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MAPPING AUSTRALIAN GEOPHYSICS: A CO-HEADING ANALYSIS

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Descriptive capacities of a new bibliometric method, namely co-heading analysis, are investigated. The method uses the appearance and co-appearance of classification subdivisions (headings) in the document records of 1988 INSPEC database to display correspondingly the main topics of Australian geophysics and their links. The findings, in the form of inclusion maps (resulting from multidimensional scaling and cluster analysis) provide new insights into geophysics national activity and into its structure.

Introduction

National research efforts (publication activity and impact) in a given (sub)field of science are increasingly represented by author participation in research fronts as determined by co-citation cluster analysis.[1] The results of such analysis in terms of highly-cited (core) documents and their links (as reflected in a set of recent journal articles) have been first considered for science structure representation and further as tools for research management and evaluation.[2] At the same time criticisms have been expressed concerning theoretical conceptions and techniques applied.[3-7] However, the idea of counting co-appearances of highly-cited publications,[8] words,[9] and authors[10] and representing them in an appropriate manner is attractive in the sense that it offers an opportunity (at least) to discuss directly quantitative (bibliometric and/or scientometric) results with experts.

The aim of this paper is to investigate a recently proposed bibliometric method[11] as a new tool and the INSPEC file as an appropriate source of information for studying the structure of scientific subfields. The specific purpose is to extract non-traditional data on Australian geophysics publications (such as subject and research characteristics, distribution over institutes and journals, etc.) and to represent the most frequently appearing topics in Australian geophysics papers in an appropriate

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manner as well as their interrelationships as depicted in different subsets of documents.

Data and method

Data for geophysics research have been extracted from the INSPEC (Information Services for the Physics and Engineering Communities) file which contains records for the world-wide literature on physics (as well as on electricity and electronics, and computer science). Together with traditional bibliographic data, an INSPEC record includes (see Table 1) a set of elements expressing the subject content of a document: Classification Codes (CC), Treatment Codes (TC), and (Controlled or Supplementary) Terms. CC stand for subject headings or topics which fall into the following categories:

- substances (or named objects) and characteristics (properties);
- phenomena, processes, effects, etc.;
- theories, methods, models;
- instruments and techniques.

The CC are assigned to documents by indexers (or by the authors themselves) according to the International Classification for Physics (ICP).[12] (These CC are later used for retrieval and generating cross-references for the printed version.)

The TC indicate the nature of the subject treated in a document (theoretical, applied, review, etc.).

For the purpose of the study all documents containing any code for geophysics and an address of an university or institute in Australia have been downloaded from the 1988 INSPEC A file (printed version: *Physics Abstracts*). A total of 224 geophysics papers have been extracted. Four record fields of the downloaded file have been selected for quantitative analysis: CC,DT (Document Type). TC, and AU (Author and affiliation). The following six sets of records have been then produced:

– one including all Australian geophysics publications (original file of 224 documents).

– two subsets from the previous file containing correspondingly experimental and theoretical papers only.

– three sets covering the geophysics subdivisions: solid Earth geophysics (SEG), hydrospheric and atmospheric geophysics (HAG), and geophysical observations and techniques (GOT).

Table 1
Sample record of 1988 INSPEC file

Field*	Data
TI	Plate boundary tectonics, global sea-level changes and the development of the eastern South Island continental margin, New Zealand,southwest Pacific.
AU	Carter, R.M. (Dept. of Geol., James Cook Univ., Townsville, Qld., Australia)
SO	Marine and Petroleum Geology (May 1988) vol.5, no.2; p. 90-107; 126 refs. CODEN: MPEGD8 ISSN: 0264-8172
DT	Journal
TC	Bibliography; General Review
LA	English
CC**	5A9145D; 5A9330K; 5A9330F; 5A9330P; 5A9210H
CT	OCEONOGRAPHY; TECTONICS
ST	plate boundary tectonics; Gondwanaland break up; Great South Basin evolution; global sea-level changes; eastern South Island continental margin; New Zealand; southwest Pacific; sedimentary evolution; seismic sequences; stratigraphic sequence

*AUthor, SOurce, Document Type, Treatment Codes, LAnguage, Classification Codes, Controlled Terms, Supplementary Terms.

**Assigned according to the International Classification for Physics:
5A9145D: Plate tectonics,
5A9330K: Large Islands,
5A9330F: Australia,
5A9330P: Pacific ocean,
5A9210H: Surface waves, tides and sea level.

An appropriate software has been developed for arranging the headings (or the CC) in every set of records in descending order of their occurrence and for constructing triangular matrices $C = \{C_{ij}\}$ containing the co-appearances of the top n headings. (Two headings C_i and C_j are said to co-occur if there is at least one record containing both C_i and C_j.) A diagonal element C_{ii} is the absolute frequency of appearance of C_i and an off-diagonal element C_{ij} represents the co-occurrence of C_i and C_j in the set of records under consideration.

The matrix $C = \{C_{ij}\}$ is used for calculating an appropriate relative measure of similarity. Since the C_i are elements of a (hierarchical) classification scheme,[13] it is convenient to use like in co-word analysis[14] the inclusion index $I_{ij} = C_{ij}/\min(C_{ii}, C_{jj})$ for highlighting the "central poles" of Australian geophysics and reveal their relations with other "peripheral" topics.[15] The I_{ij} expresses the degree to which two headings are related . It is a measure of similarity as the highest values correspond to pairs that most co-appear in the given set of documents (records).

Once this measure has been determined, the final step consists in displaying (as a geometrical model or map) the structure of Australian geophysics research. Here, multidimensional scaling (ALSCAL program) is applied to display closeness of headings through their spatial configuration within a two dimensional representation.[16] Since a representation of two dimensions is usually not enough to accommodate all interrelationships, the results of a hierarchical clustering are embedded in a map by constructing closed curves (loops) around headings that belong to the same cluster. "In this way the natural clusters are brought out in a more explicit and objective way for purposes of interpretation, labelling or comparison with independently obtained clusterings of the same objects."[17] (p.40) Additionally, relation strength (based upon the inclusion index values) has been shown by connecting highly co-appearing headings (from the lower to the higher frequency of appearance) with corresponding line type.

Results

A list of geophysics headings which appear most frequently in Australian publications is given in Table 2. In Table 3 the Australian geophysics papers are subdivided according to their treatment codes (theoretical, experimental, applied, etc). Since more than one treatment code could be allocated to a document, their sum is greater than the number of records under consideration. In Table 4 the distributions of Australian geophysics papers are shown: over states, institutions and units. (They are based only on the first author address). In Table 5 the subset of journal articles is arranged according to the source journals.

Table 2

Topics (headings) of 1988 Australian Geophysics according to the International Classification for Physics

I SOLID EARTH GEOPHYSICS

Topography: geometrical observations
Harmonics of gravity potential field
Spatial variations
Seismology
Explosion seismology
Heat flow; geothermy
Structure of crust and upper mantle
Composition of Earth' s interior
Geochronology
Volcanology
Plate Techtonics
Beach, coastal and shelf processes
Turbidity currents; sedimentation
Elasticity, fracture and flow
Geophysical aspects of geology, mineralogy and petrology

II HYDROSPHERIC AND ATMOSPHERIC GEOPHYSICS (HAG)

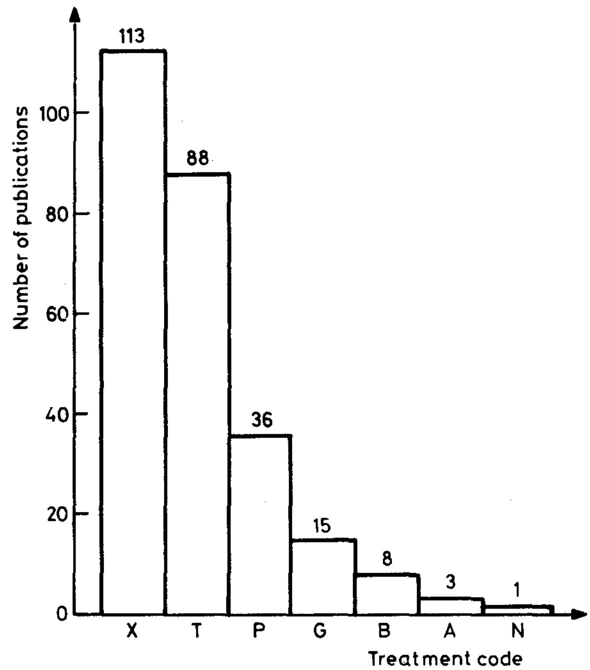
Dynamics of the deep ocean
Dynamics of the upper ocean
Surface waves, tides, and sea level
Sea-air energy exchange processes
Turbulence and diffusion
Thermohaline structure and circulation
Coastal and estuarine oceanography
Modelling; general theory
Precipitation
Rivers, runoff, and streamflow
Erosion and sedimentation
Soil moisture
Limnology
Meteorology
Convection, turbulence & diffusion
Boundary layer structure and processes
Winds and their effects
Chemical composition and chemical interactions
Water in the atmosphere
Cloud physics
Climatology
Weather analysis and prediction
Other topics in HAG

III GEOPHYSICAL OBSERVATIONS, INSTRUMENTATION, AND TECHNIQUES

Asia
Australia
Large islands
Indian Ocean
Pacific Ocean
Regional seas
Instrumentation and techniques for geophysical research
Computer techniques

Table 3

Classification of Australian geophysics publications according to their Treatment Code (TC)



T THEORETICAL	the treatment of subject is of a theoretical nature.
B BIBLIOGRAPHY	indicates documents with a bibliography or long list of references.
G GENERAL	documents including general approaches, overviews, and reviews.
X EXPERIMENTAL	the document describes an experimental method, observation or result.
A APPLICATION	the document describes the actual or potential use of an instrument, device, method or technique, computer programme, or a physical effect where some specific application is described or envisaged.
N NEW DEVELOPMENTS	a claim of novelty (in the patent sense) is made.
P PRACTICAL	the document is intended to be of direct practical use and is linkely to be of interest particularly to engineering and design staff.

Table 4
Georgraphical and institutional distribution of Australian geophysics publications

I. Geographical distribution over states and territories

Rank	State/Territory	Number of papers
1	Australian Capital Territory (ACT)	63
2	Victoria (VIC)	54
3	New South Wales (NSW)	47
4	Western Australia (WA)	18
5	South Australia (SA)	15
6	Queensland (QLD)	15
7	Tasmania (TAS)	10
8	Northern Territory (NT)	2

II. Most productive Australian institutions in geophysics (according to 1988 INSPEC A database)

Number of papers	Institutions
46	Commonwealth Scientific and Industrial Research Organization
32	AUSTRALIAN NAT. UNIV., CANBERRA, ACT
20	BUR. OF METEOROL. RES. CENTRE, MELBOURNE, VIC.
15	NEW SOUTH WALES UNIV., KENSINGTON, NSW
14	BUR.OF MINER. RESOURCES, CANBERRA, ACT.
9	SYDNEY UNIV., NSW.
8	WESTERN AUSTRALIAN UNIV., NEDLANDS, WA.
7	FLINDERS UNIV., BEDFORD PARK, SA.
7	MELBOURNE UNIV., PARKVILLE, VIC.
7	MONASH UNIV., CLAYTON, VIC.
7	QUEENSLAND UNIV., ST LUCIA, QLD.

(Table 4 cont.)

III. Most productive Australian units in geophysics (according to 1988 INSPEC A database)

Number of papers	Units
29	RES. SCH. EARTH SCI., AUSTRALIAN NAT. UNIV., CANBERRA, ACT.
15	DIV. ATMOS. RES., CSIRO, ASPENDALE/MORDIALLOC, VIC.
13	DIV. GEOPHYS., BUR. OF MINER. RESOURCES, CANBERRA, ACT.
9	DIV. ENVIRON. MECH., CSIRO, CANBERRA, ACT.
6	DIV. OCEANOGR., CSIRO, HOBART, TAS.
6	INST. ATMOS.&MARINE SCI., FLINDERS UNIV., BEDFORD PARK, SA.
6	SCH.MATH., NEW SOUTH WALES UNIV., KENSINGTON, NSW.
4	DEPT. GEOL., WESTERN AUSTRALIA UNIV., NEDLANDS, WA.
4	DIV. MINER. & GEOCHEM., CSIRO, WEMBLEY, WA.

Table 5

Distribution of Australian geophysics articles over journals titles

Rank	N	Journal title (Country)
1	19	J. GEOPHYS. RES. (USA)
2	13	EARTH PLANET. SCI. LETT. (NETHERLANDS)
3	13	WATER RESOUR. RES. (USA)
4	12	MONTHLY WEATHER REVIEW (USA)
5	10	NATURE (UK)
6	8	AUST. METEOROL. MAG. (AUSTRALIA)
7	7	J. PHYS. OCEANOGR. (USA)
8	6	J. ATMOS. SCI. (USA)
9	5	CONT. SHELF RES.(UK)
10	5	GEOPHYSICAL JOURNAL
11	4	APPLIED OPTICS (USA)
12	4	BMR J. AUST. GEOL. GEOPHYS. (AUSTRALIA)
13	4	GEOPHYS. RES. LETT. (USA)
14	4	GEOPHYSICS (USA)
15	4	TECTONOPHYSICS (NETHERLANDS)
16	3	BULL. AM. METEOROL. SOC. (USA)
17	3	COMPUT. GEOSCI. (UK)
18	3	DEEP-SEA RES. A, OCEANOGR. RES. PAP. (UK)
19	3	EARTH SURFACE PROCESSES AND LANDFORMS (UK)
20	3	IEEE TRANS. GEOSCI. REMOTE SENS. (USA)

(Table 5 cont.)

Rank	N	Journal title (Country)
21	3	J. APPLIED METEOROLOGY
22	3	PHOTOGRAMM. ENG. REMOTE SENS. (USA)
23	3	SOLAR ENERGY (USA)
24	3	TECTONICS (USA)
25	2	AUST. J. GEOD. PHOTOGRAMM. SURV. (AUSTRALIA)
26	2	BULL. SEISMOL. SOC. AM. (USA)
27	2	CHEM. GEOL.: ISOT. GEOSCI. SECT. (NETHERLANDS)
28	2	GEOJOURNAL
29	2	GEOLOGY (USA)
30	2	J. CLIMATOL. (UK)
31	2	J. COAST. RES. (USA)
32	2	J. GEOL. (USA)
33	2	J. PETROL. (UK)
34	2	J. QUANT. SPECTROSC. RADIAT. TRANSF. (UK)
35	2	MAR. PET. GEOL. (UK)
36	2	PRECAMBRIAN RES. (NETHERLANDS)
37	2	SCIENCE (USA)
38-68	1	Other 31 journals publishing one article each.

The application of multidimensional scaling and hierarchical cluster analysis as complementary methods for highlighting closeness of headings is shown in the form of maps correspondingly on Figs 1-6. Symbol plots of the headings are explained in Table 6. On Figure 1 Australian geophysics is represented. Experimental and theoretical research are separately shown on Figs 2 and 3. On Figures 4-6 "zoom" or detailed maps are displayed for the three main geophysics subdivisions (SEG, HAG, and GOT) as covered by Australian research.

Table 6
Plot symbols used for topics (headings) of 1988 Australian geophysics

Plot Symbol	Topic
1	Australia
2	Instrumentation and techniques for geophysics
3	Structure of crust and upper mantle
4	Geophysical aspects of geology, mineralogy and petrology
5	Geochronology
6	Coastal and estuarine oceanography

(Table 6 cont.)

Plot Symbol	Topic
7	Pacific Ocean
8	Plate Tectonics
9	Dynamics of the upper ocean
10	Composition of Earth's interior
11	Regional seas
12	Surface waves, tides, and sea level
13	Winds and their effects
14	Weather analysis and prediction
15	Thermohaline structure and circulation
16	Water in the atmosphere
17	Meteorology
18	Climatology
19	Rivers, runoff, and streamflow
20	Heat flow; geothermy
21	Seismology
22	Other topics in solid Earth geophysics
23	Computer techniques
24	Large islands
25	Boundary layer structure and processes
26	Asia
27	Indian Ocean
28	Beach, coastal and shelf processes
29	Volcanology
30	Cloud physics
31	Convection, turbulence & diffusion
32	Precipitation
33	Modelling; general theory
34	Dynamics of the deep ocean
35	Soil moisture
36	Elasticity, fracture and flow
37	Turbidity currents; sedimentation
38	Other topics in HAG
39	Topography: geometrical observations
40	Spatial variations
41	Harmonics of gravity potential field
42	Explosion seismology
43	Chemical composition and chemical interactions
44	Sea-air energy exchange processes
45	Limnology
46	Erosion and sedimentation
47	Turbulence and diffusion

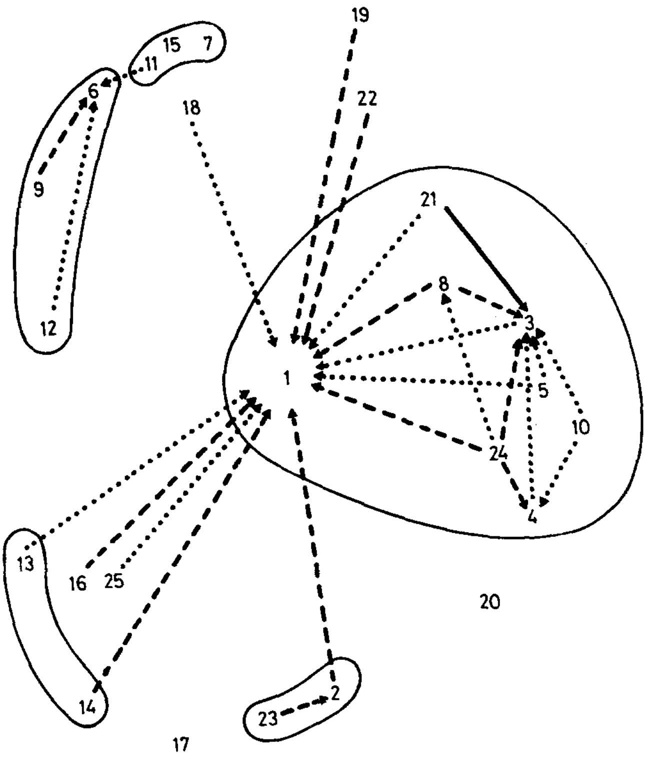


Fig. 1. Inclusion map for 1988 Australian geophysics. (Plot symbols are given in Table 6)

———— Inclusion index values ≥ 0.8
— — — — Inclusion index values ≥ 0.6
.... Inclusion index values ≥ 0.5

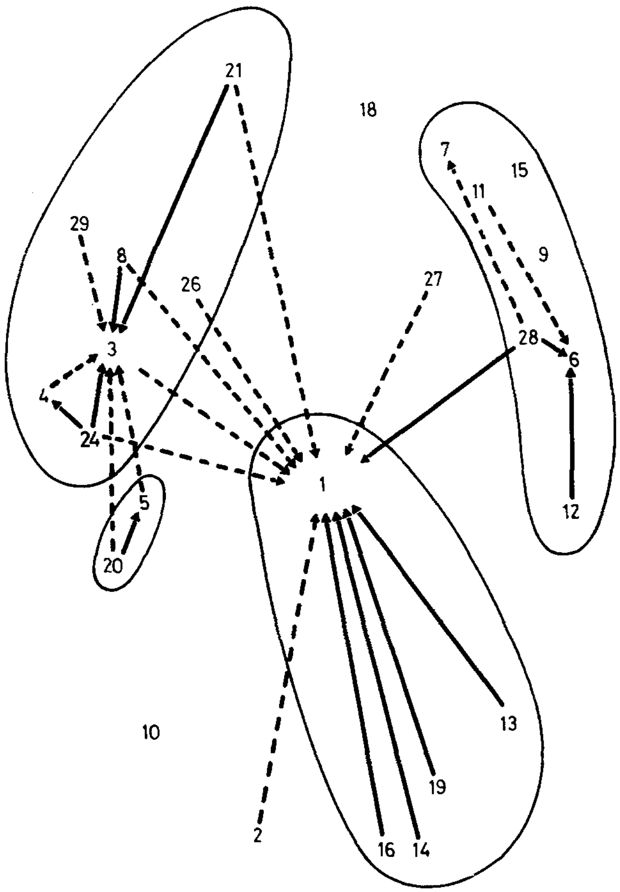


Fig. 2. Inclusion map for 1988 Australian experimental geophysics. (Plot symbols are given in Table 6)

———— Inclusion index values ≥ 0.8
– – – – – Inclusion index values ≥ 0.6

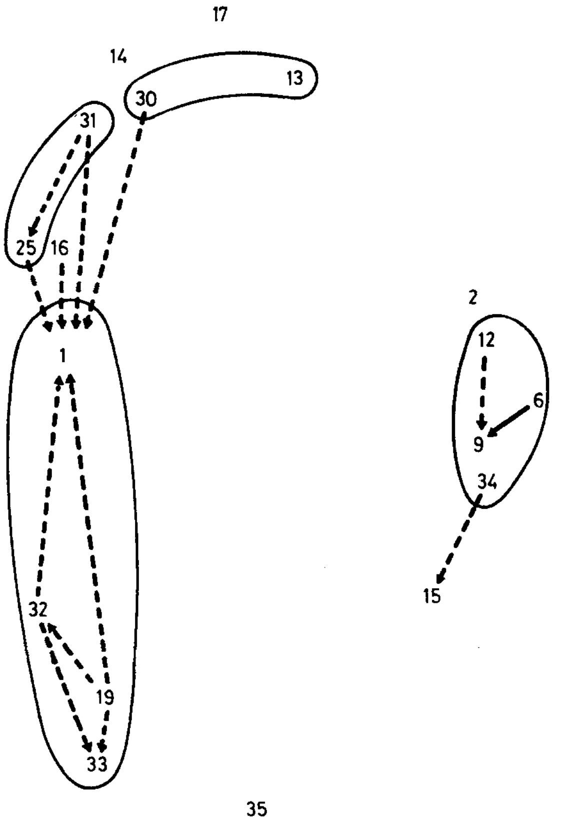


Fig. 3. Inclusion map for 1988 Australian theoretical geophysics. (Plot symbols are given in Table 6)

Inclusion index values ≥ 0.8
Inclusion index values ≥ 0.6

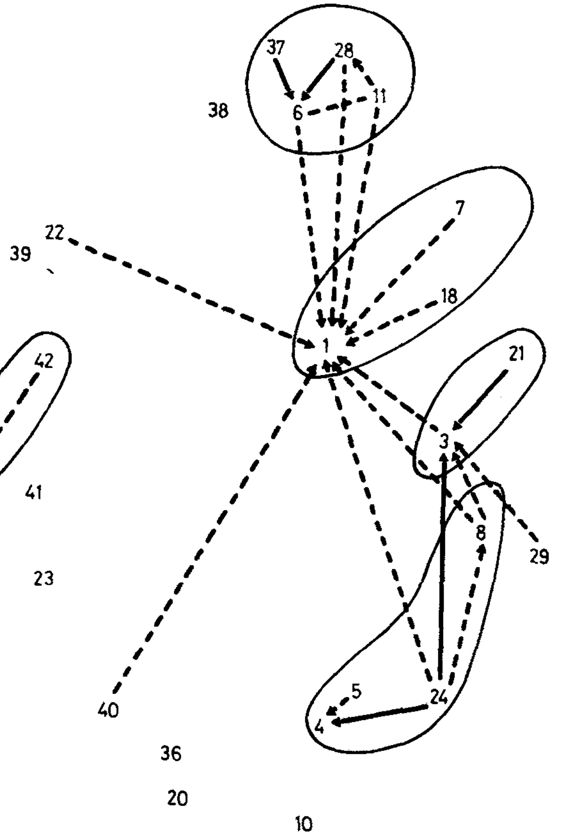


Fig. 4. Zoom map for 1988 Australian solid earth geophysics. (Plot symbols are given in Table 6)

——————— Inclusion index values ≥ 0.8
— — — — — — Inclusion index values ≥ 0.6

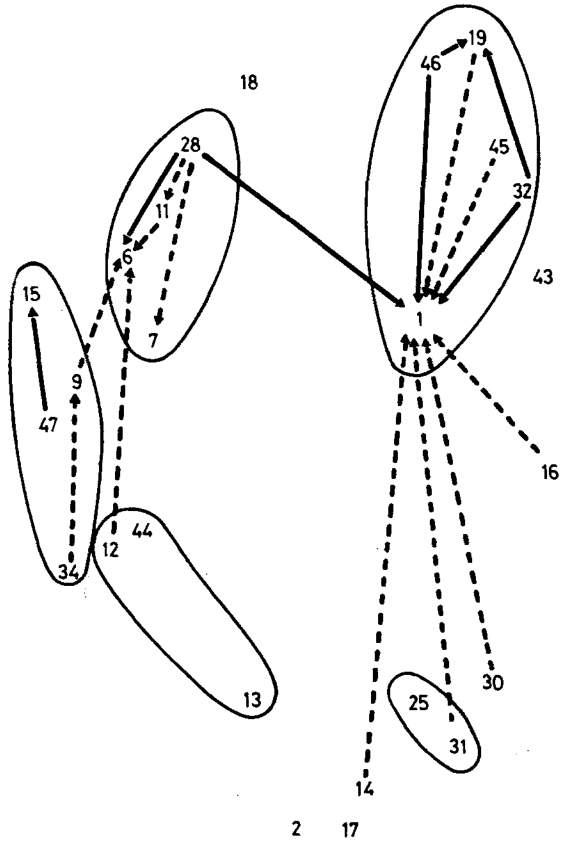


Fig. 5. Zoom map for 1988 Australian hydrospheric and atmospheric physics. (Plot symbols are given in Table 6)

——————— Inclusion index values ≥ 0.8

– – – – – – Inclusion index values ≥ 0.6

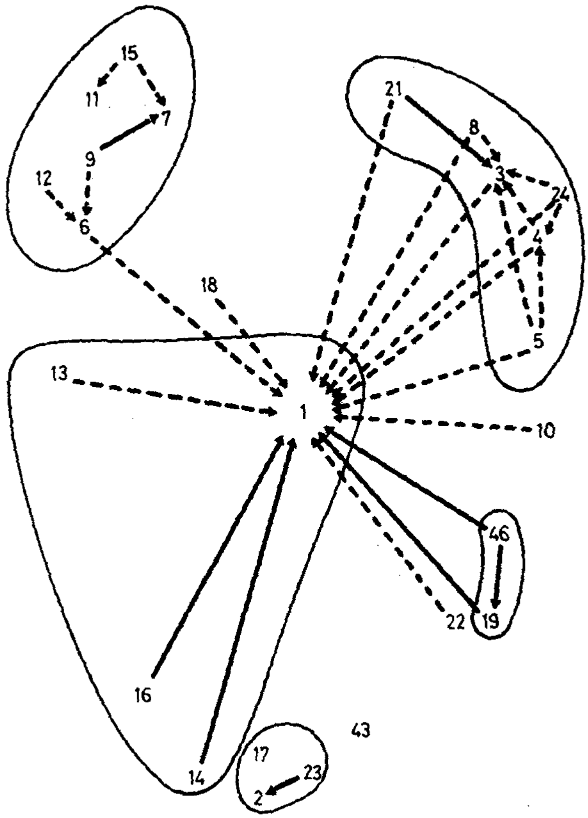


Fig. 6. Zoom map for 1988 Australian geophysics observations. (Plot symbols are given in Table 6)

——— Inclusion index values ≥ 0.8
– – – – Inclusion index values ≥ 0.6

Discussion

The idea underlying the analysis is that the co-occurrence of subject headings in a set of selected documents can be used to measure and display the degree of association (content relationship) between these headings or topics. Headings are considered as key words (as used in coword analysis) on a higher level of aggregation which have constant meaning even in a cross-subfield context. (Headings could already be related by cross-references introduces by experts).

Many scientific databases employ more or less developed classification schemes (i.e. with or without cross-references) for assigning documents to different headings. The co-appearance of such headings in a set of preselected documents is used here to represent published Australian research (topics and their links) in geophysics. Links have been further studied by taking subsets of documents with different subject and research characteristics (treatment codes). The INSPEC database appears to be appropriate for this kind of analysis since its records include additional information on type and research characteristics of the source documents (see Table 1).

Representing a subfield structure by headings (instead of highly co-cited publications or words) has some advantages such as explicit content of the headings and simplified selection of the relevant records for the analysis. Nevertheless, it should be used (like all bibliometric techniques) in conjunction with expert opinion or other quantitative methods (co-citation, co-word or other co-unit analyses). Headings are, in general, broader units as compared to keywords or citations. Some additional descriptive capabilities of co-heading analysis (not offered by other techniques and sources) could be mentioned as well:

– Since the file is discipline oriented, a large number of documents, irrespective of their type, source and language of publication, are used in the analysis (for example, problems of biases in favour of more *visible* journals are avoided).

– Headings are allocated rather uniformly irrespective of the research characteristics of the subfield or of the country of origin.

– The analysis is not restricted to a single topic or speciality (like co-word analysis). It could be extended to cover a whole filed in the selected database. Furthermore, a cross-subfield analysis does not require normalization (needed in co-citation analysis).

– The dynamics of links between headings (and even possible future development of links) could be also studied, since new headings are explicitly introduced in the environment of older ones.

– Headings are easy to access and to process (as compared to citations or keywords).

– Content of headings is explicit and, therefore, the observed links are more open to discussion. Headings are often part of a classification scheme developed on a consensus among experts.

– Time lag is smaller as compared to citation appearance.

– Maps could be simply aggregated by replacing headings of lower classification level with ones of higher level.

– Detailed map (or "zoom" map) of the links of less frequently appearing codes could be generated by taking a subset of documents with appropriate characteristics.

– A map of national research in a given subfield (or of journal publication profile) could be produced by extracting a subset with given author affiliation (journal title).

Headings are allocated by indexers according to a more or less elaborated classification scheme. However, subjective information is introduced (the so called *indexer effect*) which consists mainly in rough assignment (or insufficient depth) and uneven allocation of headings. This effect is attenuated by considering a *great* number of documents and by the fact that indexers do not know[18] that subject headings will be used in such (co-heading) analysis for mapping links between topics.

Using an appropriate software (developed for the purpose of the study), six matrices of co-appearance have been constructed. On the diagonal the frequencies of appearance of the headings are placed in descending order. The full size of a matrix is equal to the number of different codes occurring in the selected records. With a view to statistical validity and better representation (by multidimensional scaling), the initial size is reduced by introducing a threshold C_t ($C_t < C_{ii}$). The practical criteria for determining the C_t are the amount of information lost and the number of headings (and their links) to be displayed. In Table 7 are given several values for C_t and the corresponding percentage of information lost in case all Australian publications in geophysics are considered. Thus, the corresponding matrix contains 60% of the information and at the same time the analysis could be performed on a personal computer.

Table 7
Dependence of the final display of Australian geophysics (Fig.1) on the treshold value C_t

C_t	Information lost*(%)	Number of codes to be displayed
1	0	161
2	8	97
3	15	70
4	22	54
5	26	46
6	34	33
7	39	27
8	41	25
9	46	23

*Number of codes not considered (as percentage of the total number of codes used).

The selection of a similarity measure is a compromise between adequate representation of central (frequently appearing) and peripheral topics.

Correspondingly, more indices could be used:

- Jaccard index: $C_{ij} / C_{ii} + C_{jj} - C_{ij}$
- Strength index: $C_{ij} / \mathrm{sqrt}\,(C_{ii}.\,C_{jj})$
- Inclusion index: $C_{ij} / \min\,(C_{ii}, C_{jj})$
- Proximity index: $C_{ii}.\,N / C_{ii}.\,C_{jj}$ with N = number of selected records, etc.

Here the Inclusion index has been preferred for the following reasons: (a) it has high values even when C_{jj} is low and C_{ii} is high; and (b) its asymmetrical nature is appropriate for graphic representation.

Once the similarity measure is determined, multidimensional scaling has been selected for displaying the structure of Australian geophysics. On Figures 1 to 6 are shown two-dimensional solutions from ALSCAL. On these spatial representations two topics should be further apart the smaller their Inclusion index value is. Since in general two dimensions are not enough to reflect adequately all links (the residual departure from monotonicity or *stress* is large) it is appropriate to include hierarchical cluster analysis (HCA) as a complementary method for introducing information about grouping of topics. If the *stress* - value is large, it is also useful to link topics whose similarity (inclusion index) exceeds a selected threshold. In such a case, the multidimensional configuration is used only as a foundation for displaying clustering and graphic results. On Figure 1 a combined map of Australian geophysics is shown: three threshold values are introduced and indicated correspondingly by solid, dashed. and dotted lines. These lines are drawn from topics with lower to such with higher absolute frequency of appearance. Additionally, related topics are enclosed by solid lines (loops) using an appropriate cluster solution. The topics within a cluster should be connected with each other, and poorly connected with those outside the cluster. "The presence of long and haphazardly crossing lines (based on the proximities data) indicates a discrepancy between closeness in the data and closeness in the space."[19]

Preliminary interpretation of the geophysics maps

The interpretations of the models (or maps) consists mainly in identifying clusters of related headings, in determining labels (titles) for them, and in describing some (common) features relevant for revealing the structure in the set of documents under consideration.

Australian publications in geophysics are predominantly *domestic*, i.e. headings related to Australia prevail in the selected documents. However, a large part of the main topics (as determined by international research) in the subfield (see Table 2) are covered. A rather low number of publications deal with interdisciplinary aspects of oceanography which could be also explained with the subject scope of the INSPEC file. Australian papers in geophysics (see Table 3) are mainly experimental (39.8%) and theoretical (31%). More than two thirds of the publications (73%) come from institutes in the Australian Capital Territory, Victoria and New South Wales (see Table 4). Two institutions are particularly active in publishing research results: CSIRO (Commonwealth Scientific and Industrial Research Organization) and the Australian National University (see Table 4). About 90% of the papers are published in journals. Half of the articles are distributed over eleven journal titles (see Table 5), i.e. articles are rather scattered (as in any applied-oriented subfield of science). Most of the articles are in *visible* and high impact journals published in the USA, UK, Australia, and the Netherlands.

The map of Australian geophysics (see Fig. 1) displays well the three main subdivision of geophysics : HAG on the left side, SEG on the right, and the GOT between them on the bottom of the figure. No headings from other physics subfields occur: geophysics appears rather as self-contained. This could be explained by the incorporation of *external* methods or techniques or by indexer effect (insufficient depth of indexation). Instrumentation, computer techniques, and observations play an important role in geophysics research (especially in atmospheric and weather analysis). HAG is represented by one purely atmospheric cluster (13, 14). and two closely related hydrospheric clusters (6, 9, 12 and 7, 11, 15). The one could be labelled *upper and coastal oceanography* and the second is characterized by research on thermohaline structure of the Pacific Ocean and regional sees. These two hydrospheric clusters appear together (are amalgamated) when only experimental publications are considered (see Fig. 2). This means that links within *upper and coastal oceanography* are different (more theoretical) as compared to the links within the cluster (7, 11, 15). This appears clearly on Fig. 3 where only theoretical published research is displayed. On this figure only headings from HAG emerge. Three of the four theoretical clusters are linked to Australia.

The three subdivisions of geophysics (SEG, HAG, GOT) have been represented separately by "zoom" or detailed maps correspondingly on Fig. 4 to 6. SEG (see Fig. 4) is represented by five clusters: seismology (3, 21); geophysical aspects of geology and mineralogy (4, 5, 8, 24); instrumentation and techniques in explosion seismology (2, 42); coastal studies (6, 11, 28, 37); and climatology related to the Pacific Ocean (1, 7, 18).

HAG (see Fig. 5) includes also five clusters: ocean dynamics (9, 15, 34, 47); coastal oceanography (6, 7, 28); sea-air exchange(12, 13, 44); boundary layer structure and processes (25, 31); and rivers and flows (1, 19, 32, 45, 46).

The structure of GOT is shown on Fig. 6. As mentioned above instrumentation and techniques are largely used in all geophysics subdivisions: atmospheric research (1, 13, 14, 16); hydrospheric research (6, 7, 9, 12, 15); solid Earth geophysics (3, 4, 5, 8, 21, 24); rivers and flows research (19, 22, 46); and especially meteorology (2, 17, 23).

All maps are derived and discussed here without any substantive knowledge, i.e. without consulting experts in the fields under consideration. Since the method is still partly experimental, the results should be considered critically and taken as preliminary.

Conclusion

This study has been designed to investigate application (capabilities and limitations) of co-heading analysis and, more specifically, to answer questions such as: Which are the main topics of Australian research in geophysics? How are they related to other headings? How to represent and interpret these links? The answers of these questions have shown the descriptive potential of co-heading analysis. the model supplies valuable (macro-) information on central and peripheral topics in the field under consideration, as well as, on the character and strength of their links. Thus, it provides an alternative view to that of other bibliometric methods and expert judgements. The suitable visualization makes it open for discussion and testing.

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