	in force	pending
Monitoring the dipole moment vector of an airborne electromagnetic survey system (US20170123094)	US	
Electromagnetic survey system having tow assembly with attitude adjustment (WO2016/134483)	US, ZA	
Calibrated electromagnetic survey system (EP2906969)	AU, CN, US, RU, ZA	
Monitoring the dipole moment vector of an airborne electromagnetic survey system (WO2012/119254)	AU, US	IN
Receiver coil assembly for airborne geophysical surveying with noise mitigation (EP2504723)	CA, AU, CN, RU, ZA, US	**IN**
Tow assembly for fixed wing aircraft for geophysical surveying (EP2491433)	CA, AU, CN, , RU, ZA, US	IN, BR
Bucking coil and b-field measurement system and apparatus for time domain electromagnetic measurements (EP2324366)	US, AU, CN, RU, ZA	IN
Double-suspension receiver coil system and apparatus (EP2291684)	**US, AU, CA, FI, GB, SE, CN, RU, ZA**	IN
Airborne electromagnetic transmitter coil system (EP2247966)	US, AU, CA, DK, CN, RU, ZA	IN
Suspension net for airborne surveying (WO2008/071006)	US, AU, CA, IN	
Airbone electromagnetic time domain system, computer product and method (WO2004/046761)	CA, AU, CN, US, RU	
System, method and computer product geological surveying utilizing natural electromagnetic fields (US20030094952)	CA, US	
Electromagnetic surveying at low frequencies using an airborne transmitter with receivers on the ground (WO2015/085426)	-	CA

Table 7 GEOTECH airborne electromagnetic methods patents

Other important players in the field are the French Geoscience company CGG[9], with 14 patent applications in total (8 of them granted and 5 pending, Table 8) and the Dutch Geo-data specialist Fugro with 4 granted patents (Table 9).

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Apparatus for airborne geophysical prospecting using both natural and controlled source fields and method (US20160231449)	US	CA, AU
Multi-sensor system for airborne geophysical prospecting and method (US20180180758)	US	CA
Geophysical survey system using hybrid aircraft (US20160161625)	US	
Multiple receivers for airborne electromagnetic surveying (WO2014/047730)	US	CA, AU
Airborne electromagnetic system with large suspension coil assembly (WO2014/026275)	AU, US	CA
Airborne electromagnetic system with rigid loop structure comprised of lightweight modular non-rotational frames (WO2013/067624)	AU, US, ZA	CA
Airborne electromagnetic (em) survey system[10] (US20080246484)	CA, US, AU, ZA,	
Airborne geophysical measurements (EP1444536)	**AT, CA, MX, US, AU, ZA, DE**	
Apparatus and method for determining earth's near-surface properties with on-time measurements from airborne time-domain electromagnetic data (WO2017/037536)	-	CA, AU, US

[8] For country code description see Glossary => Country Codes
[9] https://www.cgg.com
[10] In co-authorship CGG and FUGRO

Magnetometer signal sampling within time-domain em transmitters and method (CA2931211)	-	AU, CA
Apparatus and method for calculating earth's polarization properties from airborne time-domain electromagnetic data (US20160282498)	-	CA
Apparatus and method for compensating for receiver motion in airborne electromagnetic systems (WO2016/124964)	-	CA, AU, US
Systems and methods for a composite magnetic field sensor for airborne geophysical surveys (EP3111255)	-	CA

Table 8 CGG airborne electromagnetic methods patents

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Airborne electromagnetic (em) survey system (AU2012204041)	AU	
Airborne electromagnetic (em) survey system (MX2008008390)	MX	
Airborne electromagnetic (em) survey system [10] **(US20080246484)**	**CA, US, AU, ZA**	
Unmanned airborne vehicle for geophysical surveying (WO2006/037237)	ZA	

Table 9 FUGRO airborne electromagnetic methods patents

As for the public research institutions the Chinese Jilin University[11] is leading with 14 patent applications in total (6 of them granted and 5 pending, see Table 10), followed by the Chinese Chengdu University of Technology[12] (5 patent applications, 2 of them granted and 3 pending, see Table 11) and the Korean Institute of Geoscience & Mineral Resources[13] (5 patent applications, 3 of them granted and 1 pending, see Table 12). Both Chinese institutions only have patented their inventions in China and did not protect in other countries/jurisdictions (domestic patenting only).

Patent title and reference number	Jurisdictions	
	in force	pending
A kind of ztem posture compensation method based on the more base stations in ground (CN110244367)		CN
Aerial magnetic resonance underground water detecting device and method (CN109814161)		CN
Correction method for aeronautical electromagnetic three-dimensional attitude based on tipper response (CN109212613)		CN
A quasi-three-dimensional space constrained integral global inversion method for aero-electromagnetic data of fixed wing in time domain (CN108984818)		CN
Helicopter magnetic resonance and transient electromagnetic combined detection device and method (CN108919366)		CN
Frequency domain semi-airborne electromagnetic exploration method controlled frequency source detection signal pulse width modulation method (CN108427145)	CN	
Method for building and judging three-dimensional strip-shaped random fault zone model in aviation time domain (CN107991711)	CN	
Aviation electromagnetic data leveling method based on measuring line differential processing and principal component analysis (CN106970426)	CN	
Time-domain aviation electromagnetic data constraint polynomial fitting leveling method (CN106226828)	CN	
Ground-airborne time-domain electromagnetic data height correction method (CN105487129)	CN	
Frequency domain ground-to-air electromagnetic prospecting method (CN104597506)	CN	

Table 10 Jilin University airborne electromagnetic methods patents

[11] http://cie.jlu.edu.cn/Home/Home.htm
[12] http://www.cdut.edu.cn/english/
[13] https://www.nst.re.kr/nst_en/member/03_18.jsp

Patent title and reference number	Jurisdictions	
	in force	pending
Airborne transient electromagnetic survey of a physical simulation test device technology interior half (CN110333538)		CN
Joint inversion method for aviation transient electromagnetic data and aviation magnetotelluric data (CN110058317)		CN
Time domain aero-electromagnetic data inversion method based on conductivity-depth imaging (CN106338774)		CN
Land and air transient electromagnetism exploring method based on combined magnetism source technology (CN103576205)	CN	
Conductivity-depth conversion method for aviation transient electromagnetic data (CN103675926)	CN	

Table 11 Chengdu University of Technology airborne electromagnetic methods patents

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Electromagnetic exploration system based on airship with adjustable depth of investigation (KR10-1993364)	KR	
Aerial electromagnetic survey device (JP2018115901)		JP
Survey apparatus for airborne electromagnetic survey and survey method using same (KR101748109)	KR	
Airship-based electromagnetic exploration device (WO2015/133810)	**KR, US**	

Table 12 Korean Institute of Geoscience & Mineral Resources airborne electromagnetic methods patents

3.1.2 Top key players – scientific publications

As for the scientific output the Danish Aarhus University plays an important role being the institution that publishes the most in the field of airborne electromagnetic methods, followed by the Chinese Jilin University.

Research institution	# papers
AARHUS UNIVERSITY (DK)	64
JILIN UNIVERSITY (CN)	46
GEOLOGICAL SURVEY OF DENMARK AND GREENLAND (DK)	33
FUGRO (NL)	26
GEOLOGICAL SURVEY OF CANADA (CA)	26
COMMONWEALTH SCIENTIFIC INDUSTRIAL RESEARCH ORGANISATION (AU)	23
UNITED STATES GEOLOGICAL SURVEY (US)	23
CHINESE ACADEMY OF SCIENCES (CN)	21
UNIVERSITY OF BRITISH COLUMBIA (CA)	21
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (FR)	20
ROYAL MELBOURNE INSTITUTE OF TECHNOLOGY (AU)	19
LEIBNIZ INSTITUT FUR ANGEWANDTE GEOPHYSIK (DE)	17
UNITED STATES DEPARTMENT OF ENERGY (US)	17
HELMHOLTZ ASSOCIATION (DE)	16
LAURENTIAN UNIVERSITY (CA)	16

Table 13 Airborne electromagnetic methods top key players – Scientific publications

3.1.3 Evolution

Analysing the timeline of general patenting in the field of airborne electromagnetic methods over the last 10 years (Fig. 8) we can see a light increase over the years (with a trough in 2013 and peaks in 2014 and 2016) with an average of 10 patents published a year since 2010. As for the evolution in scientific publications we identify a similar development as in patenting, only slightly earlier, with a peak in the years 2015 and 2016. Contrary to the patent filing behaviour we do not detect such a trough in 2013 as in patenting.

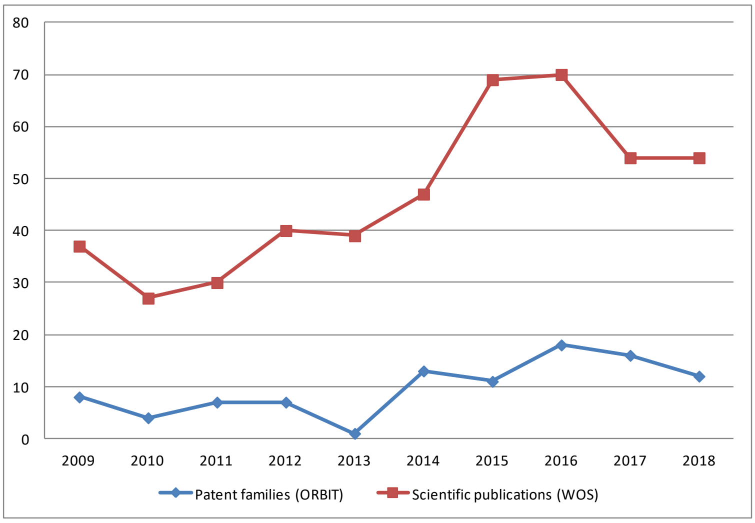


Fig. 8 Airborne electromagnetic methods evolution

When looking at the patenting evolution of the top 10 main players over the last 20 years (Fig. 9) we see that the Dutch Fugro patenting activity has stalled with no patent published since 2012. Geotech and CGG have published patents in the field of airborne electromagnetic methods since 2013 till 2017 but nothing since then. The Asian organisations (Jilin University, Chengdu University of Tec and especially the Korean Institute of Geoscience) seem to be the ones that generate innovations and protect them in most recent time (2017-2019). The 4 remaining companies have no patents in the field of airborne electromagnetic methods published in the time period, this is due that the patents in question are old (and in some cases the companies ceased to exist e.g. the Canadian Airborne Geophysics Ltd.).

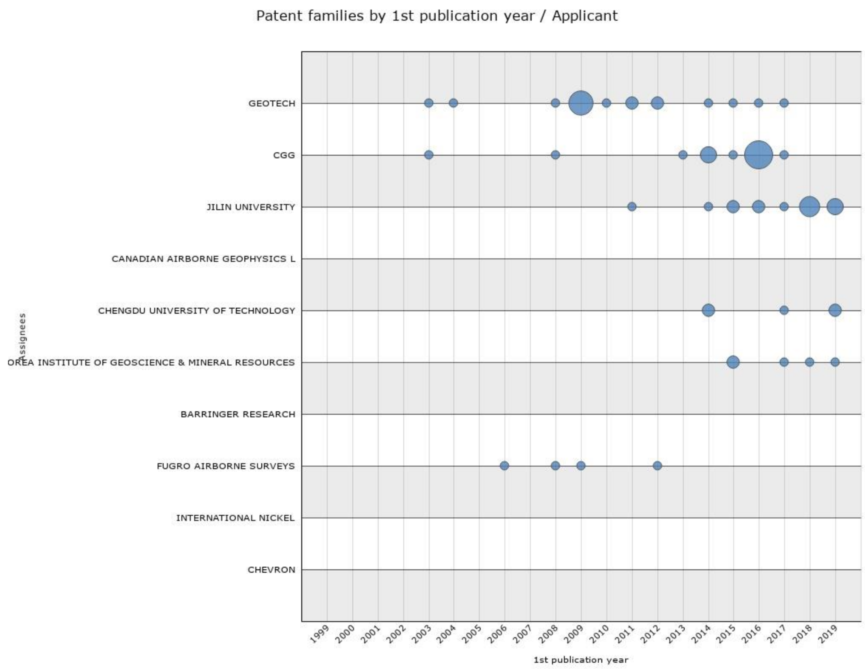


Fig. 9 Airborne electromagnetic methods key players patenting evolution (Source: Questel Orbit)

3.1.4 Innovation origin – patents

The country where an invention was filed for the first time, the priority patent application, is usually the country where the inventor is residing and thus can be considered as the innovation origin. In the case of airborne electromagnetic methods most inventions were originated in China and the US, followed by Canada.

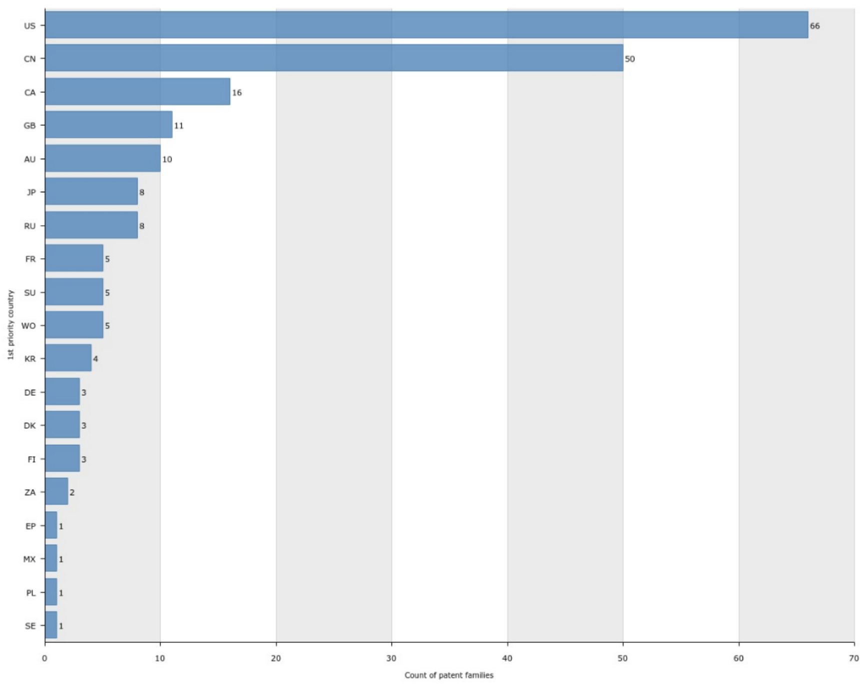


Fig. 10 Airborne electromagnetic methods innovation origin – patents (Source: Questel Orbit)

3.1.5 Innovation origin – scientific publications

When analysing the country of origin of scientific publications (by country of residence of the corresponding authors institution) we see a similar picture, with the difference that Canada and the US are leading, Australia and Denmark following and China is on 5th rank.

Institution country	# papers
CANADA	153
USA	150
AUSTRALIA	114
DENMARK	98
CHINA	88
GERMANY	62
ITALY	36
ENGLAND	32
FRANCE	29
NORWAY	24
JAPAN	23
SWEDEN	18
FINLAND	17
NETHERLANDS	15
AUSTRIA	12

Table 14 Airborne electromagnetic methods innovation origin – scientific publications (Source: WOS)

3.1.6 Markets

When analysing the countries where patent protection was sought we can identify the important markets, since the patent owner wants to protect its invention in these jurisdictions. Patents related to Airborne electromagnetic methods have been filed mainly in China, the US, Canada and Australia (Fig. 11). Most of the Chinese filings are domestic filings, meaning that Chinese applicants filed them only in China, whereas inventions that originated from other countries have been patented in more than one country (see also Fig. 10).

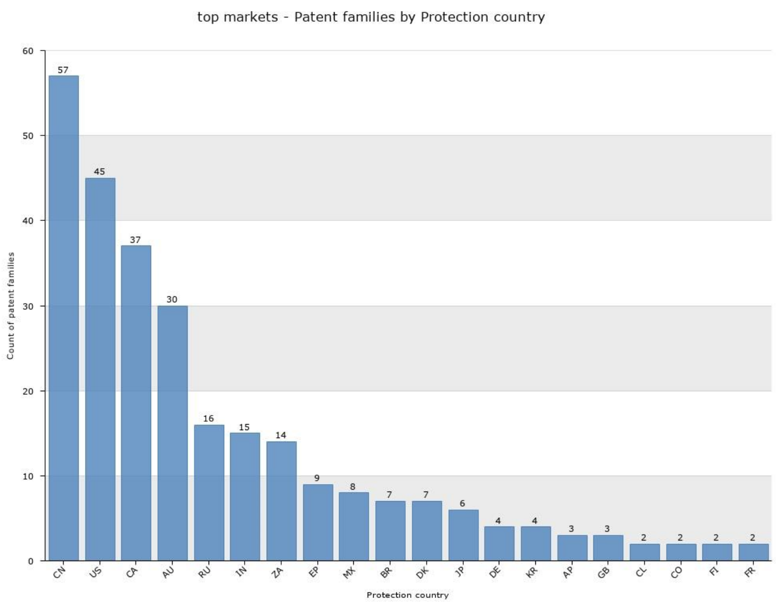


Fig. 11 Airborne electromagnetic methods – top markets (Source: Questel Orbit)

As for the applicants of inventions related to Airborne electromagnetic methods, both GEOTECH and CGG, have the most internationalised patent portfolio with patent filings in 11 countries / patent jurisdictions (Fig. 12).

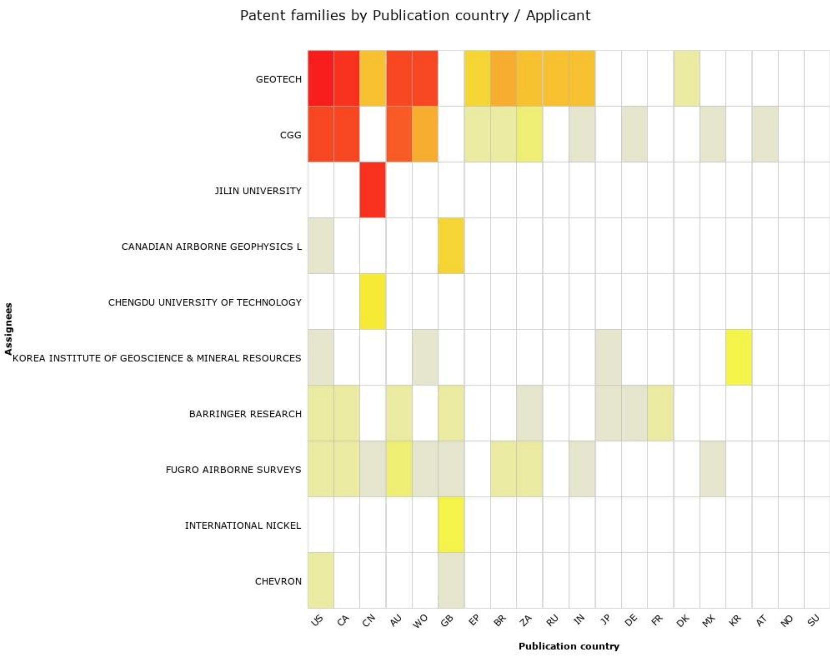


Fig. 12 Airborne electromagnetic methods – markets of top applicants (Source: Questel Orbit)

3.1.7 Patent citation & collaboration maps

When analysing patent citations of applicants a strong relation of patents from GEOTECH and CGG become evident, with 11 patents of CGG citing patents from GEOTECH. Also worth noting is the connection between CGG and FUGRO with 5 patents from CGG citing patents from FUGROs portfolio.

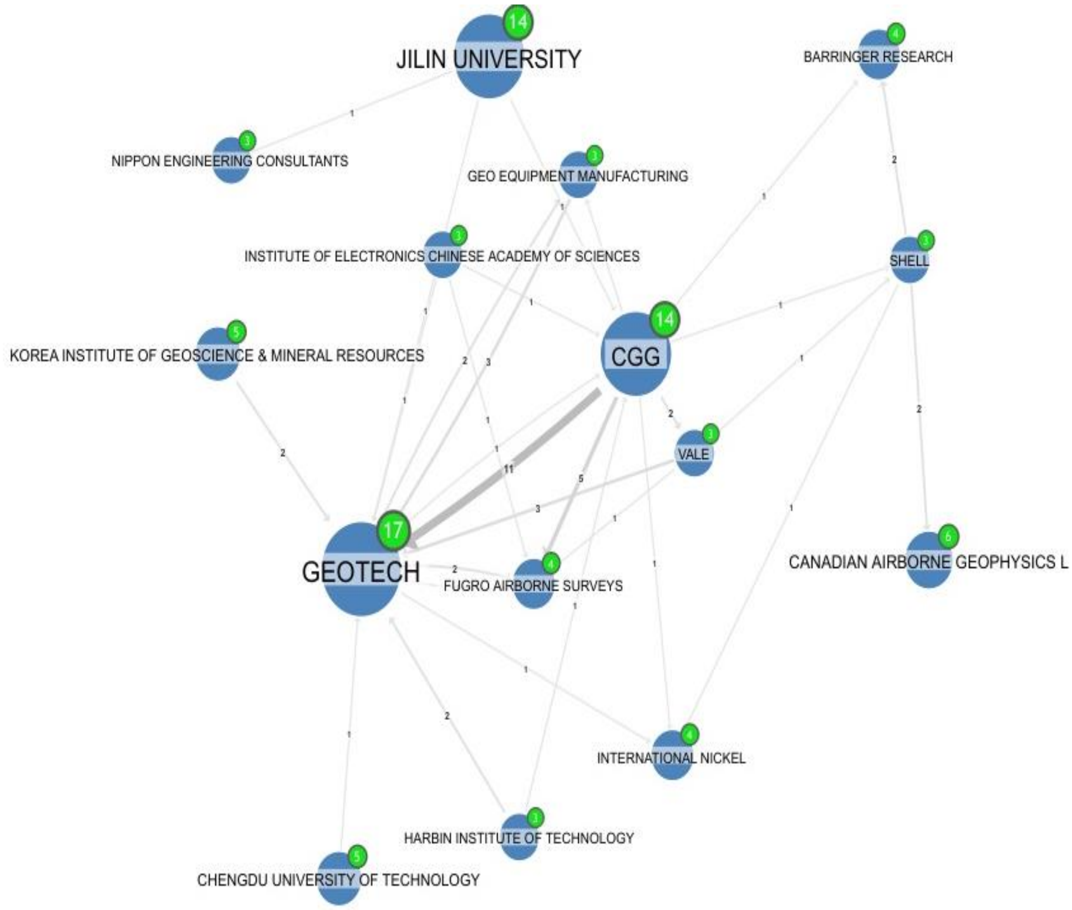


Fig. 13 Airborne electromagnetic methods patent citation node map[14] (Source: Questel Orbit)

If we analyse the co-authorship of patents few collaborations were detected, mostly only a single invention of the patent portfolios of the companies was co-authored with another company and nearly all of the collaborations were between applicants of the same country, with exception of the French CGG that co-authored one patent with the Dutch FUGRO.

[14] minimum 3 patents per applicant and minimum 1 citing patent

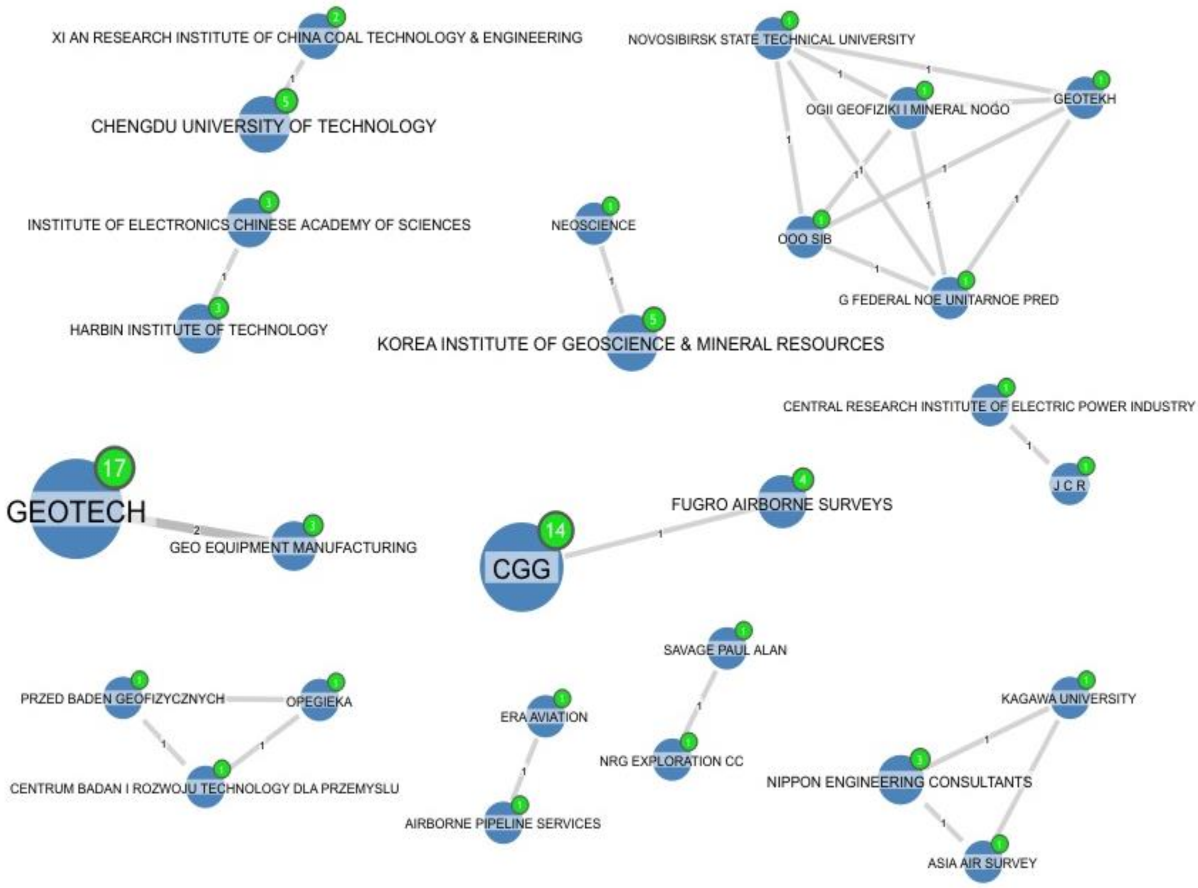
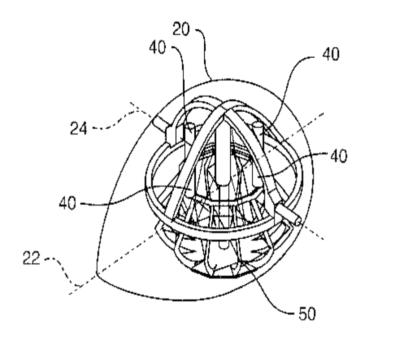


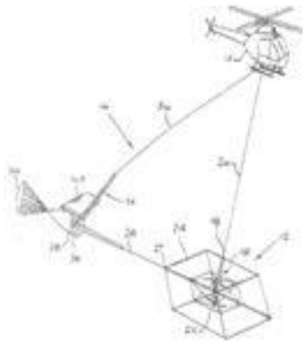
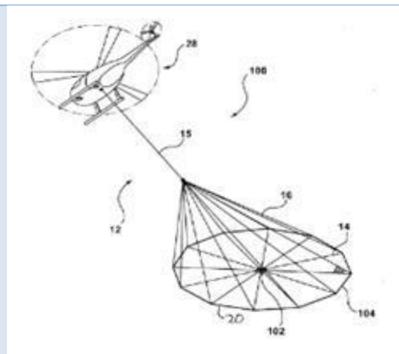
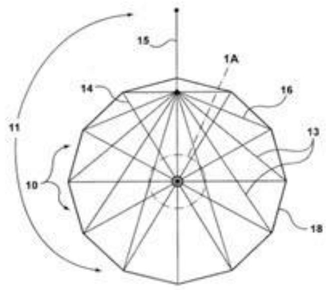
Fig. 14 Airborne electromagnetic methods patent collaboration node map[15] (Source: Questel Orbit)

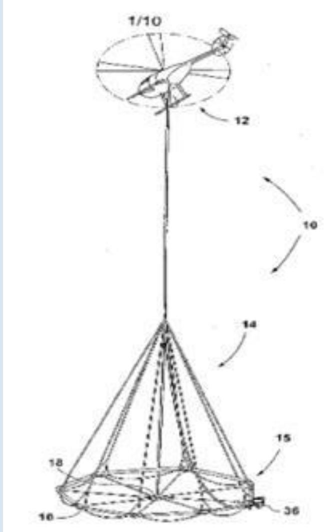
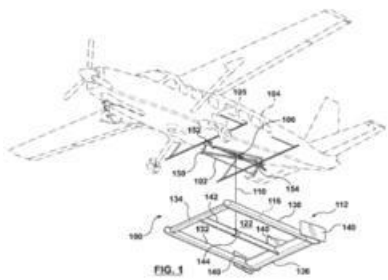
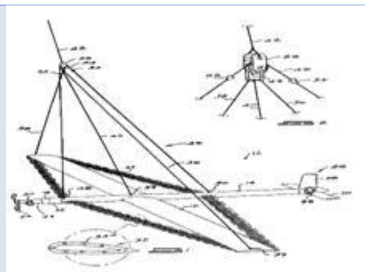
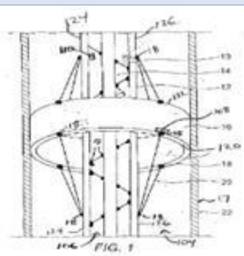
3.1.8 Top patents

The following table shows the top patents related to airborne electromagnetic methods, according to the indicators described in chapter 2.6 and detailed in the Annex.

Title & Applicant	Abstract	Image
Stabilization system for sensors on moving platforms **Applicant: VALE**	A stabilized field sensor apparatus collects field data, in particular magnetic field data, with reduced motion noise. The apparatus includes: tear drop shaped housing, tow frame in the housing, a plurality of vibration isolating dampers spaced around the frame, a base assembly mounted to the dampers, a support pedestal having a bottom end fixed to the base assembly and an upper free end, a single spherical air bearing connected to the upper free end of the pedestal, an instrument platform with a lower hollow funnel having an upper inside apex supported on the air bearing for a one point support, principal and secondary gyro stabilizers for maintaining pivotal and rotational stability, and at least one field sensor mounted to the instrument platform for collecting the field data while being stabilized against motion noise including vibration, pivoting and rotation from the base	

[15] minimum 1 patents per applicant and minimum 1 patent in co-authorship

	assembly, from the tow frame and from the housing.	
Helicopter electromagnetic prospecting system **Applicant: ANGLO AMERICAN**	An airborne electromagnetic prospecting system (10) is disclosed. The system (10) comprises a transmitter loop structure (12) hat is attached to, and arranged to be towed by, a helicopter (14). A transmitter (22) is fitted to the transmitter loop structure (12) for transmitting a primary electromagnetic field. A high drag bird (26) is attached to, and arranged to be towed by, the transmitter loop structure (12). A receiver (38) is fitted to the high drag bird (26) for receiving a primary and secondary resulting electromagnetic field, the secondary field arising from the interaction of the primary field with ground conductors that are traversed by the helicopter (14). Significantly, the high drag bird (26) is also attached to, and arranged to be towed by, the helicopter (14), so as to keep the position of the receiver (38) relative to the transmitter (22) substantially constant.	
Receiver coil assembly for airborne geophysical surveying with noise mitigation **Applicant: GEOTECH**	An airborne geophysical surveying system comprising a receiver coil assembly for towing by an aircraft, the receiver assembly including a receiver coil for sensing changes in a magnetic field component of a magnetic field, and a receiver coil orientation sensing system for sensing orientation changes of the receiver coil. A controller receives signals representing the sensed changes in the magnetic field component from the receiver coil and the sensed orientation changes from the receiver coil orientation sensing system and corrects the sensed changes in the magnetic field component to provide a signal that is corrected for noise caused by changing orientation of the receiver coil in a static geomagnetic field.	
Airborne electromagnetic transmitter coil system **Applicant: GEOTECH**	A tow assembly for an airborne electromagnetic surveying system, comprising: a semi-rigid transmitter coil frame supporting a transmitter coil, the transmitter coil frame being formed from a plurality of serially connected frame sections forming a loop, the transmitter coil frame having articulating joints at a plurality of locations about a circumference thereof enabling the transmitter coil frame to at least partially bend at the articulating joints; and a suspension assembly for towing the transmitter coil frame behind an aircraft, the suspension assembly comprising a plurality of ropes and attached to the circumference of the transmitter coil frame at spaced apart locations.	

Airbone electromagnetic time domain system, computer product and method **Applicant: GEOTECH**	An airborne time domain electromagnetic surveying system is provided. The system includes a tow assembly with a flexible support frame. The flexible support frame spaced apart from the aircraft includes a transmitter section with a transmitter loop and a receiver section with a sensor aligned with the central axis of the transmitter section. The flexible support frame has a lightweight modular structure that enables the surface area of the transmitter section to be increased and decreased to suit particular survey applications. The transmitter loop sends a pulse in an "ON" interval, and in an "OFF" interval the sensor measures the earth response to the pulse. The tow assembly also includes a sensor for generating selected survey data in the "ON" interval. A transmitter driver enables the creation of earthbound pulse. The system components are linked to a computer and control computer program linked thereto for controlling the functions thereof. The invention also includes a method for producing survey data using the tow assembly of the invention.	
Tow assembly for fixed wing aircraft for geophysical surveying **Applicant: GEOTECH**	A airborne geophysical electromagnetic (EM) survey tow assembly system for use with a fixed wing aircraft, including receiver coil assembly comprising a substantially rigid tubular receiver coil frame forming a continuous internal passageway that extends around a central open area, and a receiver coil housed within the internal passageway; a winch system having a tow cable secured to the receiver coil assembly fro extending the receiver coil assembly into a survey position; and a latch system for mounting to an underside of the aircraft having releasable latch members for engaging the receiver coil assembly when the receiver coil assembly is in a retracted position.	
Airborne electromagnetic system **Applicant: ANGLO AMERICAN**	A towed aircraft for use in an airborne electromagnetic geophysical prospecting system includes a transmitting antenna (34) and power generating means (24) for powering the antenna. A bird (72) (Figure 4) to which is mounted a receiving antenna (58) may be towed by the towed aircraft.	
Double-suspension receiver coil system and apparatus **Applicant: GEOTECH**	A receiver coil apparatus for an electromagnetic survey system, comprising: a tubular outer frame defining an internal passage; a rigid inner member; a receiver coil; a plurality of first elastic suspension members suspending the receiver coil from the rigid inner member within the internal passage; and a plurality of second elastic suspension members suspending the rigid inner member within the internal passage.	

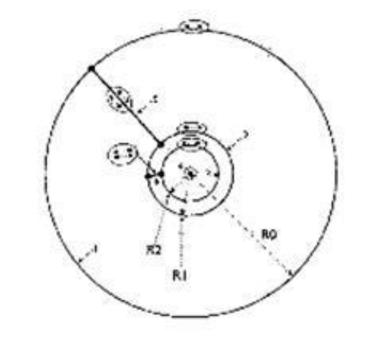
Bucking circuit for annulling a magnetic field **Applicant: VALE**	A method and apparatus is provided for bucking a magnetic field of known geometry and time variation by means of a plurality of bucking loops. It utilizes multiple loops, each of which is energized by an electric current that creates a magnetic field of the known time variation. The multi-loop field forms a bucking magnetic field that better opposes the spatial variation in the known magnetic field over a volume than can the magnetic field from a single loop. The present invention is useful in electromagnetic measurements, where the magnetic field of a controlled source transmitter must be annulled at a magnetic field sensor. It is particularly useful for cases where the magnetic sensor may move relative to the transmitter, such as in certain airborne electromagnetic measurements.	

Table 15 Airborne electromagnetic methods top patents

3.1.9 Patent activity of main market players

In order to analyse the patent activity of the most important players of the airborne EM market, we have used the selection of companies listed in Killeen's Capabilities of Airborne Geophysical Survey Contractors 2019 (Exploration Trends & Developments, 2019) and checked the number of published patent families that were retrieved using our Query. It is important to mention in this context that some players might have additional Airborne EM related patents, but as they do not use any keywords of our search query they do not appear in the results.

Results shown in Table 16 are coherent with Fig. 7 on key players as the only two airborne EM contractors that have a significant activity in patent filings are Geotech and CGG.

Company	System & type (Time domain-TD Frequency domain-FD)	Country (Head-quarter)	INFACT partner / Ref. Site Users	Patent families retrieved with Airborne EM Query
Aerogeophysica Inc.	AGP EM (TD)	RU	No	0
Aerophysics	EXPLORERHEM (FD)	MX	No	0
CGG MultiPhysics	Tempest (TD), HeliTEM (TD), Resolve (FD)	CA	Yes	14
Discovery Inter. Geo.	Heli-SAM (FD)	CA	No	0
EON Geosciences Inc.	E-THEM (TD), Hummingbird (FD)	CA	No	0
Expert Geophysics Ltd.	MobileMT	CA	No	0
Geophysics GPR	GPRTEM2	CA	No	0
Geotech Ltd.	IMPULSE (FD), VTEM (TD), ZTEM (FD)	CA	Yes	17
GeoTechnologies	EQUATOR (TD/FD)	RU	No	0
New Resolution Geophysics	Xcite (TD)	ZA	No	0
Novatem Inc.	NOVATEM (TD)	CA	No	0
NUVIA Dynamics	Nu-TEM (TD)	CA	No	0
Pico Envirotec	P-THEM (TD)	CA	No	0

Precision GeoSurveys	ITEM (TD)	CA	No	0
Prospectair Geosurveys	ProspecTEM (TD)	CA	No	0
Sander Geophysics	SGFEM (FD)	CA	No	0
SkyTEM	SkyTEM (TD)	DK	Yes	1
Spectrem Air	Spectrem2000 (TD)	ZA	No	0
Terraquest	HyRez (TD)	CA	No	0
Thomson Aviation	BIPTEM (TD)	AU	No	0
Triumph Surveys	AirTEM (TD)	CA	No	0

Table 16 Patent activity of main airborne geophysical survey contractors

3.2 AIRBORNE GRAVITY GRADIOMETRY

3.2.1 Top key players - patents

Regarding airborne gravity gradiometry technologies it is interesting to see that two Chinese military organisations are leading the ranking (Fig. 15) with the Chinese Army as the main applicant with 10 patent applications (5 of them granted and 5 pending, Table 17) and the National University of Defence as third with 7 patents (6 granted and 1 pending, Table 18). It has to be noted though that all of them are domestic (Chinese) applications only and no patent has been extended to other countries.

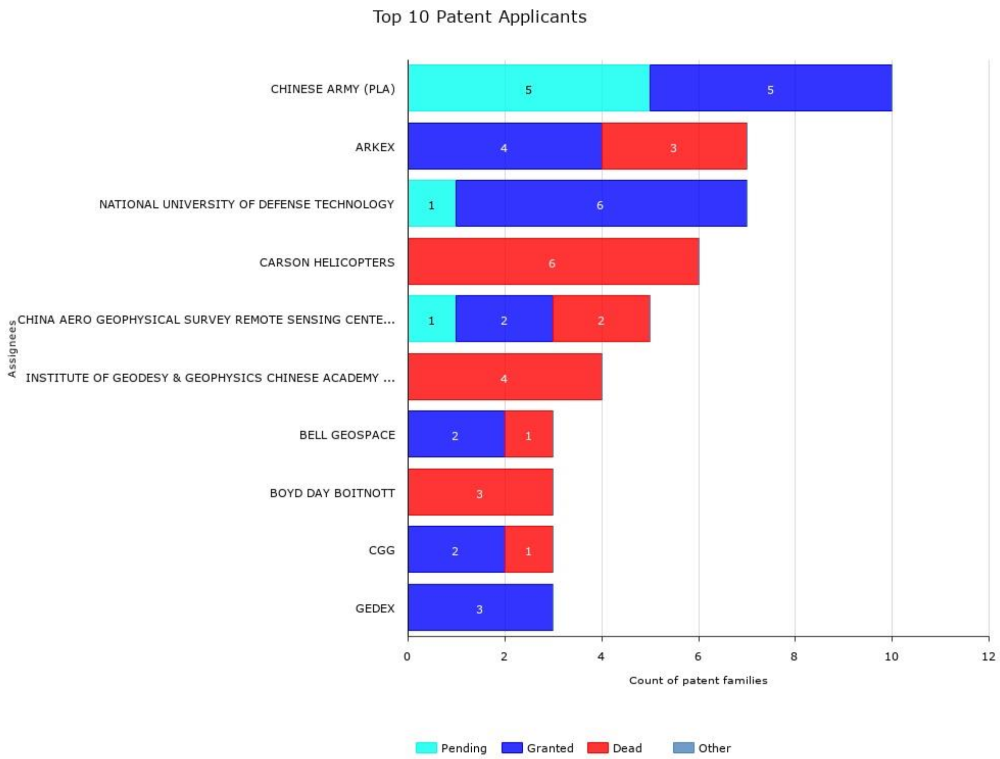


Fig. 15 Airborne gravity gradiometry top key players – patents (Source: Questel Orbit)

Patent title and reference number (bold: patent in force having the highest number	Jurisdictions

of jurisdictions)	in force	pending
Airborne gravity data downward continuation method and system combining ground gravity points (CN108919371)	CN	
New algorithm for correcting sea and air gravimeter scale value based on repeat line (CN108387951)	CN	
Two-step integration direct method for determining ground level plane based on band-limited airborne vector gravity (CN106646648)	CN	
One-step integration direct method for determining geoid based on band-limit aerial vector gravity (CN106646647)	CN	
Two-step integral inverse method for determining geoidal surface based on band-limited aerial vector gravity (CN106646644)	CN	
Aviation gravity vector downward continuation method and system based on point quality method (CN110110347)		CN
Method and system for downward continuation of airborne gravity vector based on gradient method (CN109856691)		CN
Aviation gravity data downward continuation method and system taking ground point as control (CN109283591)		CN
Cosine function edge enlargement method for restraining boundary effects in downward continuation of aerogravity data (CN109190082)		CN
Airborne gravity measurement data downward extension method and system (CN108594319)		CN

Table 17 Chinese Army granted and pending patents

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Strapdown gravimeter error correction method based on correlation analysis and empirical mode decomposition (CN106908853)	CN	
Dynamic measuring device and method for plumb line deviation kept on basis of astronomical attitude reference (CN103674030)	CN	
Method for determining dynamic accelerated speed of carrier precisely (CN103529482)	CN	
Airborne gravity downward continuation method based on integral iteration algorithm (CN103399350)	CN	
Error separation method of strapdown airborne gravitometer (CN103364842)	CN	
Smooth constellation jump error elimination method in airborne gravity measurement (CN103364841)	CN	
Strapdown airborne gravity measurement precision assessment method based on t1 repeated line (CN110231665)		CN

Table 18 National University of Defence granted and pending patents

As for the companies, on second rank appears Arkex, a former Cambridge-based geophysical service company for the oil and gas exploration (closed since 2015) with 7 patent applications and 4 of them granted (Table 19), although due to the closing of the company most of them lapsed and/or not longer maintained and only still in force in few countries, South Africa (ZA) and Russia (RU).

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Gravity gradiometer survey techniques (EP2689276)	ZA	
Terrain correction systems (WO2008/117081)	ZA	
Gravity survey data processing (WO2008/093139)	**ZA, RU**	
Gravity survey data processing (GB0515401)	ZA	

Table 19 Arkex granted and pending patents

Furthermore with 3 patents each, the US specialist in gravity gradiometry Bell Geospace[16] (2 granted), the French CGG (2 granted) and the US Gedex Systems (3 granted), acquired by FCMI Geo

[16] http://bellgeo.com/

Corporation[17]. The patent portfolio of the latter two companies can be highlighted since it is in force in multiple countries/jurisdictions.

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Method and system for geophysical data acquisition on an airship (WO2008/027026)	CA, ZA	
Method and system for evaluating geophysical survey data (EP1735639)	ZA, MX, NZ	

Table 20 Bell Geospace granted and pending patents

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Airborne geophysical measurements (EP1444536)	**AT, CA, MX, US, DE, AU, ZA**	
Gravity surveys (WO02/103398)	US, CA, BR, AU, MX, ZA	

Table 21 CGG granted and pending patents

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Gravity gradiometer and methods for measuring gravity gradients (EP2676158)	US, CA,AU,	EP
System and method for surveying underground density distributions (EP1518134)	CA, AU, GB, US	
Gravity gradiometry (EP1337879)	CA, RU,AU, US	

Table 22 Gedex granted and pending patents

3.2.2 Top key players – scientific publications

When analysing the scientific output, the US and Canadian institutions are leading, with aerospace institution NASA, followed by Natural Resources Canada, the US Geological Survey and the Geological Survey of Canada.

Research institution	# papers
NATIONAL AERONAUTICS SPACE ADMINISTRATION (US)	46
NATURAL RESOURCES CANADA (CA)	41
UNITED STATES GEOLOGICAL SURVEY (US)	41
GEOLOGICAL SURVEY OF CANADA (CA)	38
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS	36
OHIO STATE UNIVERSITY (US)	32
HELMHOLTZ ASSOCIATION (DE)	27
NATURAL ENVIRONMENT RESEARCH COUNCIL (GB)	26
COUNCIL OF SCIENTIFIC INDUSTRIAL RESEARCH CSIR INDIA	19
UNIVERSITY OF TEXAS (US)	19
CHINA UNIVERSITY OF GEOSCIENCES (CN)	18
COLUMBIA UNIVERSITY (US)	18
NATIONAL GEOPHYSICAL RESEARCH INSTITUTE (IN)	18
RUSSIAN ACADEMY OF SCIENCES (RU)	18
CALIFORNIA INSTITUTE OF TECHNOLOGY (US)	17

Table 23 Airborne gravity gradiometry top key players – scientific publications (Source: WOS)

[17] https://www.gedex.com/

3.2.3 Evolution

Analysing the timeline of general patenting in the field of airborne gravity gradiometry over the last 10 years (Fig. 16) we can see a continuous increase over the years (with a low in 2015/16) with an average of 7 patents published a year since 2010. As for the evolution in scientific publications we identify a peak in 2018 similar to the patenting behaviour.

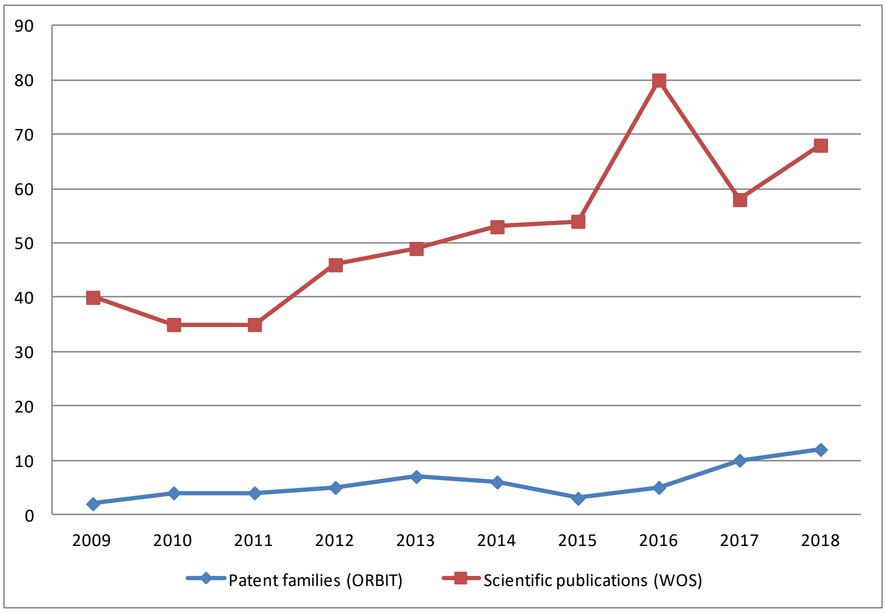


Fig. 16 Airborne gravity gradiometry publication evolution (Source: Questel Orbit)

When looking at the patenting evolution in the field of airborne gravity gradiometry of the top 10 main players over the last 20 years (Fig. 17) we see that the Chinese Defence research (Chinese Army & National University of Defence) and the Chinese Aero Geophysical Survey Remote Sensing Centre have recent patenting activity, with all of its patents published over the last 6 years, whereas the non-Chinese companies like Bell Geospace or Gedex have not published related patents in these recent years, with the exception of French CGG that published its latest patent in the field of airborne gravity gradiometry in 2016.

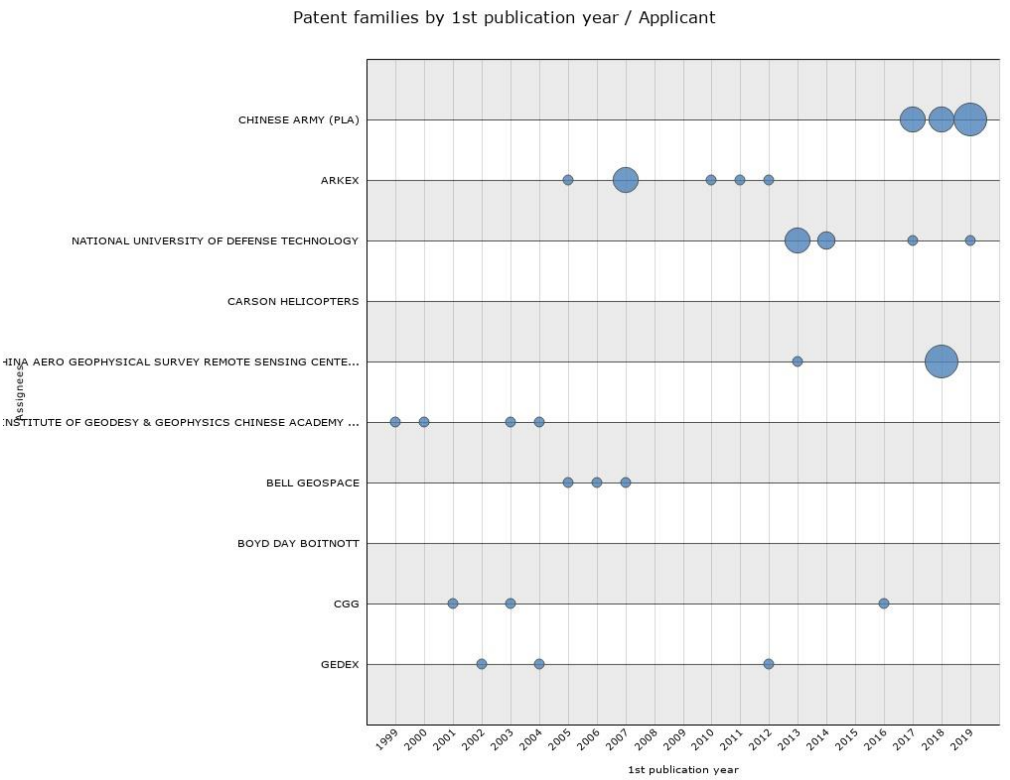


Fig. 17 Airborne gravity gradiometry key players evolution – patents (Source: Questel Orbit)

3.2.4 Innovation origin – patents

Most airborne gravity gradiometry have their first (priority) filing in China, followed by US, and Australia on third position.

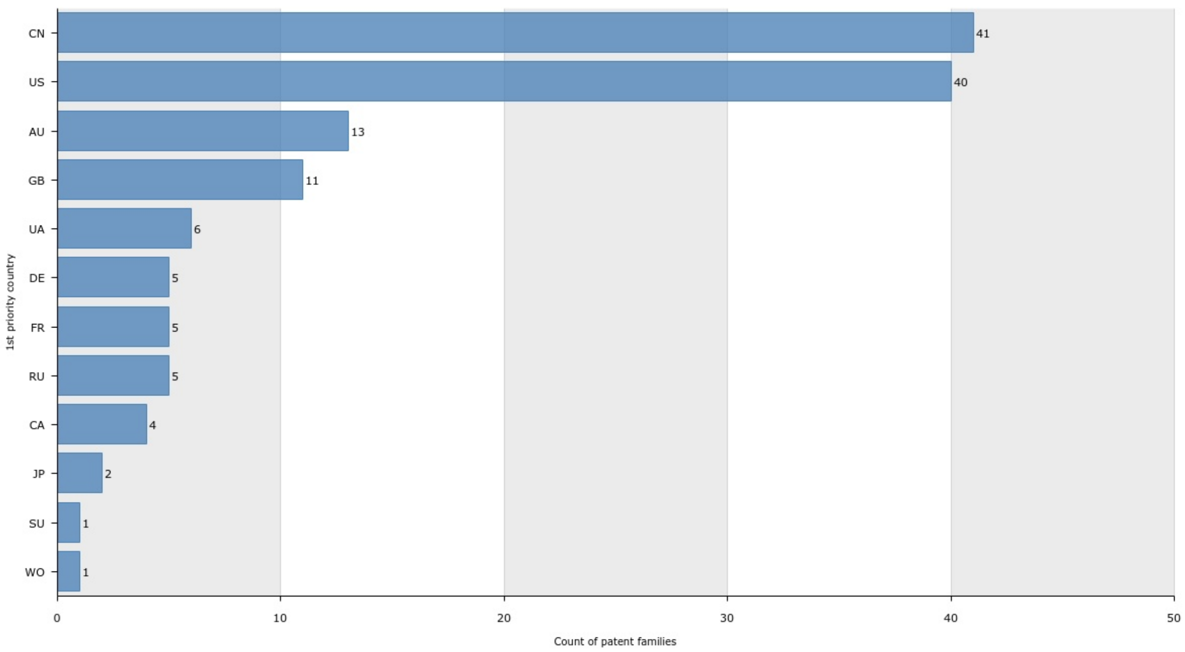


Fig. 18 Airborne gravity gradiometry patents first filing countries (Source: Questel Orbit)

3.2.5 Innovation origin – scientific publications

As for the scientific output related to airborne gravity gradiometry publications, the US is leading followed by Canada and China and Germany on 4th position.

Institution country	# papers
USA	252
CANADA	102
CHINA	93
GERMANY	76
AUSTRALIA	65
ENGLAND	65
ITALY	58
FRANCE	57
DENMARK	37
INDIA	37

Table 24 Airborne gravity gradiometry scientific publications by country of origin (institution)

3.2.6 Markets

Airborne gravity gradiometry patents are mainly filed in China, the US, Canada and Australia and being the countries where patent protection is in force (Fig. 19).

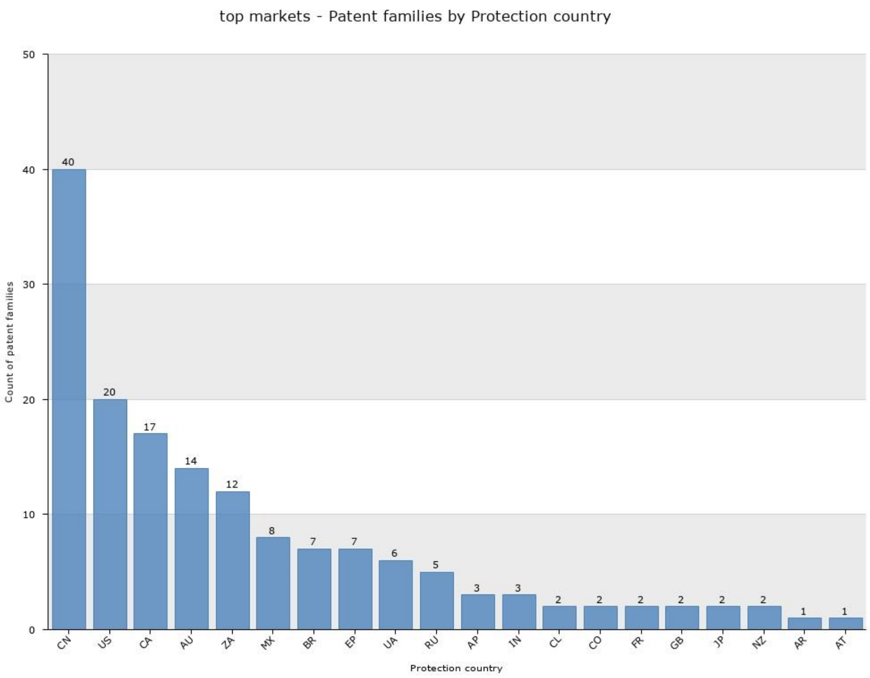


Fig. 19 Airborne gravity gradiometry- markets (Source: Questel Orbit)

As for the applicants of related patents the Chinese applicants only file in China (domestic filing), whereas CGG, GEODEX, BELL GEOSPACE and ARKEX have patented in multiple countries, being CGG the company with the most international patent portfolio with publications in 12 countries (Fig. 20).

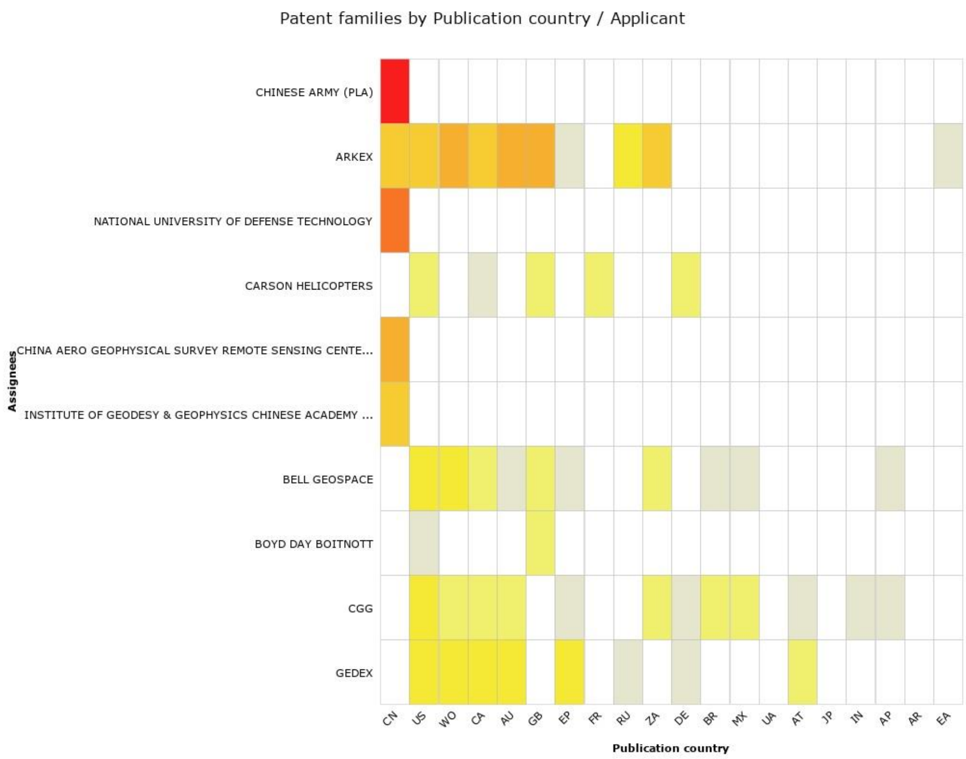


Fig. 20 Airborne gravity gradiometry top applicants markets (Source: Questel Orbit)

3.2.7 Patent citation & collaboration maps

When analysing patent citations of applicants, the patents from Gedex seem to have the biggest citation impact, with 11 citing patents from 5 different applicants. Furthermore it is worth mentioning that most of the related patents from Arkex are citing patents from Bell Geospace, which on the other hand is citing patents from CGG.

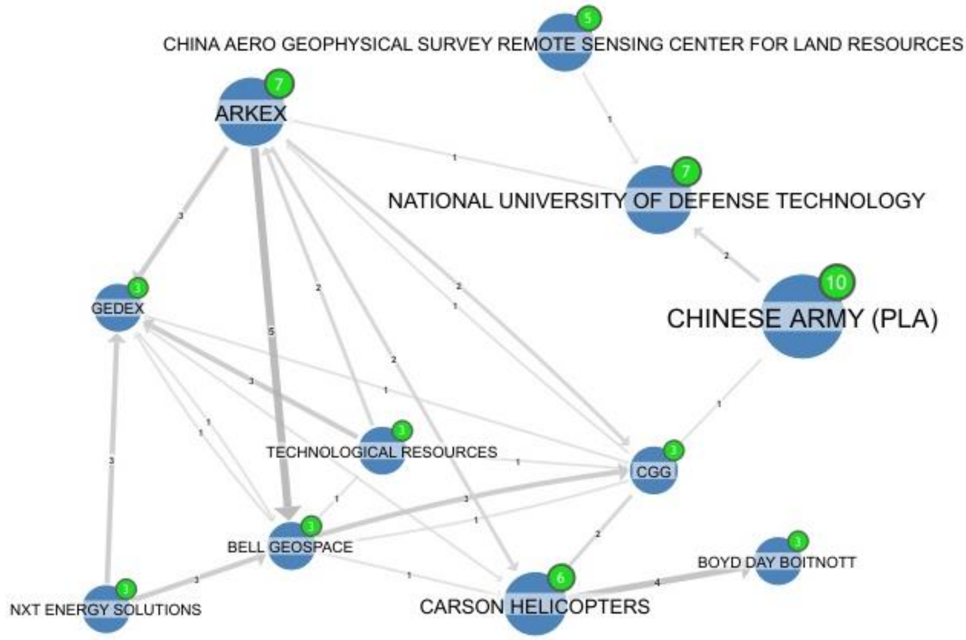


Fig. 21 Airborne gravity gradiometry patents citation node map[18] (Source: Questel Orbit)

When analysing co-authorship patterns, some company-company collaborations become evident, and also some university-company partnerships like the University of Western Australia that co-owns 2 patents with RTZ Mining & Exploration.

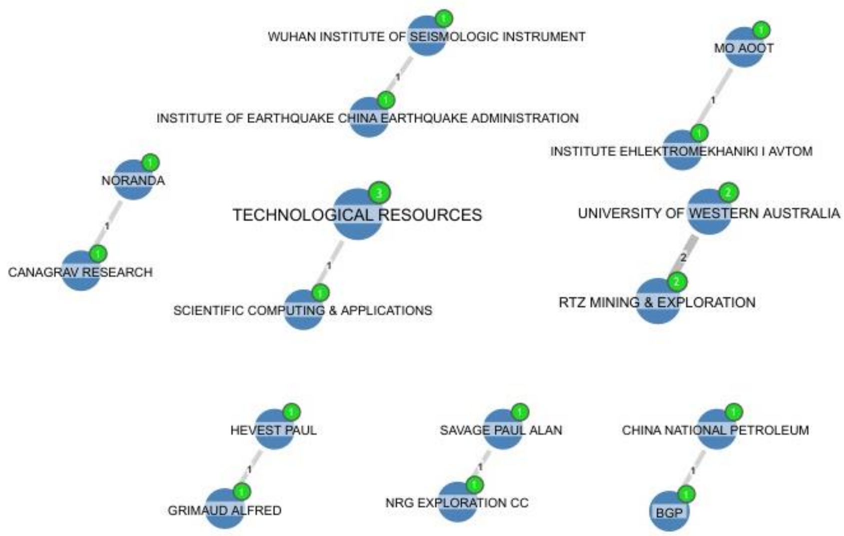
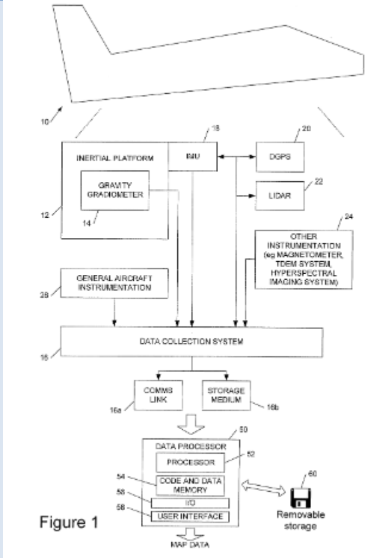
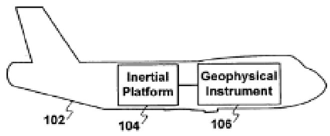
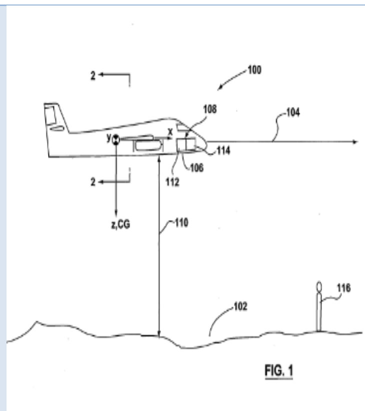


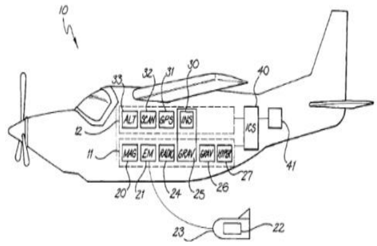
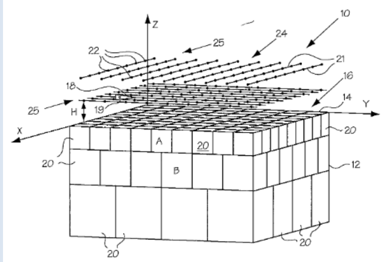
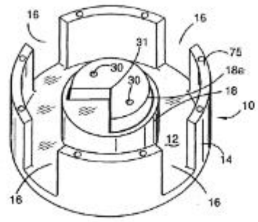
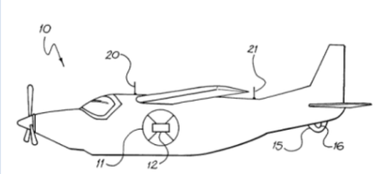
Fig. 22 Airborne gravity gradiometry patents collaboration node map[19] (Source: Questel Orbit)

[18] minimum 3 patents per applicant and minimum 1 citing patent
[19] minimum 1 patents per applicant and minimum 1 patent in co-authorship

3.2.8 Top patents

The following table show the top patents related to airborne gravity gradiometry, according to the indicators described in chapter 2.6 and detailed in the Annex.

Title & Applicant	Abstract	Image
Gravity survey data processing **Applicant: ARKEX**	This invention relates to improved techniques for processing potential field measurement data from airborne surveys such as gravity surveys, and to improved techniques for data acquisition which are enabled by the improved data processing techniques. We describe a method of processing measured potential field data from a potential field survey of the earth to determine map data for mapping said field, the method comprising: inputting said measured potential field data, said measured potential field data comprising data defining a plurality of potential field measurements and associated positions, each said position defining a position of a said potential field measurement in three dimensions; determining a plurality relationships between said potential field measurements and said positions, each said relationship relating a said potential field measurement to a function of a said associated position in three dimensions multiplied by a field mapping parameter; and determining a substantially self-consistent set of said field mapping parameters for said plurality of relationships to thereby determine said map data.	
Method and system for evaluating geophysical survey data **Applicant: BELL GEOSPACE**	A method and system for evaluating geophysical survey data is provided. Two neighboring flight paths of a geophysical survey are likely to have geophysical characteristics in common because neighboring flight paths cover geographic areas in a close proximity to one another. As such, neighboring flight paths will likely have similar geophysical characteristics and similar recorded data. Therefore, errors in data can be estimated by comparing data recorded from neighboring flight paths. If data from a flight path differs significantly from data recorded from a neighboring flight path, then the data from one or both flight paths may be corrupted and at least one of the survey lines may need to be repeated. This auto evaluate method allows field personnel to judge data close to real time to determine whether to repeat a flight path while still out in the field.	
Gravity gradiometry **Applicant: GEDEX**	A gravity gradiometer is combined with a two-stage actively controlled isolation system. The gravity gradiometer and two stage isolation system may then be mounted within (or on) a mobile vehicle such as, for example, an aircraft. It has been recognised by the inventors herein that the accelerations imparted to an aircraft during normal operations can be separated through system design into two relatively distinct regimes within the frequency domain. The invention provides a first isolation mount, which forms part of the isolation system, to isolate accelerations (and resulting translations) falling within a first of the two frequency regimes. The second isolation mount, which is mounted to the first isolation mount, isolates accelerations falling within the second of the two frequency regimes. A gravity gradiometer can then be mounted to the second isolation mount. As a result of housing the gravity gradiometer within the nested isolation system (a combination of the first and second isolation mounts), the gravity gradiometer is substantially isolated	

	from the accelerations experienced by the mobile vehicle. Consequently, gravity gradients measured by the gravity gradiometer are relatively noise free and provide heretofore-unobtainable accuracy.	
Airborne geophysical measurements **Applicant:** **CGG**	This invention concerns a method of making airborne geophysical measurements. Such measurements may be made from fixed or moving wing airplanes or dirigibles. The method comprises the following steps: taking first real time measurements from one, or more, geophysical instruments mounted in an aircraft to produce geophysical data related to the ground below that instrument. Taking second real time measurements from navigation and mapping instruments associated with or carried by the aircraft. Computing a background response of each geophysical instrument using the second real time measurements to take account of its time varying altitude, and the time varying topography of the ground below it. Adjusting an operating or data processing condition of each geophysical instrument using the respective background response and the intrument's attitude to enhance the performance of that instrument. And, adjusting the geophysical data output for that instrument having reduced effects resulting from variations in altitude, attitude and topography.	
System and method for surveying underground density distributions **Applicant:** **GEDEX**	A method for geographical surveying includes the steps of determining an observation grid (24) comprising observation points (22) above a solution (16) volume in the ground; making gravitational measurements at the observation points (22) over a survey area; compiling a matrix having elements relating a set of gravitational accelerations and gravity gradient values at the points to the mass values for volume elements in the solution volume (16); and calculating the three-dimensional density distribution of the volume under the survey area based on the gravitational measurements and the inverse of the matrix. By measuring the magnetic field and gradient at the observation points, the three-dimensional magnetic susceptibility distribution of the volume under the survey area can be determined.	
A gravity gradiometer **Applicant:** **TECHNOLOGICAL RESOURCES**	The present disclosure provides a gravity gradiometer that comprises a detector for detecting a gravity gradient. The detector comprises at least one movable sensing element and that is arranged to generate a signal in response to a change in gravity gradient. The gravity gradiometer also comprises a support structure for supporting the detector in an aircraft and a component that is arranged to reduce transmission of an aircraft acceleration to the detector. The at least one movable sensing element and the support structure together are arranged to reduce an influence of the aircraft acceleration on the signal by a factor of at least 107 when the gravity gradiometer is airborne and exposed to the aircraft acceleration.	 FIGURE 2
Gravity surveys **Applicant:** **CGG**	This invention concerns an aircraft equipped for conducting airborne gravity surveys. In another aspect it concerns a process for creating airborne gravity surveys. The aircraft is equipped to perform the method using measured attitude data, laser range data and scan angle data, and aircraft position data.	 *FIG. 1*

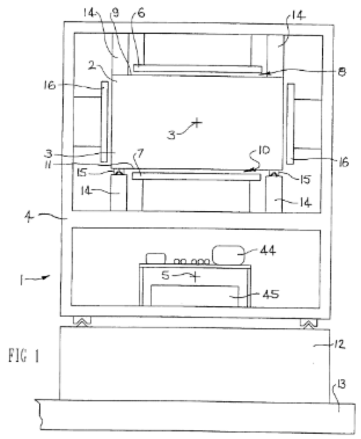
Gravity meter **Applicant:** **CSIRO COMMONWEALTH SCIENTIFIC INDUSTRIAL RESEARCH ORGANISATION**	A gravity gradiometer (1) comprising first (2) and second proof masses (4) and means (13) for providing simultaneous free flight of the proof masses under the influence of the gravitational force in which the gradient is to be measured and capacitance means (6, 7) for monitoring the movement of the centres of mass (3, 5) with respect to each other during free flight by monitoring capacitance between portions of the two proof masses.	

Table 25 Airborne gravity gradiometry top patents

3.3 AIRBORNE MAGNETOMETRY

3.3.1 Top key players - Patents

Regarding top key players that have patents related to airborne magnetometry (Fig. 23) the French atomic agency CEA appears on top, but it turns out that their patents are old (+30 years) with all of the 7 identified patents being expired.

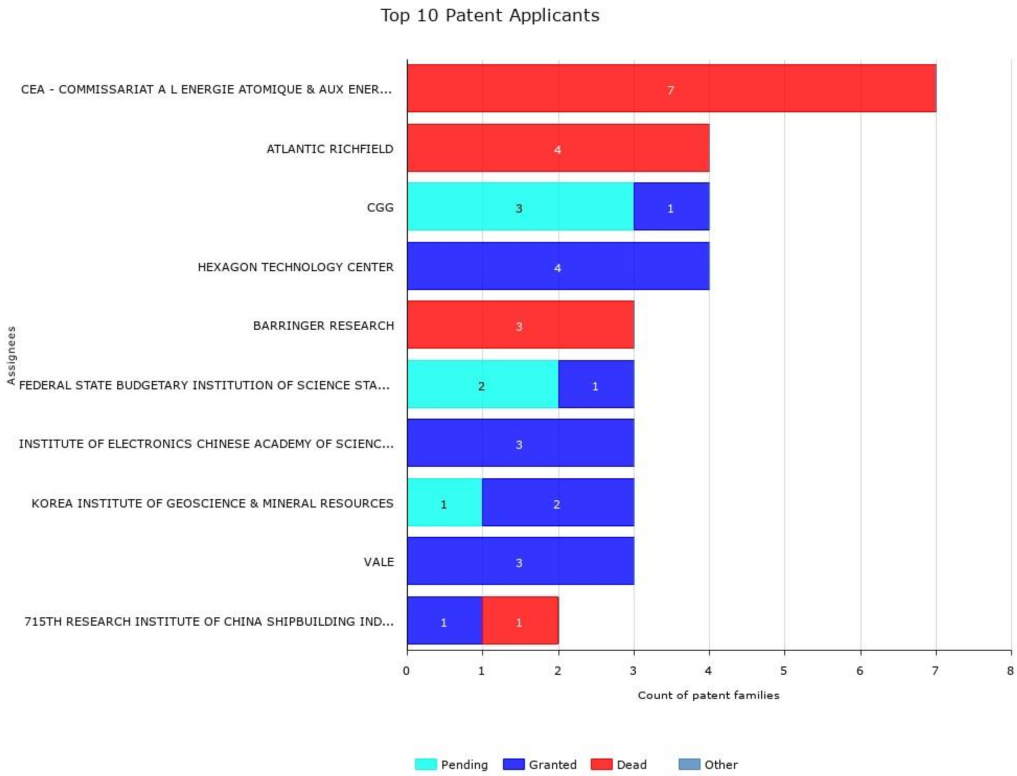


Fig. 23 Airborne magnetometry top key players – patents (Source: Questel Orbit)

As for granted and/or pending patents we have identified as main players the French CGG with 4 patents (one granted and 3 pending, Table 26), the Swiss based Hexagon Technology Centre[20] (all 4 granted, Table 27) and the Brazilian mining company Vale[21] (with 3 granted patents, Table 28). The patent portfolio of the latter two companies can be highlighted since it is in force in multiple countries/jurisdictions.

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Airborne geophysical measurements (EP1444536)	**AT, CA, MX, US, AU, ZA, DE**	
Magnetometer signal sampling within time-domain em transmitters and method (CA2931211)		AU, CA
Apparatus and method for compensating for receiver motion in airborne electromagnetic systems (WO2016/124964)		AU, CA, US
Systems and methods for a composite magnetic field sensor for airborne geophysical surveys (EP3111255)		CA

Table 26 CGG granted and pending patents in airborne magnetometry

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Method and system for controlling an unmanned aircraft EP2511781	CA, AU, KR, US, AT, CH, DE, FR, GB, IE, NL, SE	BR, IN
Geodesic marking system for marking target points EP2511659	CA, AU, KR, CN, CH, DE, FR, GB, NL, SE, US	BR, IN
Measuring system and method for new point determination EP2511658	CA, AU, KR, CN, CH, DE, FR, GB, NL, SE, US	BR, IN
Measuring system for determining the 3d coordinates of an object surface EP2511656	CA, AU, KR, CN, US, CH, DE, FR, GB, NL, JP	BR, IN

Table 27 Hexagon granted and pending patents

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Semi-rigid airborne electromagnetic transmitter antenna system (US20170123093)	US	
Magnetic compensation circuit and method for compensating the output of a magnetic sensor, responding to changes a first magnetic field (EP2976652)	US, AU, GB, CN, RU	ID, PE, CA, CL, BR, IN
Stabilization system for sensors on moving platforms (EP2524248)	**US, CA, AU, CN, FR, BR, MX, MA, US**	**CO, PE, PH, IN, CL**

Table 28 Vale granted and pending patents

As for the public research institutions the Russian federal state budgetary institution of science / Vernadsky Institute of Geochemistry[22] , the Chinese Institute of Electronics (part of the Chinese Academy of Science) and the Korean Institute of Geoscience & Mineral Resources all have 3 related patents, but only the Korean Institute has extended their patent protection internationally.

[20] https://hexagon.com/
[21] http://www.vale.com/
[22] http://www.geokhi.ru/en/default.aspx

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Pilotless complex of the remote magnetometric monitoring of natural and technogenic media (bkdm)(RU173292)		RU
Quantum rubidium mz the aerial magnetometer (RU169455)		RU
Pilotless aeromagnetic complex (RU162771)	**RU**	

Table 29 Vernadsky Institute of Geochemistry granted and pending patents

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Unmanned aerial vehicle aeromagnetic holoaxial gradient magnetic disturbance compensation method based on feedforward network CN106842344	CN	
Method for removing aeromagnetic gradient interference based on epsilon-svr (support vector regression) algorithm CN106707352	CN	
Nacelle time domain aviation transient electromagnetic surveying system based on light gas tube supporting structure CN106199741	**CN**	

Table 30 Chinese Institute of Electronics granted and pending patents

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Aerial electromagnetic survey device (JP2018115901)		JP
Induction type broadband 3-component borehole magnetic measuring sensor and borehole electromagnetic tomography method using the same (US20150145519)	**KR, US, JP, CN**	
Portable unmanned airship for magnetic-force surveying and a magnetic-force surveying system employing the same (WO2011/052822)	KR, US	

Table 31 Korean Institute of Geoscience & Mineral Resources granted and pending patents

3.3.2 Top key players – scientific publications

As for the institutions that published scientific articles related to airborne magnetometry it is interesting to see that the Iranian university of Teheran is leading the ranking, closely followed by the US research intensive NASA and the University of California.

Research institution	# papers
UNIVERSITY OF TEHRAN (IR)	7
NATIONAL AERONAUTICS SPACE ADMINISTRATION (US)	6
UNIVERSITY OF CALIFORNIA (US)	6
OAK RIDGE NATIONAL LABORATORY (US)	5
RUSSIAN ACADEMY OF SCIENCES (RU)	5
UNITED STATES DEPARTMENT OF ENERGY (US)	5
CARLETON UNIVERSITY (CA)	4
CONSIGLIO NAZIONALE DELLE RICERCHE (IT)	4
CZECH ACADEMY OF SCIENCES (CZ)	4
GHENT UNIVERSITY (BE)	4
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE (FR)	3
CHIBA UNIVERSITY (JP)	3
FRIEDRICH SCHILLER UNIVERSITY OF JENA (DE)	3
HELMHOLTZ ASSOCIATION (DE)	3
JILIN UNIVERSITY (CN)	3

Table 32 Airborne magnetometry top key players – scientific publications (Source: WOS)

3.3.3 Evolution

Analysing the timeline of general patenting in the field of airborne magnetometry over the last 10 years (Fig. 24) we can detect a slight increase with peaks in 2012 and 2018 and an average of 9 patents published a year since 2010. In scientific research output of airborne magnetometry related scientific publications the evolution is not very clear with a light peak in 2017.

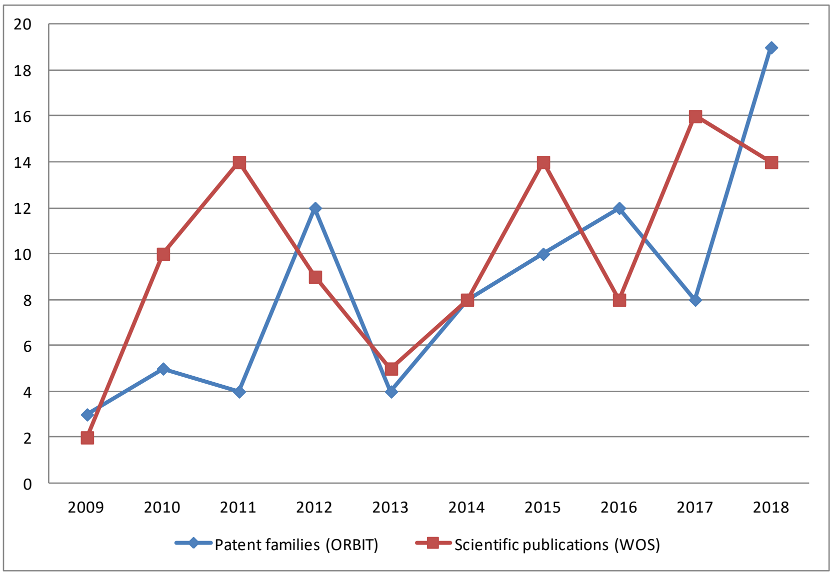


Fig. 24 Evolution in airborne magnetometry publications

When looking at the patenting evolution in the field of airborne magnetometry of the top 10 main players over the last 20 years (Fig. 25) we see that Hexagon has published all its patents in 2012 and the latest one to publish was the Korean Institute of Geoscience in 2018.

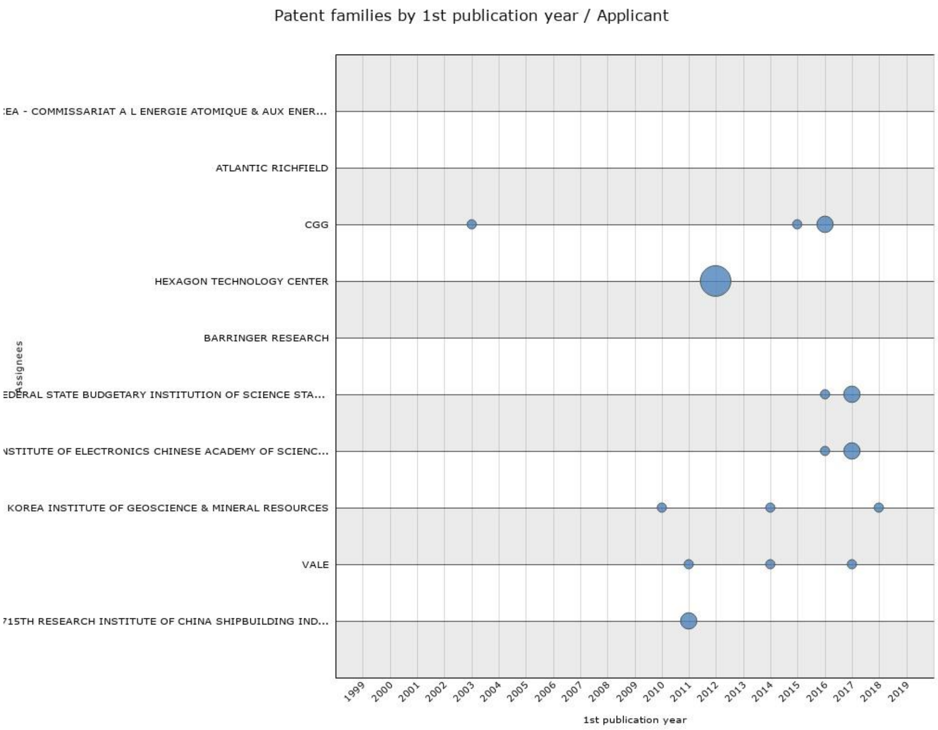


Fig. 25 Top key players in airborne magnetometry patenting evolution (Source: Questel Orbit)

3.3.4 Innovation origin – patents

Most of the patent applications in airborne magnetometry have their origin either in the United States or in China with 61 and 43 filings. On third position lies France with 9 priority filings, followed by Russia and Australia.

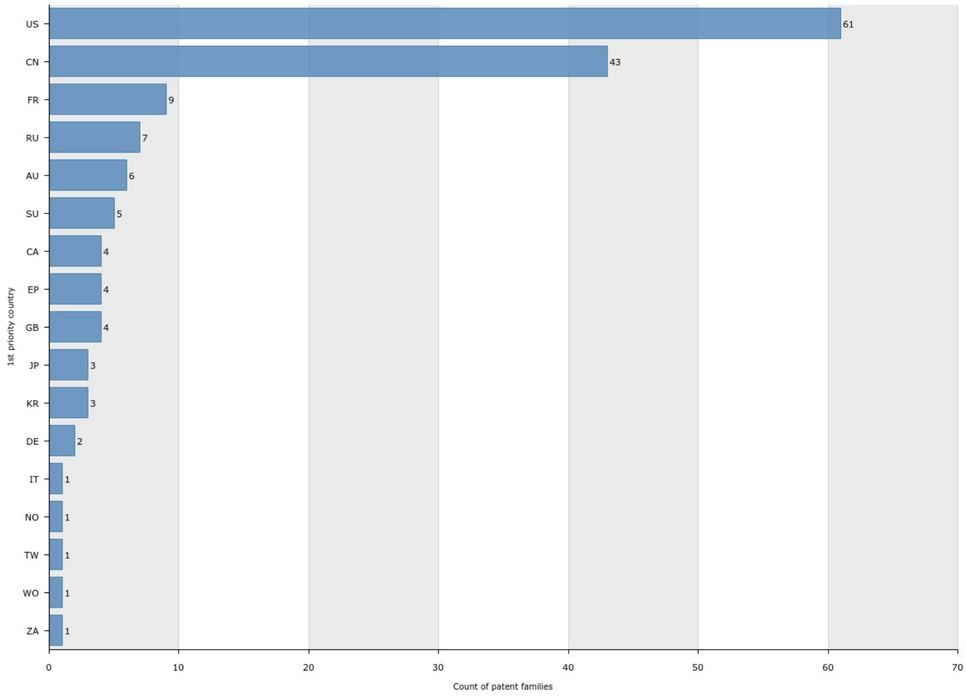


Fig. 26 First filing countries of airborne magnetometry patents (Source: Questel Orbit)

3.3.5 Innovation origin – scientific publications

As for the scientific output in airborne magnetometry the US and Canada are the most prominent countries, followed by Germany, Brazil and Italy.

Institution country	# papers
USA	27
CANADA	25
GERMANY	14
BRAZIL	13
ITALY	11
AUSTRALIA	10
CZECH REPUBLIC	10
IRAN	10
PEOPLES R CHINA	8
AUSTRIA	7
FRANCE	7
ENGLAND	6
RUSSIA	6
SWEDEN	5
BELGIUM	4

Table 33 Country origin of scientific publications related to airborne magnetometry (Source: WOS)

3.3.6 Markets

As for patents related to airborne magnetometry (Fig. 27), most of the inventions have active patent protection in China, the US and Canada and Australia, and on fourth position the European patent system (EP) was chosen for protection which leads to the assumption that the European market seems to be of certain importance for airborne magnetometry related technologies.

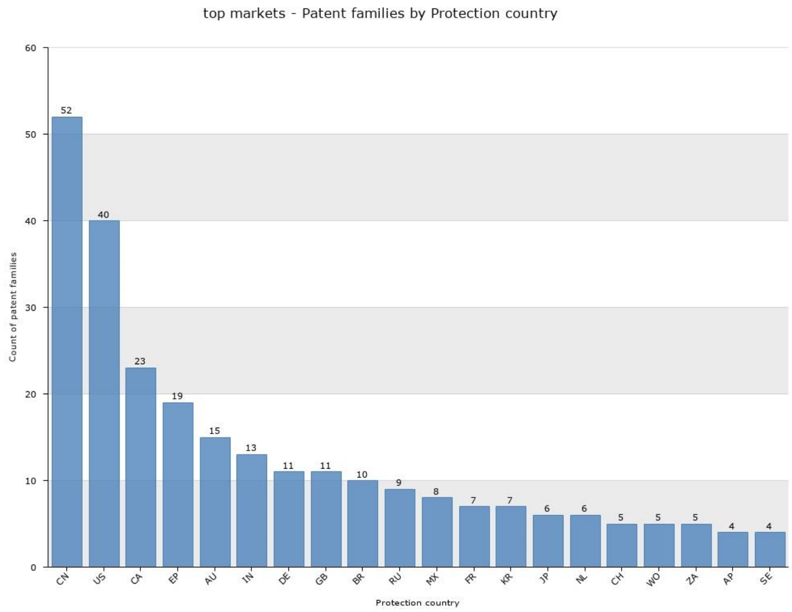


Fig. 27 Airborne magnetometry top markets (patent protection countries)

As for the applicant's portfolio internationalisation (Fig. 28) the companies CGG, HEXAGON and VALE showed to have the most internationalised one with publications in 10+ countries.

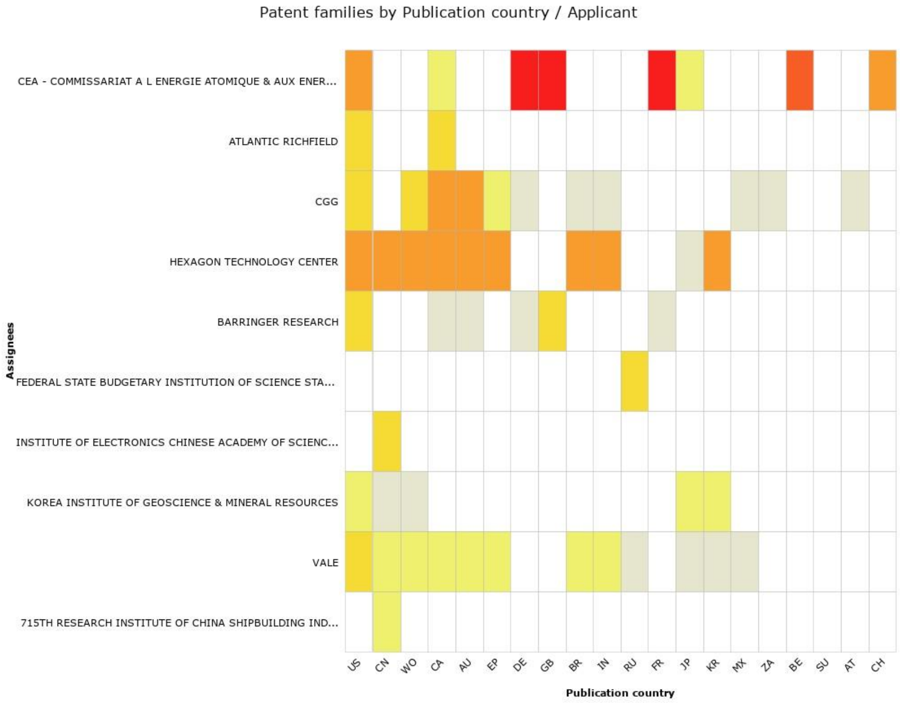


Fig. 28 Airborne magnetometry key players top markets (Source: Questel Orbit)

3.3.7 Patent citation & collaboration maps

The patent citation analyses of airborne magnetometry related patents reveal a knowledge network between the applicants, e.g. CGG patents have cited patents from GEOTECH, VALE and SHIFT GEOPHYSICS and BARRINGER RESEARCH.

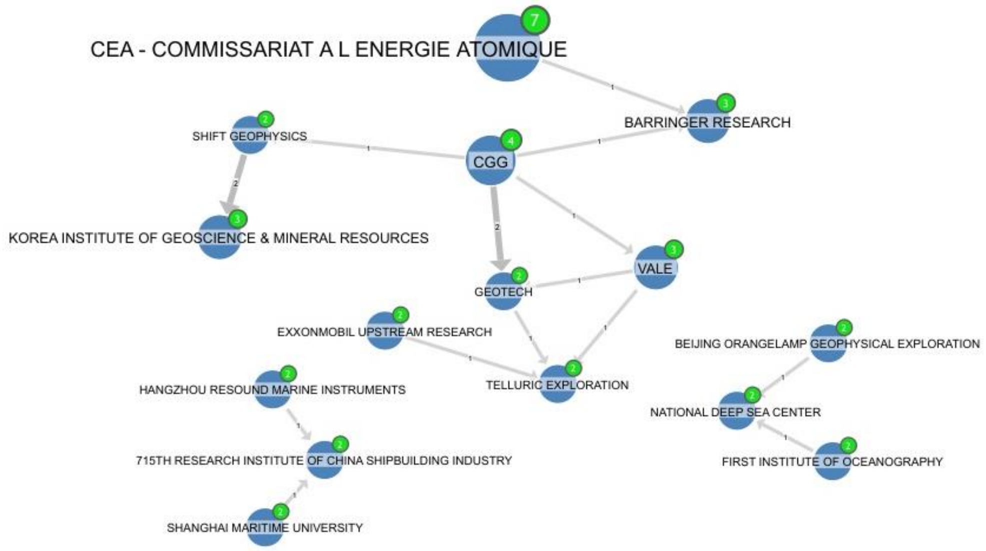


Fig. 29 Airborne magnetometry patents citation node map[23] (Source: Questel Orbit)

The co-authorship analysis reveals several small collaborations between 2 applicants, mainly between applicants from China.

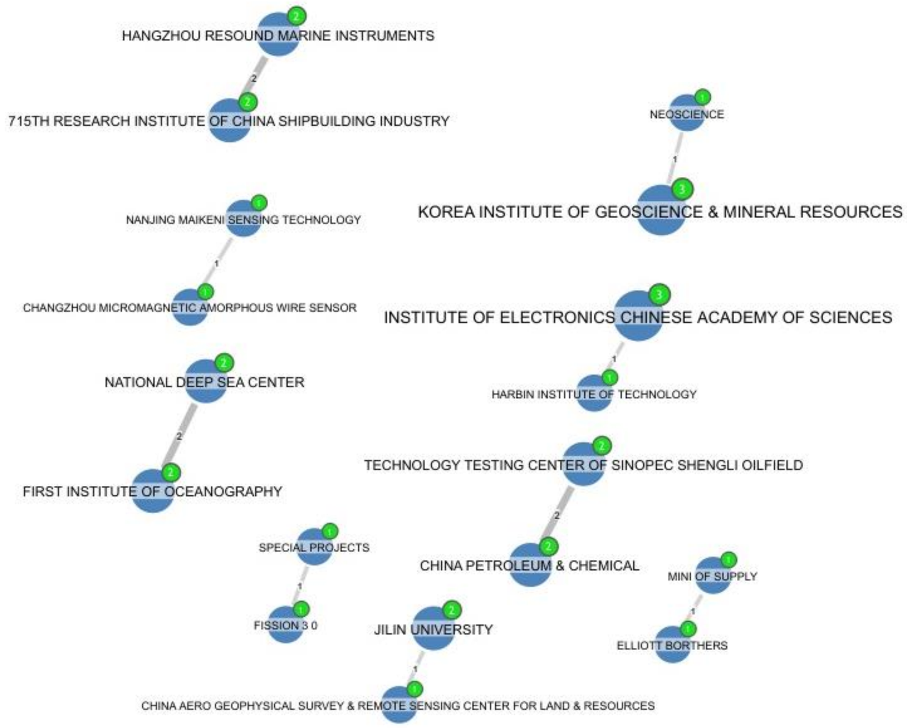
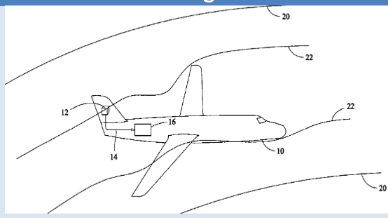
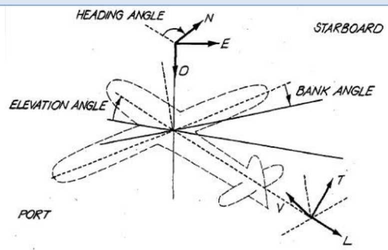
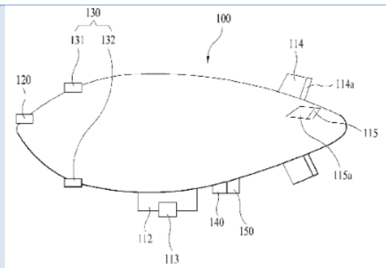


Fig. 30 Airborne magnetometry patents collaboration node map[24] (Source: Questel Orbit)

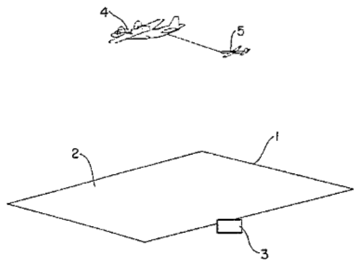
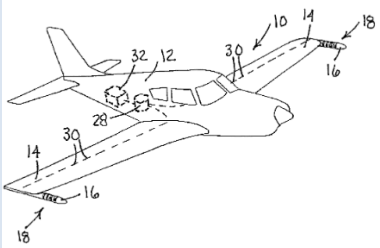
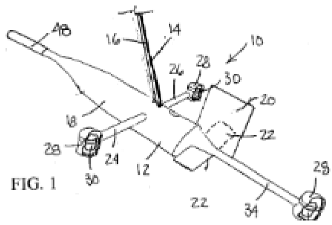
[23] with minimum 2 patents per applicant and minimum 1 citing patent

3.3.8 Top patents

The following table show the top patents related to airborne magnetometry, according to the indicators described in chapter 2.6 and detailed in the Annex.

Title & Applicant	Abstract	Image
Methods and apparatus for automatic magnetic compensation HONEYWELL INTERNATIONAL	A method for characterizing distortions in the earth's magnetic field caused by a vehicle (10) having a magnetometer (12) affixed therein is described. The method includes repeatedly measuring (52) the distorted magnetic field utilizing (62) the magnetometer and obtaining (54) a three-dimensional orientation of the vehicle axes with respect to the earth at a time of each magnetometer measurement. The method also includes receiving (56) undistorted earth magnetic field data for the vicinity of the vehicle relative to the earth at the time of each magnetometer measurement and characterizing (58) distortions caused by one or more of the vehicle and magnetometer errors utilizing the magnetic field measurements, the orientations of the vehicle, and the undistorted earth magnetic field data.	
Airborne vector magnetic surveys BHP BILLITON INNOVATION CGG FUGRO	An aircraft equipped for airborne vector magnetic exploration surveys comprising three magnetometers orthogonally mounted to measure the components of the earth's vector magnetic field; two rotation sensors mounted to measure the angular orientation of the aircraft; and a recording system to record the measurements of the magnetometers, and rotation sensors. The measured angular orientation is used to orientate the measured components of the earth's vector magnetic field to derive true vector acro-magnetic (VAM) data from airborne surveys. Also disclosed is a method for processing magnetic data by removing the permanent, induced, and eddy-current magnetic effects of the aircraft from the magnetic data.	
Portable unmanned airship for magnetic-force surveying and a magnetic-force surveying system employing the same KOREA INSTITUTE OF GEOSCIENCE & MINERAL RESOURCES	The present invention relates to a portable unmanned airship for magnetic-force surveying and to a magnetic-force surveying system employing the same, comprising: a main airship body propelled under its own power using the buoyancy of a gas; an automatic flying device for automatically flying the main airship body; a magnetic-force-measuring device which is provided on the main airship body and is for measuring the magnetic force of the earth's surface or geological strata; a wireless communication device for sending the magnetic data acquired via the magnetic-force-measuring device, to the outside; and a control module for controlling the operations of the automatic flying device and the magnetic-force-measuring device. Hence technology is disclosed whereby the overall flight time of the unmanned airship can be increased and the weight of the payload loaded onto the unmanned airship can be increased.	

[24] with minimum 1 patents per applicant and minimum 1 patent in co-authorship

Airborne transient electromagnetic method with ground loops ELIOT P	A method and apparatus for airborne geological surveying and similar applications. Typically a large loop antenna (1) is placed on the surface of an area of ground (2) which is to be surveyed and a transient current pulse is caused to flow in the antenna. An airborne receiver (5) is used to detect the electromagnetic field and TEM (Transient Electromagnetic Method), MMR (Magnetometric Resistivity) and MIP (Magnetic Induced Polarisation) analysis techniques are used to determine the survey results. The receiver (5) may be supported on an aeroplane (4), balloon, helicopter or the like and be adapted to store collected information onto a storage device for later analysis if desired.	
Remote sensing electric field exploration system TELLURIC EXPLORATION	An airborne exploration system used with an aircraft for shallow and deep exploration for oil and gas, mineral deposits and aquifers. The survey system uses natural electromagnetic EM fields as an energy source. The exploration system includes a pair of aerodynamic housing pods adapted for mounting on wing tips of the aircraft. The housing pods include electric field sensors with three orthogonal electric dipoles oriented along an X, Y and Z axis. An optional third set of orthogonal electric dipoles can be mounted in the tail of the aircraft. The field sensors are electrically attached to angular motion detectors mounted inside housing pods. The motion detectors are used for compensating for errors caused by angular motion of the aircraft when in the presence of strong electric field.	
Magnetotelluric geophysical survey system using an airborne survey bird TELLURIC EXPLORATION	A magnetotelluric geophysical survey system used with an airborne survey bird for natural resource exploration of oil and gas, mineral deposits and aquifers. The survey system uses natural electromagnetic EM fields as an energy source. The magnetotelluric airborne survey system includes an aerodynamic airborne survey bird adapted for being towed behind a helicopter or fixed wing aircraft. The survey system can also be incorporated into a fixed wind aircraft. The survey system includes a non-conductive nose boom on the survey bird with orthogonal electric dipoles for measuring electric fields from 0.01 Hz up to 480 Hz. An angular motion detector is mounted inside the bird and used for compensating for errors caused by angular motion of the bird when in the presence of strong electric field gradients. The survey bird can use a single magnetometer or pairs of magnetometers for measuring electromagnetic gradients. The magnetometers are attached to angular motion detectors for compensating for errors caused by angular motion of a line between the magnetometers, when in the presence of strong magnetic gradients. The bird can also includes the orthogonal axis coils for measuring natural magnetic fields in a frequency range of 3 to 480 Hz. The airborne survey system is used in conjunction with a ground base station that includes a cesium magnetometer, associated recording equipment and a GPS time reference for synchronization with the airborne data.	

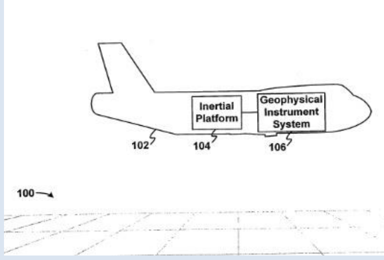
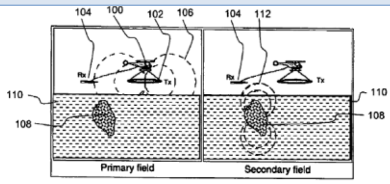
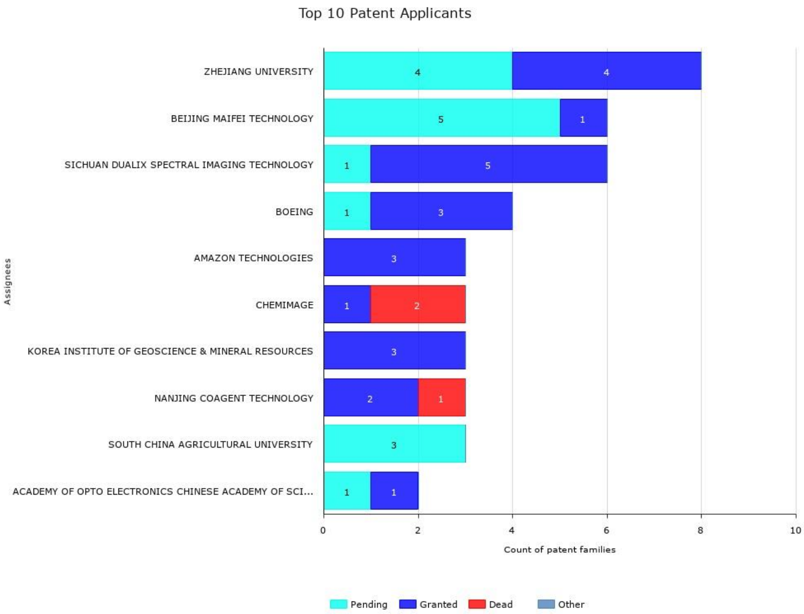
Method and system for synchornizing geophysical survey data BELL GEOSPACE	A method and system for synchronizing geophysical survey data is provided. Detection of geophysically significant subsurface anomalies potentially associated with ore bodies or hydrocarbon deposits can be made by vehicle mounted surface or airborne regional gravitational studies. Recorded geophysical survey data is processed to synchronize data collected by various sensors. Data from the various sensors is synchronized based on position coordinates corresponding to locations where the data was collected. In this manner, at one specific location on Earth , the electromagnetic reading, magnetometer reading, gravimeter reading, and altimeter reading can all be associated together so that many characteristics of the specific location can be identified.	
Induction magnetometer UNIVERSITY OF NEW BRUNSWICK	An array of induction magnetometers for use in airborne transient electromagnetic (ATEM) geophysical exploration is disclosed, having similar weight and external dimensions of prior art induction magnetometers but with improved signal strength, signal-to-noise ratio, higher frequency, self-resonance and bandwidth, and providing accurate and well monitored calibration.	

Table 34 Airborne magnetometry top patents

3.4 DRONE-BORNE HYPERSPECTRAL IMAGING

3.4.1 Top key players - patents

Drone-borne hyperspectral imaging showed to be a relatively new and innovative field in terms of patenting activity (Fig. 31), with many patents still pending and with the Chinese Zhejiang University[25] having the biggest related patent portfolio (Table 35), followed by the Chinese technology company Maifei Technology (now: McFly,) [26] with 6 patents (5 pending, 1 granted, see Table 36), both portfolios have domestic protection only (China) and their inventions are mainly related to agricultural applications.



[25] https://www.zju.edu.cn/english/
[26] http://www.mcfly.com.cn/en/

Fig. 31 Drone-borne hyperspectral imaging top key players – patents (Source: Questel Orbit)

Patent title and reference number	Jurisdictions	
	in force	pending
Method for identifying barnyard grass of rice field by utilizing a hyperspectral imaging technology (CN109765190)		CN
Rice yield estimation by unmanned aerial vehicle remote sensing based on imaging hyperspectral vegetation index and length of growing period (CN109508693)		CN
Self -propelled on -line measuring device based on spectral imaging technique (CN206920021)	CN	
Unmanned aerial vehicle snap formula hyperspectral remote -sensing system CN206832361	CN	
Snapshot type high spectral remote sensing system with drone and consistency radiation correction method CN107402069		CN
Orchard pest and disease damage general investigation system and method based on uav (unmanned aerial vehicle) remote sensing CN106778888		CN
Imaging spectrometer based on etching diffraction grating CN205537958		CN
Imaging spectrometer on the basis of etched diffraction grating CN105547478	CN	

Table 35 Zhejiang University granted and pending patents

Patent title and reference number	Jurisdictions	
	in force	pending
Rice leaf nitrogen content based on an unmanned aerial vehicle high spectrum monitoring method CN110376167		CN
To the extent of disease diagnosis method based on the hyper-spectral CN110361344		CN
Hyperspectral real-time radiometric calibration method based on light sensing module CN109253976		CN
All -in -one system of beating is examined to agricultural CN208095182	CN	
Intelligent pest observing and killing system based on unmanned plane hyperspectral remote sensing CN108693119		CN
Agricultural investigation and attack integrated unmanned aerial vehicle system and spraying control method CN108684282		CN

Table 36 Maifei Technology granted and pending patents

Furthermore the US aviation company Boeing and the US e-commerce giant Amazon also are active in the field with 4 and 3 patents respectively (3 granted each).

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
System and method for monitoring crops US20190220964		US
Hyperspectral resolution using three-color camera US20160132748	US, GB	AU
Systems and methods for measuring polarization of light in images EP2905590	**US, CA, JP, KR, CN, DE, FR, GB,**	**BR**
Methods and systems for plume characterization US20090222207	US	

Table 37 Boeing granted and pending patents

Patent title and reference number (bold: patent in force having the highest number of jurisdictions)	Jurisdictions	
	in force	pending
Commercial and general aircraft avoidance using acoustic pattern recognition US20160247405	US	
Commercial and general aircraft avoidance using multi-spectral wave detection US20160247407	US	
Commercial and general aircraft avoidance using light, sound, and/or multi-spectral pattern detection EP3230972	**CA, JP**	**CN, DE, EP, IN**

Table 38 Amazon granted and pending patents

3.4.2 Top key players – scientific publications

Few scientific publications have been identified in this field, with the Chinese Academy of Science and the Italian National Research Centre leading with 4 publications each.

Research institution	# papers
CHINESE ACADEMY OF SCIENCES (CN)	4
CONSIGLIO NAZIONALE DELLE RICERCHE (IT)	4
FINNISH GEOSPATIAL RESEARCH INSTITUTE (FI)	3
KING ABDULLAH UNIVERSITY OF SCIENCE TECHNOLOGY (SA)	3
MARCHE POLYTECHNIC UNIVERSITY (IT)	3
THE NATIONAL LAND SURVEY OF FINLAND (FI)	3
UNIVERSITY OF NEW BRUNSWICK	3
UNIVERSITY OF QUEENSLAND	3
UTAH STATE UNIVERSITY (US)	3
ANHUI UNIVERSITY (CN)	2

Table 39 Drone-borne hyperspectral imaging top key players – scientific publications (Source: WOS)

3.4.3 Evolution

Analysing the timeline of general patenting in the field of drone-borne hyperspectral imaging over the last 10 years we detect a strong increase in publications with a peak in 2018 with 49 patents (Fig. 32). In scientific publications related to Drone-borne hyperspectral imaging we see a similar evolution to the patent publications, with a steady increase in the last years, being 2018 the most productive year so far, with 19 publications. This technology field is the only of the analysed ones where more patents have been filed than scientific works being published.

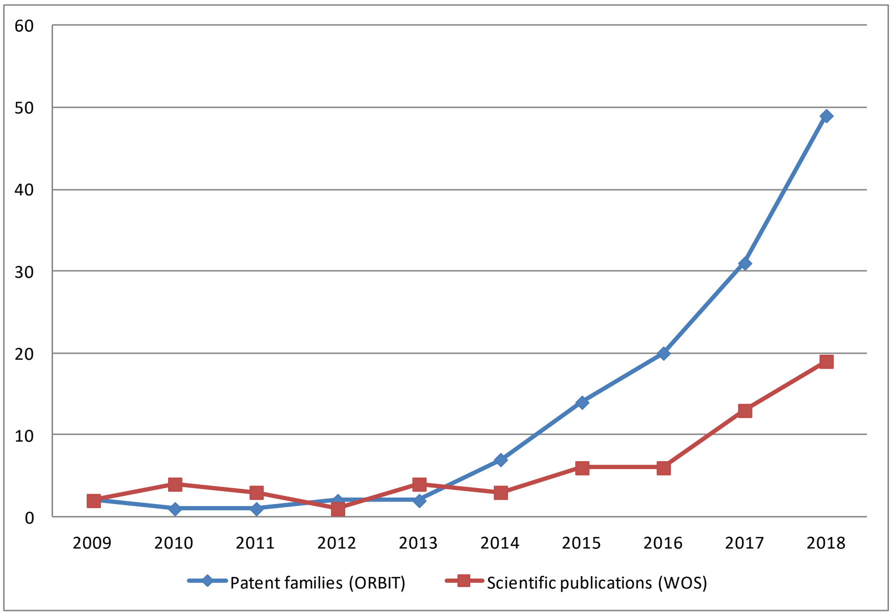


Fig. 32 Drone-borne hyperspectral imaging evolution

Analysing the patenting evolution by key players (Fig. 33) reveals that most companies have a very recent patenting activity with most publications occurring since 2016, especially the Chinese Maifei technology and Zhejiang University.

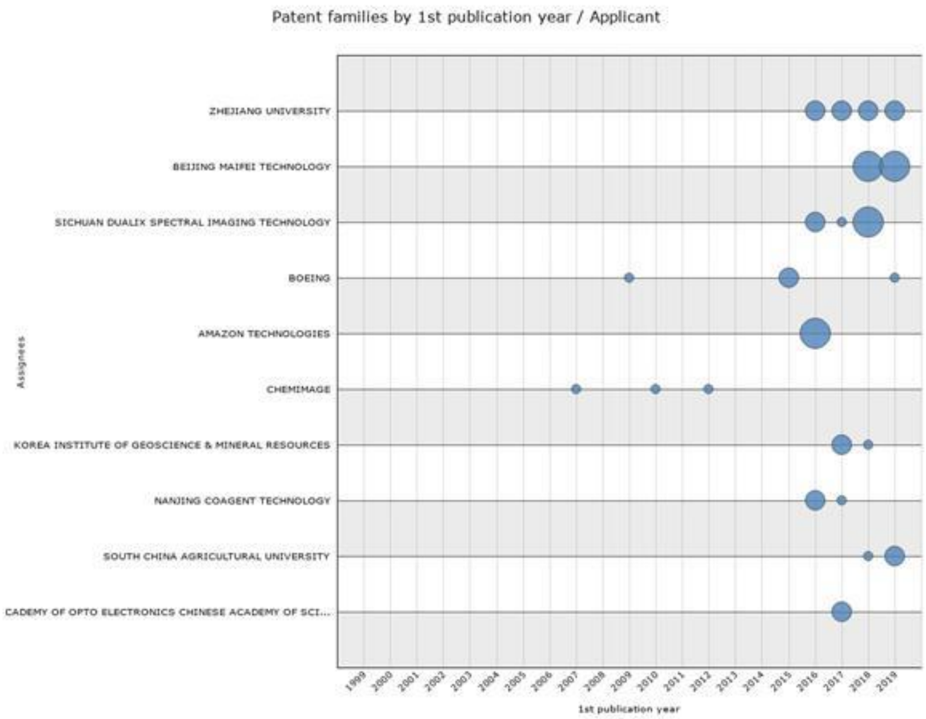


Fig. 33 Drone-borne hyperspectral imaging patenting evolution – key players (Source: Questel Orbit)

3.4.4 Innovation origin – patents

Most patents in this field have their origin in China (priority filings), followed by the United States with half the patent filings, and followed by South Korea, France and Japan.

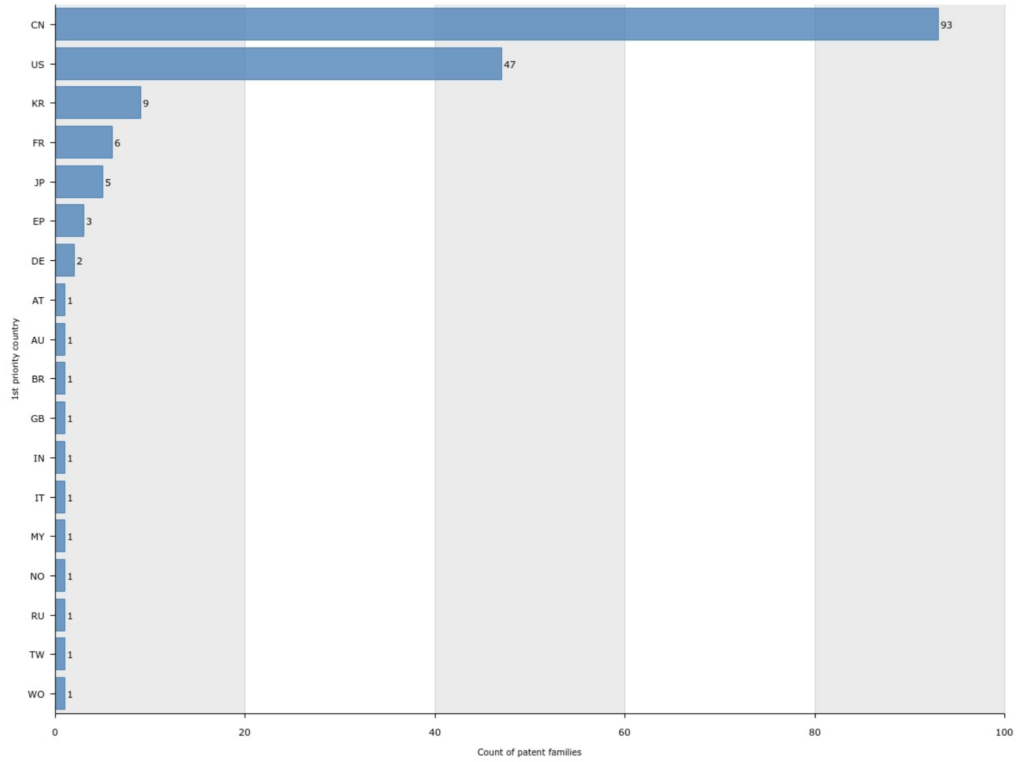


Fig. 34 Drone-borne hyperspectral imaging patent first filings (Source: Questel Orbit)

3.4.5 Innovation origin – scientific publications

We encounter a similar picture when analysing the scientific publications related to Drone-borne hyperspectral imaging, with the difference that the difference between China and US is not that accentuated. It is interesting to see Italy on third position with nearly the same amount of publications, but far less patent filings.

Institution country	# papers
PEOPLES R CHINA	14
USA	13
ITALY	12
AUSTRALIA	6
AUSTRIA	5
CANADA	4
SOUTH KOREA	4
ENGLAND	3
FINLAND	3
GERMANY	3
SAUDI ARABIA	3
SPAIN	3
BELGIUM	2
CYPRUS	2
FRANCE	2

Table 40 Drone-borne hyperspectral imaging top scientific publication countries (Source: WOS)

3.4.6 Markets

As for the countries where patents related to drone-borne hyperspectral imaging are in force (protection countries), the most important markets seem to be China, the US and Europe with most patents protected in these jurisdictions, followed by WO patent applications[27].

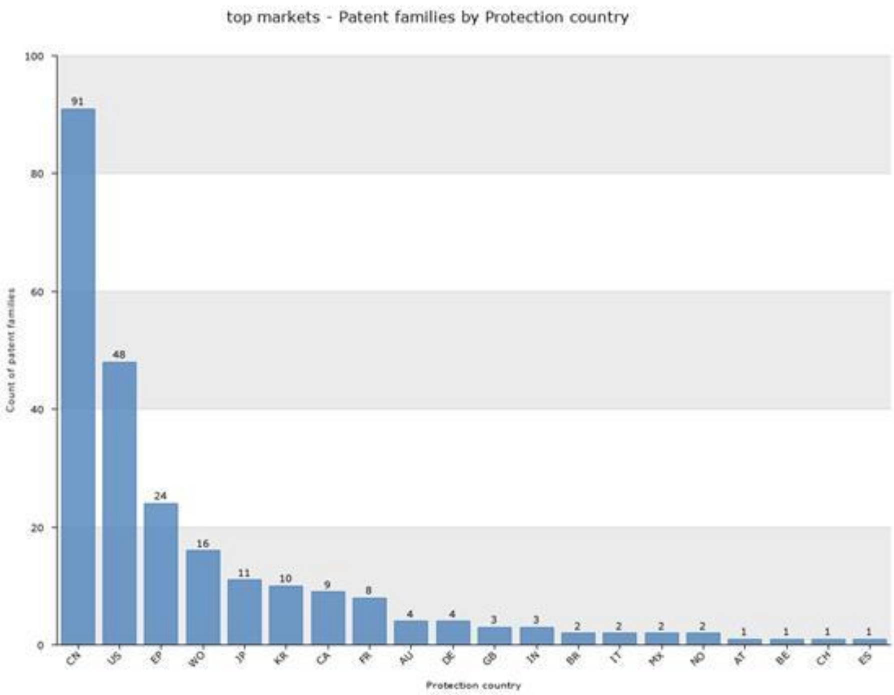


Fig. 35 Drone-borne hyperspectral imaging patent protection countries (Source: Questel Orbit)

As for the applicant's portfolio internationalisation (Fig. 36), the main Chinese applicants only file in China, whereas BOEING and AMAZON have the most internationalised patent portfolio with publications in 9 and 7 countries respectively.

[27] WO is not a jurisdiction but a worldwide patent extension (so called "PCT applications", see also glossary), giving the applicant 18 months more time before having to decide for the countries to protect.

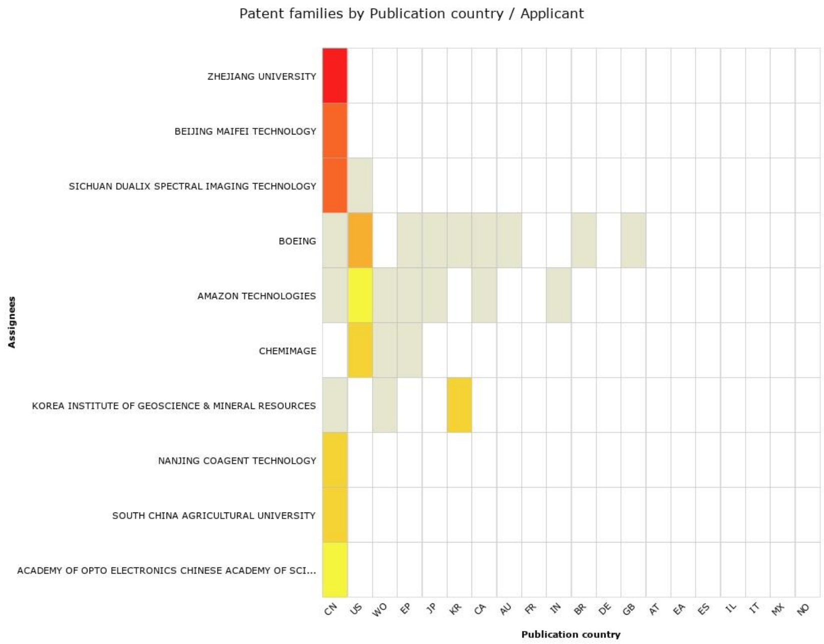


Fig. 36 Drone-borne hyperspectral imaging key players patents by country (Source: Questel Orbit)

3.4.7 Patent citation & collaboration maps

Drone-borne hyperspectral imaging related patent citations shows a more scattered landscape, with few citation networks that include more than two applicants.

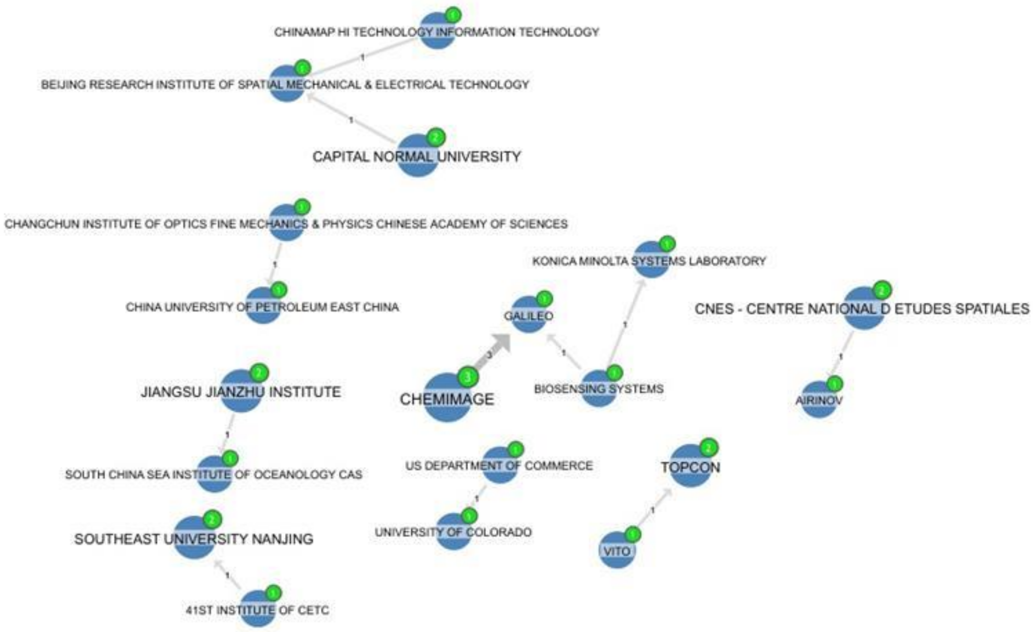


Fig. 37 Drone-borne hyperspectral imaging patents citation node map[28] (Source: Questel Orbit)

[28] with minimum 1 patents per applicant and minimum 1 citing patent

Patent co-authorship analysis reveals some company-university partnerships as the Japanese Fujifilm and Hiroshima University. Most collaboration is on domestic level only and with maximum 2 partners.

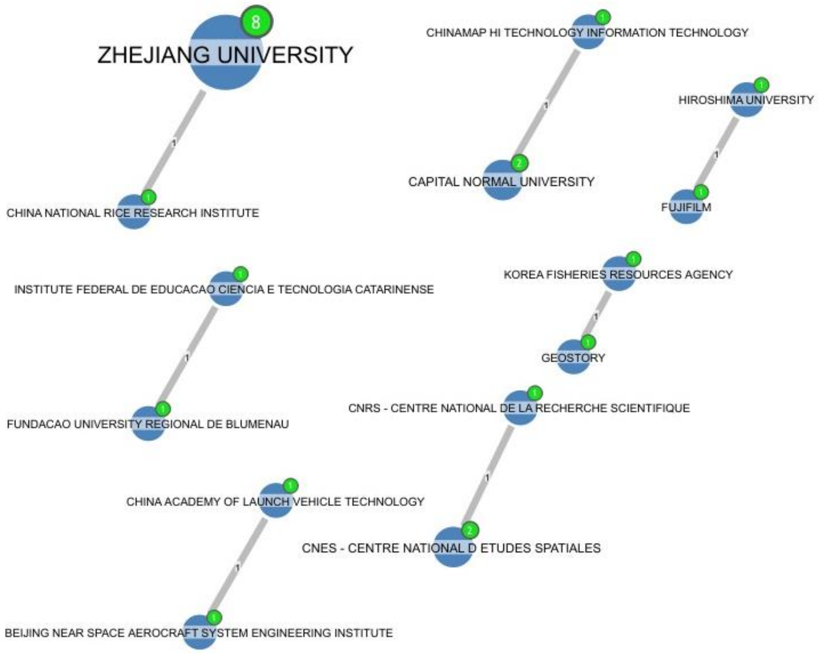
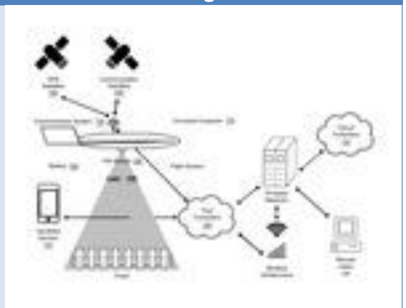


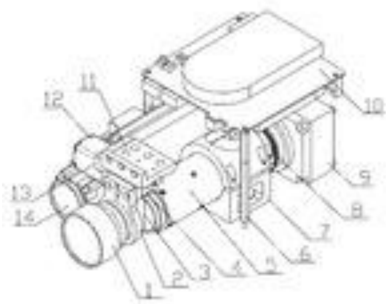
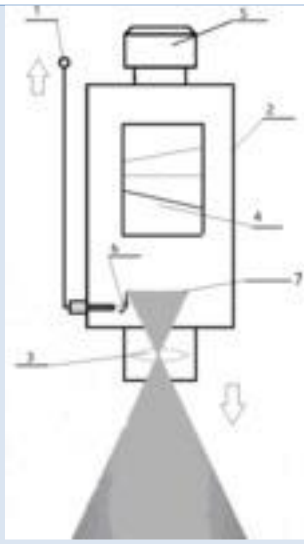
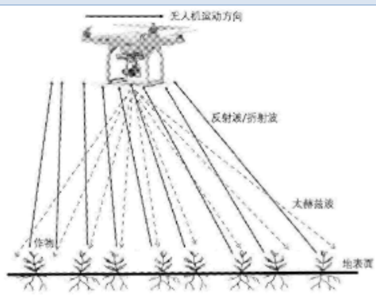
Fig. 38 Drone-borne hyperspectral imaging patents collaboration node map[29] (Source: Questel Orbit)

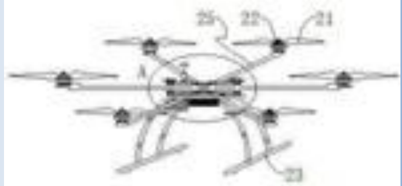
3.4.8 Top patents

The following table show the top patents related to drone-borne hyperspectral imaging, according to the indicators described in chapter 2.6 and detailed in the Annex.

Title & Applicant	Abstract	Image
Apparatuses and methods for bio-sensing using unmanned aerial vehicles BIOSENSING SYSTEMS	Described herein are methods, apparatuses, and systems that enable a light weight autonomous unmanned aerial vehicle (UAV) to process hyperspectral (HSI) data during its flight and send information to the ground computer via radio-link. This capability is not currently available owing to the severe combination of technical constraints: the typical processing power required to analyze HSI data in real time; the small space and power available for the payload in a light-weight UAV; and the limited bandwidth available on the wireless link.	

[29] with minimum 1 patents per applicant and minimum 1 patent in co-authorship

Lens scanning mode hyperspectral imaging system and rotor unmanned aerial vehicle SICHUAN DUALIX SPECTRAL IMAGING TECHNOLOGY	A lens scanning mode hyperspectral imaging system and a rotor unmanned aerial vehicle include: an imaging lens, an imaging spectrometer and a surface array detector arranged in sequence and coaxial to a main optic axis, wherein the imaging spectrometer and the surface array detector are connected and mounted to each other; wherein the lens scanning mode hyperspectral imaging system further includes: a driving device for driving the imaging lens to translate relative to a plane where a slit of the imaging spectrometer is. The hyperspectral imaging system of the present invention overcomes the technical bias in the prior art that the imaging lens must be fixed, and the present invention provides relative motion between the target object and the imaging spectrometer by the lens scanning mode for imaging, which solves the image distortion problem of conventional hyperspectral imaging system using a slit scanning mode or a scanning mode.	
Unmanned plane borne hyperspectral image detector and method with function of synchronization radiation correction NANJING COAGENT TECHNOLOGY	The invention discloses an unmanned plane borne hyperspectral image detector with a function of synchronization radiation correction, and the detector comprises a target spectrum image detector and an image processor which carries out data communication with the target spectrum image detector. The target spectrum image detector comprises a camera lens, a spectrum splitter and an image detector. One end, opposite to the camera lens, of the spectrum splitter is provided with a signal collection slit. The detector also comprises a reference light collector and a curved surface reflector. The reference light collector is disposed at an upper no-shading place of an unmanned plane. The curved surface reflector is disposed at one end of the signal collection slit of the spectrum splitter. Meanwhile, the invention also provides an unmanned plane borne hyperspectral image detection method with the function of synchronization radiation correction. The detector corrects the offset of the detection data in real time, facilitates the remarkable improvement of the data calculation precision, and is especially suitable for the sweeping detection of an unmanned plane borne hyperspectral image under the varied radiation conditions.	
Unmanned aerial vehicle-borne terahertz wave and hyperspectral remote sensing crop monitoring system SHENZHEN AUSPICIOUS TERAHERTZ TECHNOLOGY RESEARCH INSTITUTE	The invention discloses an unmanned aerial vehicle-borne terahertz wave and hyperspectral remote sensing crop monitoring system. A hardware platform is an unmanned aerial vehicle, and a terahertz reflection spectral imaging system and a passive hyperspectral imaging instrument are carried in the unmanned aerial vehicle; the terahertz reflection spectral imaging system comprises an active terahertzsource, a terahertz camera and a terahertz imager; the terahertz source emits terahertz waves to crops and earth surfaces; the terahertz camera receives spatially distributed reflected wave data of the terahertz wave which are finally formed in the crops and the earth surfaces through multiple reflection, refraction, transmission, and absorption; and the terahertz camera transmits the reflected wave data to the terahertz imager and forms corresponding terahertz wave imaging data. The unmanned aerial vehicle-borne terahertz wave and hyperspectral remote sensing crop monitoring system providedby the invention can help to solve the problems existing in the early discovery and diagnosis of crop growth, and facilitates to take effective intervention or	

	remediation measures prior to the occurrence of a hazard to restore the crop health and avoid the influence on the crop yield.	
Hyper-spectral imaging system based on hyper-spectral camera and area-array camera as well as pos system SICHUAN DUALIX SPECTRAL IMAGING TECHNOLOGY	The invention discloses a hyper-spectral imaging system based on a hyper-spectral camera and an area-array camera as well as a POS system. The hyper-spectral imaging system comprises the hyper-spectral camera for acquiring target one-dimensional image data, the hyper-spectral camera is connected with a processor, the area-array camera for acquiring target two-dimensional image data is fixedly connected with one side of the hyper-spectral camera, a two-dimensional area photographed by the area-array camera comprises a linear area photographed by the hyper-spectral camera, the POS system for acquiring position data and attitude area of the hyper-spectral camera is also arranged on the hyper-spectral camera, and both the area-array camera and the POS system are connected with the processor. The hyper-spectral imaging system disclosed by the invention has strong practicability, is low in carrying platform cost, and can control a carrying platform through wireless transmission and remote control, and observe a to-be-photographed target area, the flying attitude of an unmanned aerial vehicle, the effect of an acquired image and the like on the ground in real time.	
Detection methods of ore body containing chrome using drone equipped hyperspectral images sensor KOREA INSTITUTE OF GEOSCIENCE & MINERAL RESOURCES	The present invention relates to a chrome ore detection method using a drone with a hyperspectral image sensor mounted thereon. The chrome ore detection method includes the steps of: obtaining hyperspectral image recording data of an explored area by using the drone with a hyperspectral image sensor camera mounted thereon in the air; and generating the distribution map of dark dunite bodies within the explored area based on the recording data. Accordingly, the present invention can quickly discover the dark dunite bodies being the main base rocks including chrome ores by utilizing the drone with the hyperspectral image sensor mounted thereon, thereby significantly reducing the time needed to explore a wide area for detecting the chrome ores.	No image available
Water quality hyperspectral aerial remote sensing system based on multi-rotor unmanned aircraft SOUTH CHINA SEA INSTITUTE OF OCEANOLOGY CAS	The invention relates to the technical field of a multi-rotor unmanned aircraft, and specifically relates to a water quality hyperspectral aerial remote sensing system based on a multi-rotor unmanned aircraft. The system comprises a multi-rotor unmanned aircraft and a data analysis and processing system. A hyperspectral image detection system is arranged on the multi-rotor unmanned aircraft. The data analysis and processing system receives information acquired by the hyperspectral image detection system. According to the water-quality hyperspectral aerial remote sensing system, the multi-rotor unmanned aircraft is adopted as an aerial remote sensing carrier, such that load and stability can be improved, and large-area data acquisition can be easily realized. Also, with the hyperspectral image detection system, water quality hyperspectral information is acquired, and source data is provided for the data analysis and processing system.	

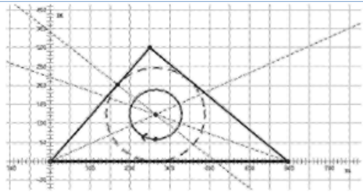
Geological prospecting route planning method and system CHINA UNIVERSITY OF GEOSCIENCES	The invention relates to a geological prospecting route planning method. The geological prospecting route planning method comprises: determining a non-key prospecting region and a key prospecting region according to digital map information, wherein the key prospecting region comprises m prospecting units, m is no less than 1, and m is an integer; determining, according to a cost function, a first optimal route of a multi-rotor unmanned aerial vehicle carrying a hyper-spectrometer from a start point to the key prospecting region, and obtaining a prospecting unit corresponding to the first optimal route; determining, according to the cost function and the prospecting units, a prospecting sequence of the m prospecting units via the multi-rotor unmanned aerial vehicle; determining, according to the m prospecting units, the prospecting sequence and the cost function, an optimal prospecting route of the multi-rotor unmanned aerial vehicle in each prospecting unit and a prospecting endpoint in the key prospecting region; determining, according to the cost function, a second optimal route of the multi-rotor unmanned aerial vehicle from the prospecting endpoint to the start point, so as to complete geological prospecting route planning. According to the geological prospecting route planning method, the geological prospecting efficiency and accuracy of an unmanned aerial vehicle are improved, and the prospecting cost is reduced.	

Table 41 Drone-borne hyperspectral imaging top patents

3.5 INFACT researchers' analysis

In this chapter we present a bibliometric analysis based on the scientific publications of the main researchers working in the INFACT project. In a separated search in the WOS database 606 publications were retrieved of authors working in the INFACT project.

We analysed the collaboration of the INFACT researchers on three aspects:

- Author level: co-authorship with other authors
- Institution level: co-authorship with authors institutions
- Country level: co-authorship with authors institutions country

3.5.1 Author level

In the following figure we have visualised via a co-authorship network map with whom the researchers are co-authoring in their scientific publications. We can see that Gloaguen, Renn and Ghamisi occupy the whole centrality thus being the most important ones. Furthermore Stolz has very strong connections to the whole author set.

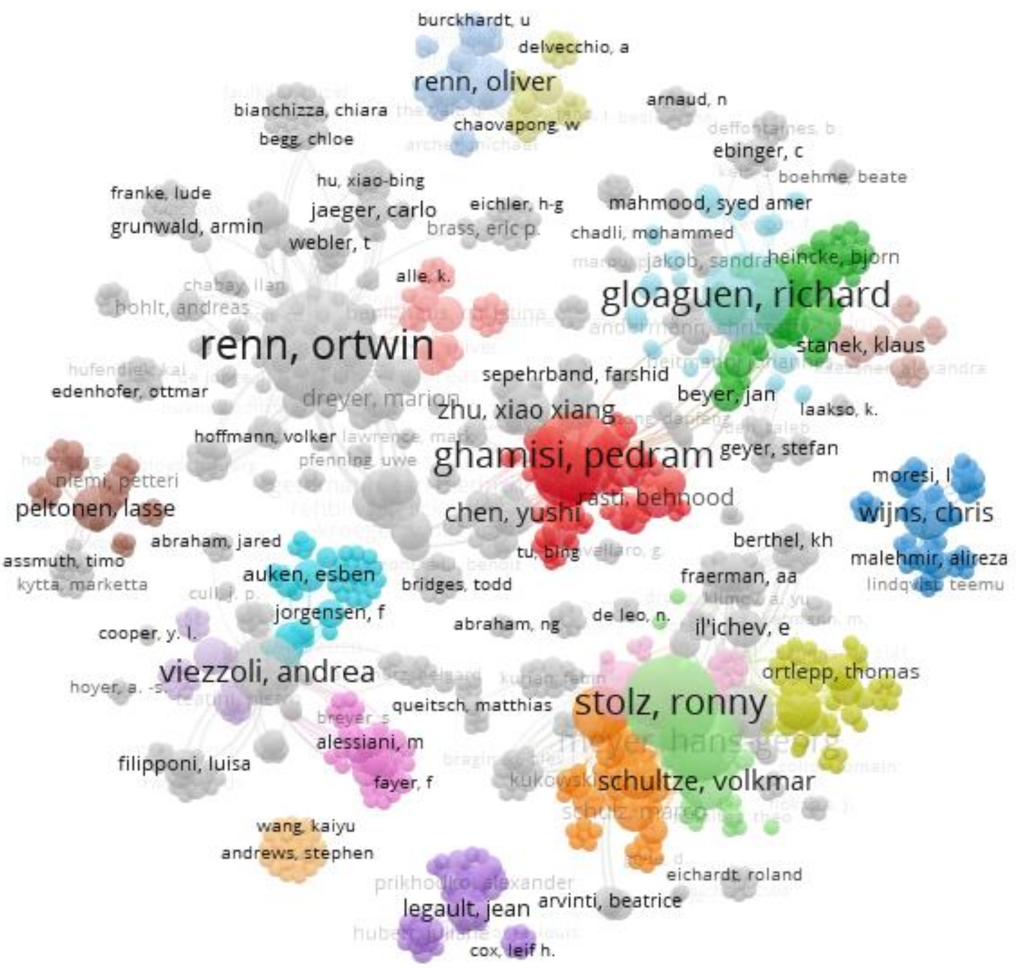


Fig. 39 INFACT researchers co-authorship node map

3.5.2 Institution level

When analysing the researchers' collaboration on the institutional level we see a strong collaboration between University of Stuttgart, Helmholtz Institute, Leibniz University of Hannover and Freiberg University.

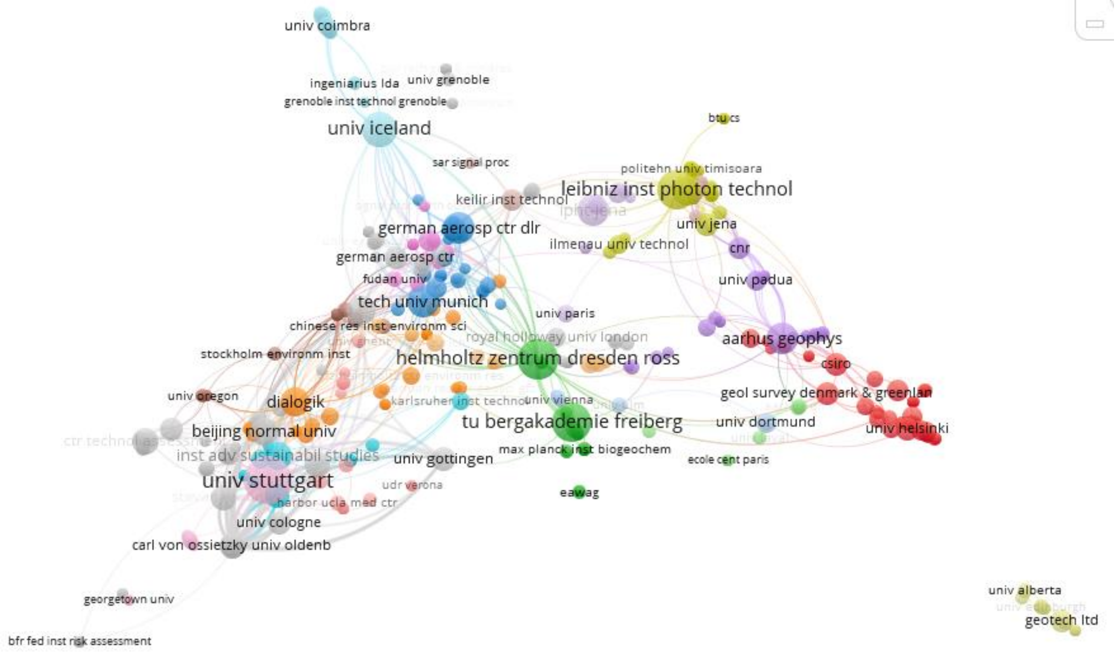


Fig. 40 INFACT researchers co-authorship node map (institution level)

3.5.3 Country level

When analysing the researchers' collaboration on the country level, Germany is the central node, being the country with most of the before mentioned institutions. The co-authorship analysis reveals connections to other European countries (Denmark, Iceland, Norway and Switzerland) but also to China, Japan and Australia.

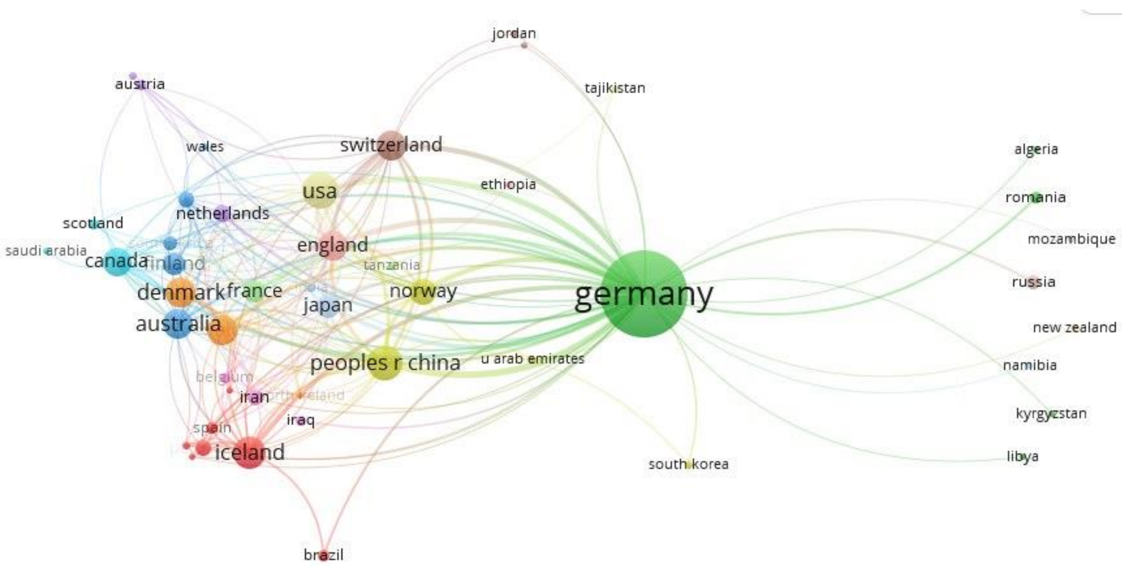


Fig. 41 INFACT researchers co-authorship node map (country level)

4 DISCUSSION AND CONCLUSION

This study has analyzed a total of 669 patent families and 2019 scientific publications corresponding to the 4 Key Intelligent technologies selected by INFACT partners.

Considering that a patent analysis exercise usually deals with a significantly higher number of documents (10.000+), the selected technologies can be considered niche technologies. Indeed, Daly et al (2019) identified a total of 114.676 patent families in the mining exploration subsector filed between 1990 and 2015. Despite the difference in the period of analysis which makes the comparatives difficult (25 years against 10 years of our research), mining patents in general have outpaced the overall patenting activity since 2004, therefore we could say that the patents of the technologies studied in this report represent an order of magnitude of 10^{-2} compared to all patents retrieved in mining exploration. These results are thus coherent with FRA & SRK (2019) and FRA (2019) where, through a consultation with experts in the field of geoscience and beyond, it became evident that the utilization frequency of the INFACT reference sites with non-invasive mineral exploration technologies only, may stay low.

In general terms, when comparing the 4 technologies, we observe that considerably more scientific publications were retrieved than patents, especially in the fields of EM methods and gravity gradiometry. This indicates that these technologies involve a considerable amount of basic research. Drone-borne hyperspectral imaging technologies seem to be more applied to the market with more patents than scientific works. Airborne magnetometry has yielded similar number of documents on patents and scientific publications. Other reasons for the discrepancy between patent and research could lie in the different application cases of the technologies.

INFACT technologies become more important over time, with significant increases in airborne hyperspectral imaging and airborne magnetometry. This trend is encouraged through the transferability of these technologies into other sectors, thus increasing the overall patenting activity. Indeed, the increased patenting activity of less-invasive technologies may however not solely be reflected in the attempt to reduce impact, but by the economic opportunities associated with it.

Different applications of sensors and sensing systems, may lead to an increased research activity across industries. Hence, publications exceed patents, as application specific research multiplies.

The statistical country profiles yield information on the patenting behaviour across the globe. China has acquired a leading position in publication and patents, yet lacking in collaboration statistics. Statistical patent analysis within the mining technology sector show similar results. Daly et. al (2019), illustrate that the country comparison resulting of the present study and the one performed for mining technology patents share a number of key features.

Similar to the present study the authors show that patenting activities in China have sprung in recent years. Comparison with Daly et. al (2019) shows further similarities, indicating a strong inward focus of the Chinese patenting behaviour. Eberhardt et al (2017) as well as Long (2016) argue that China's increased research actions are related to the encouragement of research through the Chinese government (e.g. subsidy of patent fees and a lax examination policy of the Chinese patent office)

Despite the intensity of Chinese patenting and publication behaviour, the present study indicates a discrepancy between market impact and research intensity.

Reasons for this relation might stem from Chinas strong inward focus. INFACT partners outscore in this field. Global scientific partnerships are more frequent in other countries compared to China. Concerning innovative capacity generation within a sector and beyond, cooperation's are an important instrument (Verspangen, 1997). Expanding the scientific focus of INFACT by means of expanding the test site portfolio is therefore expected to complement the technological development and demonstration at the sites.

Portfolio diversification could be realized by integrating technology developers to the test sites that work on similar platform, with similar systems or face similar challenges.

When analysing the key players in each technology and the relative position of INFACT partners and INFACT reference site users, we find the following results and give some recommendations for increasing the frequency of use of the reference sites:

1. *Airborne electromagnetics (AEM): transient electromagnetics (TEM)*

   During INFACT project, several TEM systems have been employed: the Geotech VTEM-ET (INFACT partner) was flown at Sakatti and Geyer, and the VTEM-Max was flown at Rio Tinto and Las Cruces. Not planned when the project started, the SkyTEM and CGG HeliTEM systems were also flown at Las Cruces demonstrating the interest of the key players in mineral exploration industry on the INFACT reference sites.

   We see that the top 2 players in patent filings are the Canadian Geotech being the leading company in patenting activity and the French Geoscience company CGG. Moreover, Geotech and CGG showed to have the most internationalised patent portfolio. Thus, both companies seem to follow similar IP strategies. In contrast, the Dutch SkyTEM has only one patent and thus has not passed the threshold to be included in the top applicants and top patents list. The reasons behind SkyTEM for using different IP protection mechanisms could be multiple (Gallié & Legros 2012): 1) the business model is based on this one patent only or 2) the company prefers to maintain some of its technology as a trade secret instead of revealing their innovation to the public via patents, or 3) it buys-in technology from other companies, or 4) a mixture of all 3 beforementioned IP strategies.

   When analysing the list of top patents, we observe that the mining companies Anglo American (INFACT partner) and the Brazilian Vale are both included with 2 patents each, demonstrating the relevance of their innovations in EM, even though they have less patents filed compared to companies offering exploration services. These results are coherent with Daly et al (2019) where they show that despite the low levels of mining firms with patents, they file most of their mining technologies precisely in the exploration sub-sector.

   Concerning scientific output, the Danish Aarhus University is the institution that publishes the most in the field of airborne electromagnetic methods. One the main reason for this scientific productivity is due to the decision of the University to set up an EM test site for calibration and validation of airborne and ground based TEM systems in 2001. INFACT partners have thus exchange knowledge intensively during the project. It is also worth to mention that Helmholtz Association is included in the list of top 15 players, being HZDR one of its members.

   Finally, it would be of interest for INFACT partners to contact the Chinese public research institution JILIN UNIVERSITY as it seems to play an important role not only in relation to patent activity but also in terms of publishing productivity. However, the market potentiality of the patents must be further analysed as they have received few citations, hence have low relevance. One of the reasons could be that they have been filed in most recent time (2017-2019).

2. *Airborne gravity gradiometry (AGG): Full Tensor Gravity Gradiometry (FTG)*

   Airborne gravity gradiometry (AGG) has not been applied yet in the INFACT reference sites. According to our knowledge, three oil and mineral exploration contractors currently fly AGG equipment: CGG with Falcon-AGG, HeliFalcon and Falcon Plus; Bell Geospace with FTG; and

AustinBridgeporth with FTG. CGG (INFACT site user) and Bell Geospace have both 3 patents filed each, being CGG the company with the most international patent portfolio.

Interesting would be to explore cross-sectoral technology transfer cooperation from defence sector to mineral exploration as two Chinese military organisations are leading in patenting. It must be noted that those patents are domestic (Chinese) applications only and no patent has been extended to other countries. Aerospace sector is also an opportunity as the US aerospace institution NASA is leading scientific output and could also lead to other application fields at the INFACT reference site. An example, although not related to AGG, is the LMAP project, led by NASA Ames Research Center in Rio Tinto, which main objective is to increase development and technological maturity of a system of drilling and sampling in the subsoil for the search for life and planetary exploration, mainly on Mars.

Finally, here again Helmholtz Association (HZDR is one of its members) ranked the 7th position in the list of top players in terms of scientific output with 27 papers.

3. *Airborne magnetometry: Full Tensor Magnetic Gradiometry (FTMG)*

   During INFACT project, a magnetic gradiometry survey was performed over the Sakatti and Geyer reference sites using a Superconducting Quantum Interference Device (SQUID) by Supracon (INFACT Partner). This tech-based firm has 5 patents, however all of them describe technologies without any mention to mining exploration, so they were not retrieved from the queries. Indeed, apart from geophysics, the most common commercial use of SQUIDs is in magnetic property measurement systems (MPMS) for many application fields such as ultra-sensitive medical devices and bolometer cameras for sky exploration. Regarding granted and/or pending patents, we have identified as potential reference site user the French CGG, the Swiss based HEXAGON TECHNOLOGY CENTRE and the Brazilian mining company VALE. As for the institutions that published scientific articles, the Iranian university of Teheran is leading the ranking, closely followed by the US research intensive NASA and the University of California. Approaching those institutions to explore scientific cooperation by INFACT is recommended.

4. *Drone-borne hyperspectral imaging (HSI): long-wave/thermal infrared, near infrared, short-wave infrared.*

   During the INFACT project, drone-borne hyperspectral imaging has been employed by HZDR in the Rio Tinto and Las Cruces reference areas. Most publications and patents are occurring recently, although evolving almost exponentially, the total number is still relatively low, especially for scientific publications. Interesting would be to explore cross-sectoral technology transfer cooperation from agriculture and aeronautics fields approaching Chinese key players such as ZHEJIANG UNIVERSITY and the Agri-tech company MAIFEI TECHNOLOGY (now: McFly). In the US, collaboration with the aviation company BOEING and the US e-commerce giant AMAZON could be also interesting because they are active in the field with several granted and internationalised patents.

Technology watch activities are essential to systematically analyse and monitor new technology developments in the field of non-invasive exploration that could be tested and further developed in INFACT reference sites. The present report has analysed 4 key intelligent technologies selected by INFACT partners as were considered the most important for the reference sites. However, patent landscape is evolving every day, so frequent update of this report is recommended. To do so, the search queries we applied are in the annex 5.3 and the data sources used are mentioned in the methodology section (chapter 2.3). In further reports, other technologies included in annex 5.2 could be incorporated in the analysis.

5 APPENDIX

5.1 TECH WATCH NEEDS ANALYSIS QUESTIONNAIRE

Technology WATCH Questionnaire (Poll)

Of the five families of technologies related to INFACT (GEOPHYSICAL SENSORS, SPECTROSCOPY, SURVEY PLATFORMS, LOW-IMPACT SAMPLING and GEOGRAPHIC INFORMATION SYSTEM) could you tell us the specific technologies that would be of interest to be analysed?

GEOPHYSICAL SENSORS

Technology that would be of interest to be analysed	Proposed search keywords	Related known papers, patents, companies, etc.

SPECTROSCOPY

Technology that would be of interest to be analysed	Proposed search keywords	Related known papers, patents, companies, etc.

SURVEY PLATFORMS

Technology that would be of interest to be analysed	Proposed search keywords	Related known papers, patents, companies, etc.

LOW-IMPACT SAMPLING

Technology that would be of interest to be analysed	Proposed search keywords	Related known papers, patents, companies, etc.

GEOGRAPHIC INFORMATION SYSTEM (GIS)

Technology that would be of interest to be analysed	Proposed search keywords	Related known papers, patents, companies, etc.

Any additional comments?

5.2 TECH WATCH NEEDS ANALYSIS SURVEY SUM UP

Technology field	Technology that would be of interest to be analysed	Proposed search keywords	Related companies	Related research	Contributor
GEOPHYSICAL SENSORS	*High-sensitivity, Low-cost vector/tensor magnetic sensors*	*Squids, CVD (Carbon Vapour Diamonds), Fluxgate magnetometers*	*Supracon, Element Six*	*IPHT (Jena)*	*JJ*
GEOPHYSICAL SENSORS	*Airborne EM*	*AEM, Base frequency, Dipole moment, penetration, noise, calibration, accuracy, dual moment*	*Geotech, SkyTEM, CGG, NRG*		*AV*
GEOPHYSICAL SENSORS	*Airborne IP*	*AIP, AIIP, Induced Polarization, chargeability, exploration, VMS, deposit, base frequency, Cole Cole, ground IP*	*Geotech, CGG,*	*Macnae (2016), Viezzoli and Kaminski (2017), Smith (1989)*	*AV*
GEOPHYSICAL SENSORS	*Airborne IP processing & Ground Floor EM*		SkyTEM		MKO
GEOPHYSICAL SENSORS	*Time Domain Electromagnetic method*	*TDEM, Transient Electromagnetic*	*GEONICS, ZONGE*	*Methods electromagnetics in applied geophysics, M. Nabighian (papers, books)*	*AB*
GEOPHYSICAL SENSORS	*GRAVITY*	*"AIRBORNE GRAVITY GRADIOMETRY", GRAVITY-METER, "GROUND GRAVITY", "REGIONAL AND RESIDUAL GRAVITY ANOMALIES", "GRAVITY ANOMALY"*		*https://seg.org/Publications , https://www.eage.org/en/publications*	IF
GEOPHYSICAL SENSORS	*EM METHODS*	*"AUDIO MAGNETO-TELLURICS (AMT)", "TIME DOMAIN ELECTROMAGNETICS (TEM)", "FREQUENCY DOMAIN ELECTROMAGNETICS (FDEM)", "AIRBORNE EM", "INDUCED POLARIZATION (IP)", "EM ANOMALY", "IP ANOMALY"*		*https://seg.org/Publications , https://www.eage.org/en/publications*	IF
GEOPHYSICAL SENSORS	*MAGNETOMETRY*	*"GROUND MAGNETIC", "AIRBORNE MAGNETICS", "MAGNETIC ANOMALY"*		*https://seg.org/Publications , https://www.eage.org/en/publications*	IF
GEOPHYSICAL SENSORS	*SEISMIC METHODS*	*"PASSIVE SEISMIC"*		*https://seg.org/Publications , https://www.eage.org/en/publications*	IF
GEOPHYSICAL SENSORS	*FTMG*	*Magnetometry, airborne Mag., airborne EM, SQUID*	*Supracon, SIMIT, CSIRO, Spectrem*	-	JK
GEOPHYSICAL SENSORS	*Airborne Mag.*	*Optically pumped magnetometers*	*GEM Systems, Geometrics, MAG Aerospace, Intrepid Geophysics, GeoExplo Ltda., Pioneer Aerial Surveys, Sander Geophysics Limited (SGL), ABITIBI Geophysics, MagSpec airborne surveys*	-	JK
GEOPHYSICAL SENSORS	*Enhanced Full Tensor Gravity Gradiometry (eFTG)*	*Enhanced Full Tensor Gravity Gradiometry; eFTG, FTG*	AustinBridgeporth www.austinbridgeporth.com	-	JR
GEOPHYSICAL SENSORS	*Mobile MagnetoTellurics (MMT)*		*Expert Geophysics Limited, Andrei Bagrianski*	-	MK
GEOPHYSICAL SENSORS	*Airborne Gravity Gradiometry*		*CGG,*	-	MK
GEOPHYSICAL SENSORS	*Muon Tomography*		*Muons Solutions*	-	MK
GEOPHYSICAL SENSORS	*Magnetic Gradiometry*		*Supracon*	-	MK
GEOPHYSICAL SENSORS	*Passive Seismic*		*Sisprobe, SmartSolo,*	-	MK
GEOPHYSICAL SENSORS	*Drone-borne Mag*		*Sensys, MGT-geo, GEMsystems*	-	MK
GEOPHYSICAL SENSORS	*Drone-borne EM*		*MGT-geo, Luleå University*	-	MK
GEOPHYSICAL SENSORS	*Drone-borne Radiometrics*		*Georadis, radai*	-	MK

GEOPHYSICAL SENSORS	*(Drone-borne) LiDAR*		*Yellowscan, Riegl, Phoenix Lidar, DiMAP, Trimble*	-	MK
GEOPHYSICAL SENSORS	*Airborne EM*		*HeliSAM, SkyTEM, Geotech, CGG*	-	MK
GEOPHYSICAL SENSORS	*Ground Floor EM*		*MGT-geo*	-	MK
GEOPHYSICAL SENSORS	*Drone-borne Gravity*		*Rene Forsberg, Tim Jensen, Dept of Geodynamics DTU-Space, microMEMS accelerometers*	-	MK
GEOPHYSICAL SENSORS	*Drone-borne Seismic*		*Total (METIS project)*	-	MK
GEOPHYSICAL SENSORS	*Drone-borne Thermal imaging*			-	MK
GEOPHYSICAL SENSORS	*Ground EM*			-	MK
GEOPHYSICAL SENSORS	*Ground Gravity*			-	MK
GEOPHYSICAL SENSORS	*Ground Mag*		*Sensys, Geometrics, GEMsystems*	-	MK
GEOPHYSICAL SENSORS	*Ground Penetrating Radar*			-	MK
GEOPHYSICAL SENSORS	*Towed transient EM (tTEM)*		*Auken et al. 2019 (Geophysics)*	-	MK
GEOPHYSICAL SENSORS	*QuietSeis*	*most sensitive MEMS (Micro Electro-Mechanical System), detecting subsidence and landslides*	*Sercel Structural Monitoring and Sercel Earth Monitoring*	-	MP
GEOPHYSICAL SENSORS	*ESA - magnetometers*	*Magnetic mapping, World Magnetic Model,*	*ESA/Swarm/Champ*	-	MP
GEOPHYSICAL SENSORS	*Muon tomography*	*Muongraphy, muon tomography*	*Muon Solutions Oy*	-	RJ
GEOPHYSICAL SENSORS	*Airborne EM (VTEM, SkyTEM, ZTEM)*	*VTEM, SkyTEM, ZTEM, airborne EM*	*Geotech, SkyTEM*	-	RJ
GEOPHYSICAL SENSORS	*Full Tensor Magnetic Gradiometry (FTMG)*	*SQUID, FTMG*	*Supracon AG*	-	RJ
GEOPHYSICAL SENSORS	*Gravity survey*	*Gravity survey, gravity Gradiometry (ground)*	*Scintrex*	-	RJ
GEOPHYSICAL SENSORS	*Multi-Induced Polarisation, galvanic contact. (low impact)*	*IP, multi-electrode IP*	*Scintrex*	-	RJ
GEOPHYSICAL SENSORS	*Passive seismic measurements*	*passive seismics, H/V method, Seismic interferometry*	*Sercel, Nanometrics*	-	RJ
GEOPHYSICAL SENSORS	*Very Low Frequency Electromagnetic survey (VLF-EM)*	*VLF-EM*	*Scintrex, IRIS instruments*	-	RJ
GEOPHYSICAL SENSORS	*Nuclear Magnetic Resonance (NMR) Method for hydrology*	*NMR*	*Iris Instruments*	-	RJ
SPECTROSCOPY	*Downhole mineral or elemental analysis*	*SWIR, XRD, XRF, LIBS, PGNAA, Plasma emission*	*Sodern, GA Drilling*	*Delft (LIBS), CSIRO (PGNAA)*	*JJ*
SPECTROSCOPY	*Lif (Laser-induced fluorescence)*		*Freiberg Instruments, HZDR*		MK
SPECTROSCOPY	*Drone-borne Hyperspectral Imaging (near infrared)*		*SENOP (Rikola), Cubert GmbH, Vito*		MK
SPECTROSCOPY	*Drone-borne Hyperspectral Imaging (short-wave infrared)*		*Global UAV Tech, NEO (Hyspex), Headwall*		MK
SPECTROSCOPY	*Drone-borne Hyperspectral Imaging (long-wave/thermal infrared)*		*Telops*		MK
SPECTROSCOPY	*Raman spectroscopy*				MK
SURVEY PLATFORMS	*Any RPAS (drone) with endurance and payload*		*Boeing, Airbus*		*JJ*

SURVEY PLATFORMS	*Integration of infrastructure facilitates*	*Research Infrastructure*	*EPOS, the European Plate Observing System*		*MKO*
SURVEY PLATFORMS	*Airborne IP processing & Ground Floor EM*	*EM, IP*	*SkyTEM*		*MKO*
SURVEY PLATFORMS	*Helicopter / fixed wing (towed) platform*		*IMAR*		*JK*
SURVEY PLATFORMS	*UAV platform*	*UAV / UAS, Fluxgate,*	*MGT - Mobile Geophysical Technologies, IMAR*		*JK*
SURVEY PLATFORMS	*Long-endurance UAV (UAV survey platforms capable of long flight times)*	*UAV, drones, fixed-wing, long-endurance*	*UAVE Ltd. https://uave.co.uk/*		*JR*
SURVEY PLATFORMS	*Helicopter*				*MK*
SURVEY PLATFORMS	*Drone-swarms*				*MK*
SURVEY PLATFORMS	*Balloon*				*MK*
SURVEY PLATFORMS	*satellite*	*Magnetics, gravity, surface height*			*MP*
SURVEY PLATFORMS	*Multiple drone surveys*	*Drone swarms,*			*MP*
SURVEY PLATFORMS	*UAV (e.g. hyperspectral, magnetic, electromagnetic measurements)*	*Drone geophysics, UAV*	*RADAI Ltd.*		RJ
LOW-IMPACT SAMPLING	*Low-field NMR*	*Nuclear magnetic resonance*			JK
LOW-IMPACT SAMPLING	*Coil-tube drilling*	*Coil-tube drilling*		*DET-CRC, now MINEX*	*JJ*
LOW-IMPACT SAMPLING	*Ionic leach*		*ALS GEOCHEMISTRY (www.alsglobal.com)*	*UNIVERSITY OF LEICESTER https://www2.le.ac.uk/departments/chemistry/research/lil*	MKO
LOW-IMPACT SAMPLING	*Ionic leach geochemistry;Mobile Metal Ions*	*Ionic leach geochemistry; mobile metal ions; MMI*	*ALS Geochemistry (https://www.alsglobal.com/services-and-products/geochemistry/geochemistry-testing-and-analysis/generative-exploration), SGS https://www.sgs.com/en/mining/exploration-services/geochemistry/mobile-metal-ions-mmi*		*JR*
LOW-IMPACT SAMPLING	*Portable X-Ray Fluorescence Analysis , Portable X-Ray Diffraction*	*XRF, pXRF analysis, analyser, XRD, pXRD*	*Olympus (https://www.olympus-ims.com/en/innovx-xrf-xrd/) , Niton (http://www.nitonuk.co.uk/)*		*JR*
LOW-IMPACT SAMPLING	*Coiled Tubing Drilling*	*Coiled Tubing Drilling, CT drilling, low-impact diamond drilling*	*Deep Exploration Technologies http://detcrc.com.au/programs/program-1/project-1-1/*		*JR*
LOW-IMPACT SAMPLING	*Potable XRF, XRD, Infrared Spectrometer*		*Bruker, Olympus, SciAps*		*MK*
LOW-IMPACT SAMPLING	*Soil and Plant sampling*				*MK*
GEOGRAPHIC INFORMATION SYSTEM (GIS)	*3D (voxel) modelling*	*Voxel, 3D*	*OneGeology, British Geological Survey (UK) GDM Suite, BRGM (France)*	*EPOS, the European Plate Observing System*	MKO
GEOGRAPHIC INFORMATION SYSTEM (GIS)	*Artificial intelligence*	*AI*	*Earth AI (http://www.earth-ai.com/#/home), Produvia (https://produvia.com/)*		MKO
GEOGRAPHIC INFORMATION SYSTEM (GIS)	*Big data*	*Big data*	*Earth AI (http://www.earth-ai.com/#/home) Produvia (https://produvia.com/)*		MKO
GEOGRAPHIC INFORMATION SYSTEM (GIS)	*3D Geological Modelling*	*3D Geological Modelling, mineral resource estimation*	*Leapfrog, Leapfrog Edge (http://www.leapfrog3d.com/products/leapfrog-edge)*		JR
GEOGRAPHIC INFORMATION SYSTEM (GIS)	*Digital field mapping*	*Tablet mapping, digital geological field mapping*	*Collector for ArcGIS (https://doc.arcgis.com/en/collector/faq/whats-new.htm)*		JR

GEOGRAPHIC INFORMATION SYSTEM (GIS)	*Internet access in remote areas*	*Satellite internet access, Iridium, Inmarsat, portable, lightweight, networking*	*Iridium Go! (https://www.iridium.com/products/iridium-go/)*		JR

5.3 TECH WATCH SEARCH STRATEGY

KIT	AIRBORNE ELECTROMAGNETIC METHODS	AIRBORNE GRAVITY GRADIOMETRY	AIRBORNE MAGNETOMETRY	DRONE-BORNE HYPERSPECTRAL IMAGING
KEYWORDS concept 1 (TI/AB/CLMS)	AERIAL OR AERO OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER	AERIAL OR AERO OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER	AERIAL OR AERO OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER	DRONE OR UAV OR ((UNMANNED OR UNCREWED) AND (AIR+ OR AERIAL))
KEYWORDS concept 2 (TI/AB/CLMS)	ELECTROMAGNETIC+	GRAVIT+ OR GRADIOMET+ OR FULL_TENSOR_GRAVI+ OR EFTG OR FTG	FULL_TENSOR_MAGNET+ OR MAGNETOMET+ OR SQUID OR FTMG OR NITROGEN_VACANC+	HYPER_SPECTR+ OR MULTI_SPECTR+
KEYWORDS concept 3 (TI/AB/CLMS)	SURVEY+ OR MAPPING OR PROSPECT+ OR EXPLOR+	SURVEY+ OR MAPPING OR PROSPECT+ OR EXPLOR+	SURVEY+ OR MAPPING OR PROSPECT+ OR EXPLOR+	none
CPC/IPC concept 1	none	none	none	B64C2201 Unmanned aerial vehicles;
CPC/IPC concept 2	none	G01V7 Measuring gravitational fields or waves; Gravimetric prospecting or detecting	G01V3/175 ...operating with electron or nuclear magnetic resonance	G01J3 (Spectrometry) G06K2009/00644 using hyperspectral data, i.e. more or other wavelengths than RGB
CPC/IPC concept 3	G01V3 Electric or magnetic prospecting or detecting	G01V7 Measuring gravitational fields or waves; Gravimetric prospecting or detecting	G01V3 Electric or magnetic prospecting or detecting	G01N21/35 Investigating or analysing materials by the use of optical means... using infra-red light
generic PATENT CLASS CPC/IPC ((used without keywords)	G01V3 Electric or magnetic prospecting or detecting	G01V7 Measuring gravitational fields or waves; Gravimetric prospecting or detecting	G01 MEASURING; TESTING	G01 MEASURING; TESTING
ORBIT QUERY (for patent retrieval)	((AERIAL OR AERO OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER)/TI/AB AND (ELECTROMAGNETIC+)/TI/AB/CLMS AND (SURVEY+ OR MAPPING OR PROSPECT+ OR EXPLOR+)/TI/AB/CLMS) AND (G01V-003)/IPC/CPC	(G01V-007)/IPC/CPC AND (AERIAL OR AERO OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER)/TI/AB/CLMS AND (GRAVIT+ OR GRADIOMET+ OR FULL_TENSOR_GRAVI+ OR EFTG OR FTG)/TI/AB/CLMS	(G01#)/IPC/CPC AND (AERIAL OR AERO OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER)/TI/AB/CLMS AND ((FULL_TENSOR_MAGNET+ OR MAGNETOMET+ OR SQUID OR FTMG OR NITROGEN_VACANC+)/TI/AB/CLMS OR (G01V-003/175)/IPC/CPC) AND ((SURVEY+ OR MAPPING OR PROSPECT+ OR EXPLOR+)/TI/AB/CLMS OR (G01V3)/IPC/CPC)	(G01#)/IPC/CPC AND ((HYPER_SPECTR+)/TI/AB/CLMS OR (G06K-2009/00644)/IPC/CPC OR (G01J-003)/IPC/CPC) AND ((B64C-2201)/IPC/CPC OR (DRONE OR UAV OR ((UNMANNED OR UNCREWED) AND (AIR+ OR AERIAL)))/TI/AB/CLMS)
RESULTS (Patent families, ORBIT)	203	134	156	176
WOS QUERY (for papers retrieval)	TOPIC: (AERIAL OR AERO* OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER) AND TOPIC: (ELECTROMAGNETIC*) AND TOPIC: (SURVEY* OR MAPPING OR PROSPECT* OR EXPLOR*) Refined by: WEB OF SCIENCE CATEGORIES: (GEOCHEMISTRY GEOPHYSICS OR GEOSCIENCES MULTIDISCIPLINARY OR REMOTE SENSING) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.	TOPIC: (AERIAL OR AERO* OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER) AND TOPIC: (GRAVIT* OR GRADIOMET* OR FULL_TENSOR_GRAVI* OR EFTG OR FTG) AND TOPIC: (SURVEY* OR MAPPING OR PROSPECT* OR EXPLOR*) Refined by: WEB OF SCIENCE CATEGORIES: (GEOCHEMISTRY GEOPHYSICS OR GEOSCIENCES MULTIDISCIPLINARY OR REMOTE SENSING) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S,	TOPIC: (AERIAL OR AERO* OR AIRBORNE OR AIRCRAFT OR AIRPLANE OR AIRSHIP OR AVIATION OR HELICOPTER) AND TOPIC: (FULL_TENSOR_MAGNET* OR MAGNETOMET* OR SQUID OR FTMG OR NITROGEN_VACANC*) AND TOPIC: (SURVEY* OR MAPPING OR PROSPECT* OR EXPLOR*) Refined by: WEB OF SCIENCE CATEGORIES: (GEOSCIENCES MULTIDISCIPLINARY OR GEOCHEMISTRY GEOPHYSICS OR REMOTE SENSING) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.	TOPIC: (DRONE OR UAV OR ((UNMANNED OR UNCREWED) AND (AIR* OR AERIAL))) AND TOPIC: (HYPER_SPECTR* OR MULTI_SPECTR*) Refined by: WEB OF SCIENCE CATEGORIES: (REMOTE SENSING OR GEOSCIENCES MULTIDISCIPLINARY) Timespan: All years. Indexes: SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI, CCR-EXPANDED, IC.

		BKCI-SSH, ESCI, CCR-EXPANDED, IC.		
RESULTS (scientific publications, WOS core)	772	1002	168	77

5.4 TOP PATENTS FULL LISTINGS

Top patents of each technology group were selected according to the following patent value indicators:

#1 : Number of citations received
#2 : Number of jurisdictions where a patent is pending or granted
#3 : Number of litigated patents
#4 : Number of opposed patents

Important: The indicators are not weighed and the list is not ranked.

AIRBORNE ELECTROMAGNETIC METHODS

Title	**Family Normalized Applicant name**	**Patent publication numbers**	**1st patent application date**	#1	#2	#3	#4	Access to full document (Espacenet database)
Stabilization system for sensors on moving platforms	VALE	EP2524248 EP2524248 EP2524248 WO201185462 US20110175604 US8456159 US20130200248 US8829899 JP2013517462 EC201212076 KR20120123078 DO201200202 BR112012017560 BR112012017560 MX2012008270 CO6630078 CL201201983 IN2012DN06935 CA2787177 CA2787177 AU2011206865 AU2011206865 DKPA201270475 DK-177893 AP201206396 AP---3317 CN102792190 CN102792190B CU20120106 CU--24061 MA--33996 EA201290645 EA--22224 DK2524248T	2010-01-15	63	6	0	0	https://worldwide.espacenet.com/patent/search/family/044277160/publication/WO2011085462A1?q=WO2011085462A1

Helicopter electromagnetic prospecting system	ANGLO AMERICAN	EP1740980 EP1740980 WO2005106536 US20080211506 US7830150 DE602005008938 RU2006141691 RU2358294 MX2006PA012363 AU2005238718 CA2564183 AU2005238718 CA2564183 CN1985189 CN100442082C IN2006DN06420 IN-283412 BR200509816 BR200509816 UA--83430 ATE404891 ZA200608966	2005-04-19	19	7	0	0	https://worldwide.espacenet.com/patent/search/family/034966550/publication/EP1740980A1?q=EP1740980
Receiver coil assembly for airborne geophysical surveying with noise mitigation	GEOTECH	EP2504723 EP2504723 WO201163510 US20110181290 US8878538 US20120293177 US9372275 RU2012126003 RU2552587 IN2012CN05153 BR112012012552 BR112012012552 CA2781782 CA2781782 AU2010324493 AU2010324493 CN102763007 CN102763007B ZA201203936	2010-11-26	26	5	0	0	https://worldwide.espacenet.com/patent/search/family/044065778/publication/WO2011063510A1?q=WO2011063510
Airborne electromagnetic transmitter coil system	GEOTECH	EP2247966 EP2247966 EP2247966 WO2009105873 US20090212778 US7948237 US20110001480 US8674701 US20110272522 US8766640 RU2010134804 RU2494420 IN2010MN01123 BR200906004 AU2009219062 CA2702346 CA2702346 AU2009219062 CN101981469 CN101981469B ZA201005931 DK2247966T	2008-02-25	30	5	1	0	https://worldwide.espacenet.com/patent/search/family/040997652/publication/WO2009105873A1?q=WO2009105873
Airbone electromagnetic time domain system, computer product and method	GEOTECH	WO200446761 US20050001622 US7157914 USRE42217 RU2005119284 RU2383905 RU2007123135	2003-11-20	42	4	1	1	https://worldwide.espacenet.com/patent/search/family/032326565/publication/WO2004046761A1?q=WO200446761

		RU2454684 BR200316408 CN101067660 CA2450155 CA2794179 CA2450155 CA2794179 AU2003286017 AU2003286017 CN1714303 CN1327247C AU2009243419 AU2009243419 AU2009243419 AU2009243419 AU2013205468 AU2013205468						
Tow assembly for fixed wing aircraft for geophysical surveying	GEOTECH	EP2491433 EP2491433 EP2491433 WO201147472 US20110115489 US8493068 US20130307545 US8847599 RU2012115492 RU2529584 BR112012009567 IN2012MN00986 CA2777874 CA2777874 AU2010310405 AU2010310405 CN102770784 CN102770784B ZA201202996	2010-10-21	20	6	0	0	https://worldwide.espacenet.com/patent/search/family/043899755/publication/WO2011047472A1?q=WO2011047472
Airborne electromagnetic system	ANGLO AMERICAN	EP1040371 EP1040371 EP1040371 WO9932905 US6244534 ZA9811489 CA2315781 CA2315781 AU9916765 AU-746814 AP200001845 AP---1187 BR9813748 BR9813748 CN1285046 CN1195995C OA--11426 IN2000DN00065 IN-216257	1998-12-15	20	0	0	1	https://worldwide.espacenet.com/patent/search/family/025586711/publication/WO9932905A1?q=WO9932905
Double-suspension receiver coil system and apparatus	GEOTECH	EP2291684 EP2291684 EP2291684 WO2009135296 US20090278540 US8030933 US20110050230 US8362779 RU2010145004 RU2529822 IN2010MN02298 BR200908695 AU2009243872 CA2722457 CA2722457	2008-05-09	12	5	0	0	https://worldwide.espacenet.com/patent/search/family/041264363/publication/WO2009135296A1?q=WO2009135296

		AU2009243872 CN102016644 CN102016644B ZA201007731 CN103760611 CN103760611B						
Bucking circuit for annulling a magnetic field	VALE	EP2976663 WO2014146185 WO2014146185 US20140285206 US9297922 RU2015144971 RU2661996 CA2907087 BR112015023202 IN2015DN09324 CL201502823 AU2014234970 AU2014234970 CN105452905 CN105452905B	2013-04-23	6	6	0	0	https://worldwide.espacenet.com/patent/search/family/050478115/publication/WO2014146185A2?q=WO2014146185

AIRBORNE GRAVITY GRADIOMETRY

Title	**Family Normalized Applicant name (value)**	**Patent publication numbers**	**1st application date**	#1	#2	#3	#4	Access to full document (Espacenet database)
Gravity survey data processing	ARKEX	WO200712895 WO200712895 US20090216451 US8437960 RU2008107327 RU2431873 CA2616218 CN102636819 AU2006273791 AU2006273791 AU2006273791 CN101278210 CN101278210B	2006-07-17	31	0	0	0	https://worldwide.espacenet.com/patent/search/family/037683704/publication/WO2007012895A2?q=WO200712895
Method and system for evaluating geophysical survey data	BELL GEOSPACE	EP1735639 WO200588346 US20050197773 US7065449 NO20064527 MX2006PA010099 BR200508469 NZ-549671 AU2005220600 CA2558400 AU2005220600 CA2558400 AP200603725 AP200603725 AP---2082 ZA200607584	2004-03-05	50	0	0	0	https://worldwide.espacenet.com/patent/search/family/034912303/publication/EP1735639A1?q=EP1735639
Gravity gradiometry	GEDEX	EP1337879 EP1337879 WO200244757 WO200244757 US20020092350 US6837106 DE60114655 RU2003119136 RU2298211 AU200221398 CA2429828 CA2429828 ATE308763	2001-11-27	48	3	0	0	https://worldwide.espacenet.com/patent/search/family/022960682/publication/EP1337879A2?q=EP1337879

		AU2002221398						
Airborne geophysical measurements	CGG	EP1444536 EP1444536 WO200332015 US20050017721 US7365544 DE10259899 DE10259899 CA2925829 MX2004PA003397 BR200213228 IN2004KN00604 AT200200082 AT-410927 CA2467034 CA2847625 CA2467034 CA2847625 AP200403031 AP200403031 AP---1773 ZA200403526 AU2002328690	2002-01-18	39	3	0	0	https://worldwide.espacenet.com/patent/search/family/025646813/publication/EP1444536A1?q=EP1444536
System and method for surveying underground density distributions	GEDEX	EP1518134 EP1518134 WO200403594 US20040000910 US6954698 CA2488511 CA2488511 AU2003245762 AU2003245762 ATE526595	2003-06-26	59	2	0	0	https://worldwide.espacenet.com/patent/search/family/030000797/publication/EP1518134A1?q=EP1518134
A gravity gradiometer	TECHNOLOGICAL RESOURCES	WO201034075 US20110138909 US8789415 MX2011000110 IN2010KN04948 EA201071386 CO6351828 NZ-579819 AU2009295360 CA2729571 AU2009295360 CA2729571 AP201005517 AP201005517 AP---2750 CN102089676 CN102089676B ZA201009276 BR200914125 BR200914125	2009-09-22	8	5	0	0	https://worldwide.espacenet.com/patent/search/family/042059218/publication/WO2010034075A1?q=WO201034075
Gravity surveys	CGG	WO2002103398 US20030033086 US6804608 AU-575701 MX2003PA011665 CA2487276 CA2487276 ZA200302795 BR200210514 BR200210514 AU2002304979	2001-06-18	39	3	0	1	https://worldwide.espacenet.com/patent/search/family/003829729/publication/WO02103398A1?q=WO2002103398
Gravity meter	CSIRO COMMONWEALTH SCIENTIFIC INDUSTRIAL	WO9741459 US6082194 AU-951096 CA2252594	1996-04-26	32	0	0	0	https://worldwide.espacenet.com/patent/search/family/003793824/publication/WO9741459A1?q=WO

	RESEARCH ORGANISATION	CA2252594 AU9725622 ZA9703645 AU-711173 TW-346543						9741459

AIRBORNE MAGNETOMETRY

Title	Family Normalized Applicant name (value)	Patent publication numbers	1st application date	#1	#2	#3	#4	Access to full document (Espacenet database)
Methods and apparatus for automatic magnetic compensation	HONEYWELL INTERNATIONAL	WO2004/061391	2003-12-01	61	1	0	0	https://worldwide.espacenet.com/patent/search/family/032659464/publication/US2004123474A1?q=US6860023%20%20
Airborne vector magnetic surveys	BHP BILLITON INNOVATION CGG FUGRO	WO03/69373	2003-02-10	27	2	0	0	https://worldwide.espacenet.com/patent/search/family/027735467/publication/US2005116717A1?q=US20050116717
Portable unmanned airship for magnetic-force surveying and a magnetic-force surveying system employing the same	KOREA INSTITUTE OF GEOSCIENCE & MINERAL RESOURCES	WO2011/052822	2009-10-28	25	2	0	0	https://worldwide.espacenet.com/patent/search/family/042759385/publication/WO2011052822A1?q=WO2011%2F052822
Airborne transient electromagnetic method with ground loops	ELLIOT; PETER J.	WO92/19989	1992-04-15	27	0	0	0	https://worldwide.espacenet.com/patent/search/family/027157614/publication/US5610523A?q=US5610523
Remote sensing electric field exploration system	TELLURIC EXPLORATION	WO2006/011893	2004-09-24	28	0	0	0	https://worldwide.espacenet.com/patent/search/family/035786509/publication/WO2006011893A1?q=WO2006%2F011893
Magnetotelluric geophysical survey system using an airborne survey bird	TELLURIC EXPLORATION	US6765383	2002-12-23	27	0	0	0	https://worldwide.espacenet.com/patent/search/family/032684699/publication/US6765383B1?q=US6765383
Method and system for synchornizing geophysical survey data	BELL GEOSPACE	WO2006/011997	2004-06-24	17	0	0	0	https://worldwide.espacenet.com/patent/search/family/035515081/publication/WO2006011997A2?q=WO2006%2F011997
Induction magnetometer	COLPITTS, BRUCE GORDON DUPUIS, JEROME CHRISTIAN PETERSEN, BRENT ROBERT UNIVERSITY OF NEW BRUNSWICK	US20050156601	2003-11-25	11	1	0	0	https://worldwide.espacenet.com/patent/search/family/034596830/publication/US2005156601A1?q=US20050156601

Drone-borne hyperspectral imaging

Title	Family Normalized Applicant name (value)	Patent publication numbers	1st application date	#1	#2	#3	#4	

Apparatuses and methods for bio-sensing using unmanned aerial vehicles	BIOSENSING SYSTEMS	EP3295370	42388	21	1	0	0	https://worldwide.espacenet.com/patent/search?q=EP3295370
Water quality hyperspectral aerial remote sensing system based on multi-rotor unmanned aircraft	SOUTH CHINA SEA INSTITUTE OF OCEANOLOGY CAS	CN103175789	41338	10	1	0	0	https://worldwide.espacenet.com/patent/search/family/048635795/publication/CN103175789A?q=CN103175789
Geological prospecting route planning method and system	CHINA UNIVERSITY OF GEOSCIENCES	CN107478233	42972	1	1	0	0	https://worldwide.espacenet.com/patent/search/family/060601653/publication/CN107478233A?q=CN107478233
Detection methods of ore body containing chrome using drone equipped hyperspectral images sensor	KOREA INSTITUTE OF GEOSCIENCE & MINERAL RESOURCES	KR101806488	42786	1	1	0	0	https://worldwide.espacenet.com/patent/search/family/060920489/publication/KR101806488B1?q=KR101806488
Unmanned aerial vehicle-borne terahertz wave and hyperspectral remote sensing crop monitoring system	SHENZHEN AUSPICIOUS TERAHERTZ TECHNOLOGY RESEARCH INSTITUTE	CN109187417	43361	0	1	0	0	https://worldwide.espacenet.com/patent/search/family/064908272/publication/CN109187417A?q=CN109187417
Hyper-spectral imaging system based on hyper-spectral camera and area-array camera as well as POS system	SICHUAN DUALIX SPECTRAL IMAGING TECHNOLOGY	CN108051407	43112	0	1	0	0	https://worldwide.espacenet.com/patent/search/family/062127512/publication/CN108051407A?q=CN108051407

6 REFERENCES

- Daly, A.,Valacchi, G., & Raffo, J. (2019) Measuring Innovation in the Mining Industry with Patents. WIPO Economic Research Working Paper. Volume 56
- Epo-A (2019) Espacenet. https://worldwide.espacenet.com/ Accessed 10.11.2019
- Escorsa, P., Maspons, R., & Llibre, J. (2001). De la vigilancia tecnológica a la inteligencia competitiva (Vol. 5). Prentice Hall.
- Eberhardt, M, Helmers, C., Yu, Z. (2017) What can explain the Chinese patent explosion?, Oxford Economic Papers, Volume 69, Issue 1, Pages 239–262,
- Fleisher, C. S., & Bensoussan, B. E. (2003). Strategic and competitive analysis: methods and techniques for analyzing business competition (p. 457). Upper Saddle River, NJ: Prentice Hall.
- FRA (2019) INFACT DELIVERABLE D6.13 TEST SITE BUSINESS MODEL PART 1
- FRA & SRK (2019) INFACT DELIVERABLE D6.6 BUSINESS MODEL MECHANISMS: EASE OF USE; VISITORS BEST PRACTICE; RELEVANCE TO THE INDUSTRY; BUDGET – PART 1
- Gallié, E.P., & Legros, D., (2012). French firms' strategies for protecting their intellectual property. Research Policy, Elsevier, vol. 41(4), 780-794.
- Herring, J. P. (1999). Key intelligence topics: a process to identify and define intelligence needs. Competitive Intelligence Review, 10(2), 4-14.
- Hodgson, A., Arman, H., & Gindy, N. N. (2008). An intelligent technology watch function for the high technology enterprise. International Journal of Industrial and Systems Engineering, 3(1), 38-52.
- Jürgens, B., Herrero-Solana, V. (2011). Estudios sectoriales de vigilancia tecnológica para la comunidad empresarial e investigadora de Andalucía. El profesional de la información, 20(5), 533-541.
- Jürgens, B., Herrero-Solana, V. (2015). Espacenet, Patentscope and Depatisnet: A comparison approach. World Patent Information, 42, 4-12.
- Killeen, P. (2019) Mineral exploration trends and developments in 2018. The Northern Miner. URL: https://issuu.com/bigmininglp/docs/etd-march2018_issuede
- Meyer, M. (2002). Tracing knowledge flows in innovation systems. Scientometrics, 54(2), 193-212.
- Miller, S. H. (2001). Competitive Intelligence–an overview. Competitive Intelligence Magazine, 1(11).
- Narin, F. (1994). Patent bibliometrics. Scientometrics, 30(1), 147-155.
- Negash, S. (2004). Business intelligence. The communications of the Association for Information Systems, 13(1), 54.
- Lichtenthaler, E. (2004). Technology intelligence processes in leading European and North American multinationals. R&D Management, 34(2), 121-135.
- Long C.X., Wang J. (2016) Evaluating Patent Promotion Policies in China: Consequences for Patent Quantity and Quality. In: Prud'homme D., Song H. (eds) Economic Impacts of Intellectual Property-Conditioned Government Incentives. Springer, Singapore
- Lloyd, M. (2015). Patent vs scientific literature - how do they compare?, Amberblog. http://www.ambercite.com/index.php/amberblog/entry/patent-vs-scientific-literature-a-comparison (Accessed 10.10.2015)
- Savioz, P. (2003). Technology Intelligence: Concept Design and Implementation in Technology Based Sme's. Palgrave macmillan.
- Palop, F., & Vicente, J. M. (1999). Vigilancia tecnológica e inteligencia competitiva: su potencial para la empresa española. Madrid: Cotec.

- Pavitt, K. (1985). Patent statistics as indicators of innovative activities: Possibilities and problems, Scientometrics 7(1-2), 77–99.
- Pritchard, A. (1969). Statistical bibliography or bibliometrics?. Journal of documentation, (25), 348-349.
- Zuniga, P., Guellec, D., Dernis, H., Khan, M., Okazaki, T., & Webb, C. (2009). OECD patent statistics manual. Organisation for economic co-operation and development.

7 GLOSSARY

Cooperative Patent Classification (CPC)

The Cooperative Patent Classification (CPC) was created as a joint partnership between the United States Patent and Trademark Office and the European Patent Office where the offices agreed to unify their own existing classification systems. It is a relatively new classification and is used to classify patents at the EPO since the beginning of 2013, at the USPTO since 2014, and recently also at some mayor Asian patent offices, with the Chinese Patent Office being the most prominent (EPO- 2013). The CPC is based in large part on the former European Classification System (ECLA) that is an extension of the International Patent Classification (IPC). Therefore the CPC ensures compatibility with the IPC, but it has more classes at the main group/sub group level making it far more detailed with over 250.000 classification symbols (vs. 70.000 of the IPC).

Country codes (CC)

Country codes (CC) consist of two letters indicating the country or organisation where the patent application was filed or granted[30].

CC	Name
AL	Albania
AP	African Regional IP Organization
AR	Argentina
AT	Austria
AU	Australia
BA	Bosnia and Herzegovina
BE	Belgium
BG	Bulgaria
BR	Brazil
CA	Canada
CH	Switzerland
CL	Chile
CN	China
CO	Colombia
CR	Costa Rica
CS	Czechoslovakia (up to 1993)
CU	Cuba
CY	Cyprus
CZ	Czech Republic
DD	German Democratic Republic
DE	Germany
DK	Denmark
DZ	Algeria
EA	Eurasian Patent Organization
EC	Ecuador
EE	Estonia
EG	Egypt
EP	European Patent Office
ES	Spain
FI	Finland
FR	France
GB	United Kingdom
GC	Gulf Cooperation Council
GE	Georgia
GR	Greece
GT	Guatemala

CC	Name
LU	Luxembourg
LV	Latvia
MA	Morocco
MC	Monaco
MD	Republic of Moldova
ME	Montenegro
MK	Republic of North Macedonia
MN	Mongolia
MT	Malta
MW	Malawi
MX	Mexico
MY	Malaysia
NC	New Caledonia
NI	Nicaragua
NL	Netherlands
NO	Norway
NZ	New Zealand
OA	African Intellectual Property Organization
PA	Panama
PE	Peru
PH	Philippines
PL	Poland
PT	Portugal
RO	Romania
RS	Serbia
RU	Russian Federation
SE	Sweden
SG	Singapore
SI	Slovenia
SK	Slovakia
SM	San Marino
SU	Soviet Union (USSR)
SV	El Salvador
TJ	Tajikistan
TR	Turkey
TT	Trinidad and Tobago

[30] Source: https://worldwide.espacenet.com/help?locale=en_EP&method=handleHelpTopic&topic=countrycodes

HK	Hong Kong SAR (China)
HR	Croatia
HU	Hungary
ID	Indonesia
IE	Ireland
IL	Israel
IN	India
IS	Iceland
IT	Italy
JP	Japan
KE	Kenya
KR	Korea (South)
LI	Liechtenstein
LT	Lithuania

TW	Chinese Taipei
UA	Ukraine
US	United States of America
UY	Uruguay
VN	Viet Nam
WO	World Intellectual Property Organization
YU	Yugoslavia/Serbia and Montenegro
ZA	South Africa
ZM	Zambia
ZW	Zimbabwe

International Patent Classification (IPC)

The International Patent Classification (IPC) was created in 1971 and is administered by the World Intellectual Property Organization (WIPO). It became a de facto standard since it is currently used in patent authorities in over 100 countries worldwide. The IPC is a hierarchical system, which divides technology into eight sections with currently approximately 70,000 subdivisions. Each subdivision has a symbol consisting of Arabic numerals and letters of the Latin alphabet. The highest hierarchical levels are eight 'sections' corresponding to very broad technical fields. The sections are subdivided into 'classes' (e.g. 120 in the latest edition of the IPC) and classes are further subdivided into more than 640 'subclasses' which are divided into 'main groups' and 'subgroups'.

Patent families

Patent families are used in patent statistics to count per invention and not per document since the same invention disclosed by a common inventor(s) due to the territoriality of the patent system can be patented in more than one country and thus generates a patent document in every country where protection is sought. There are different types of patent families, for the present study the common **simple patent family** was used, where all patent documents have exactly the same priority date or combination of priority dates.

Patent Cooperation Treaty (PCT)

The Patent Cooperation Treaty (PCT), signed on June 1970 and entered into force in the beginning of 1978 is an international treaty with more than 148 contracting states. Managed by the World Intellectual Property Organization (WIPO) the PCT patent application makes it possible to seek patent protection for an invention simultaneously on a nearly worldwide scale by filing a single 'international' PCT patent application instead of filing several separate local patent applications.