INDUSTRIAL RESEARCH LIMITED
Te Tauihu Pūtaiao

Confidential Report for Mighty River Power:

A Bibliometric Study of Geothermal Research in New Zealand

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Abstract

We conduct a bibliometric study of geothermal research in New Zealand, examining total published output, co-author relationships, and international collaboration. We identify a number of trends in the volume of outputs published and in co-author networks. We observe an increasingly connected geothermal community, with a growing number of new players and a decline in the dominance of countries such as the United States, the traditional leader in geothermal research.

Introduction

The purpose of this report is to aid understanding of geothermal research capability in New Zealand. The report uses bibliometric data to track geothermal research in New Zealand and its connection to geothermal research conducted overseas from the mid 1960s through to the present day. The report details the total published output in geothermal research and the revealed networks of collaboration between geothermal researchers within New Zealand and with other countries.

By examining changes in the volume of outputs over time and by looking at changes in patterns of collaboration, we will illustrate changes in world and New Zealand geothermal research. We first consider the distribution of publications by country, before focussing on the volume of total outputs from New Zealand, the United States and the rest of the world. We then consider changes in New Zealand co-author networks over time and finally we examine the strength of collaboration between New Zealand and the rest of the world.

Share of Published Outputs over Time

The proportion of publications produced by each country over time (binned in five-year periods) is shown in Figure 1. Note that the fraction of publications in each time period for which no address information is available is also shown; from 1975 onwards, the fraction of publications for which no address information is available becomes small enough that it is possible to make comparisons between different countries over time.

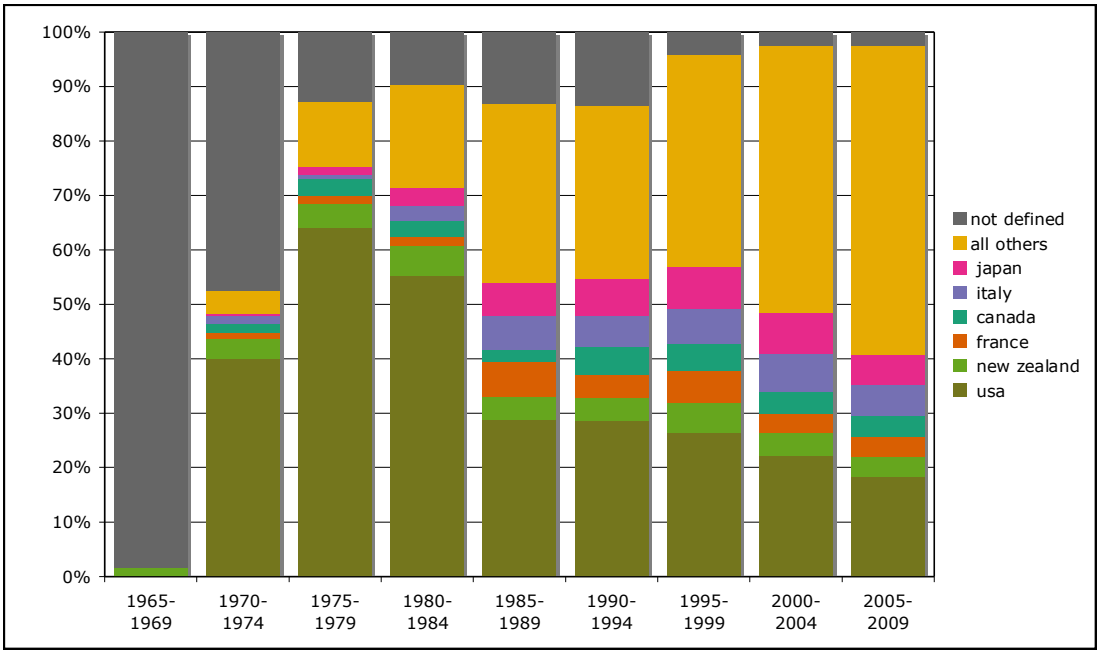

Figure 1: Fraction of publications per five-year period for New Zealand and the five most prolific countries.

The most marked trend is the decline in the fraction of publications from the United States and the growth of output from countries other than New Zealand and the remainder of the top five. The fraction of publications which New Zealand contributes to the total appears to peak in the 1980-1984 period, declining to possibly its lowest fraction in the following period before peaking again in 1995-1999. Publication trends over time are investigated further in the following section.

Volume of Published Outputs over Time

In Figure 2 we plot the number of publications each year where at least one of the authors has a New Zealand address. The data is not monotonic: there is a peak in published output around 1982, but output falls to a minimum over the period 1988-1990 before a subsequent recovery and further growth.

A similar trend is seen for the published output from the United States, the country with which New Zealand has traditionally had the strongest co-author relationship (as will be evident in the next section), shown in Figure 3. The published output for the entire world is shown in Figure 4. There is a decline in world output during the period 1988-1990, but this is largely due to the drop-off in United States outputs. It is apparent that the decline in published outputs seen in the United States and New Zealand is not mirrored in the rest of the world. Also of interest is the trend post 1990; while world publications increase reasonably steadily, roughly doubling in the 20 year period 1990-2010, the trend is much flatter for New Zealand and the United States.

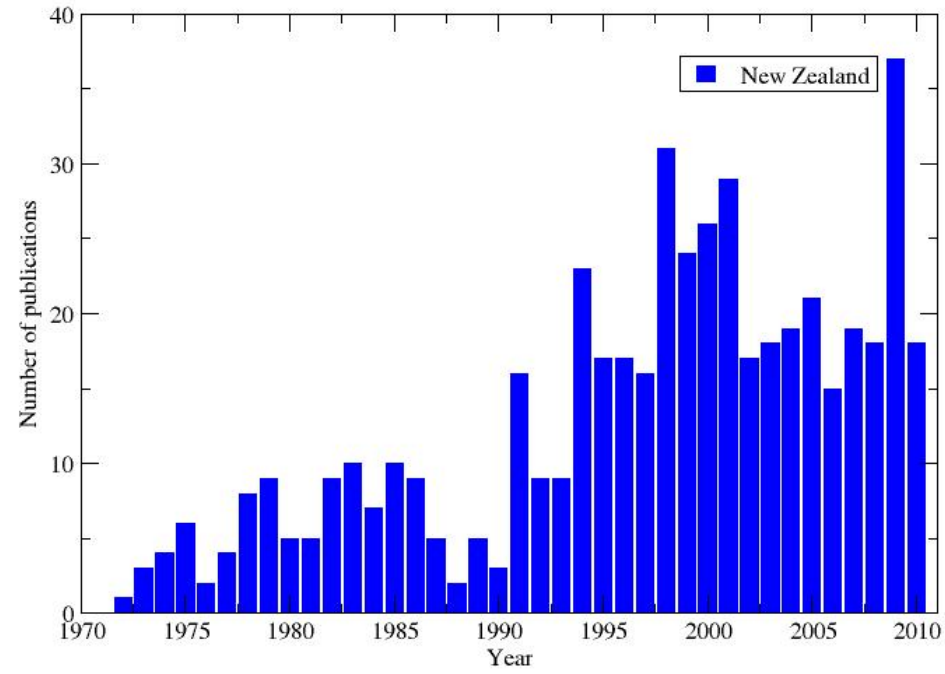

Figure 2: Number of publications in each year since 1970 to present where at least one author has a New Zealand address.

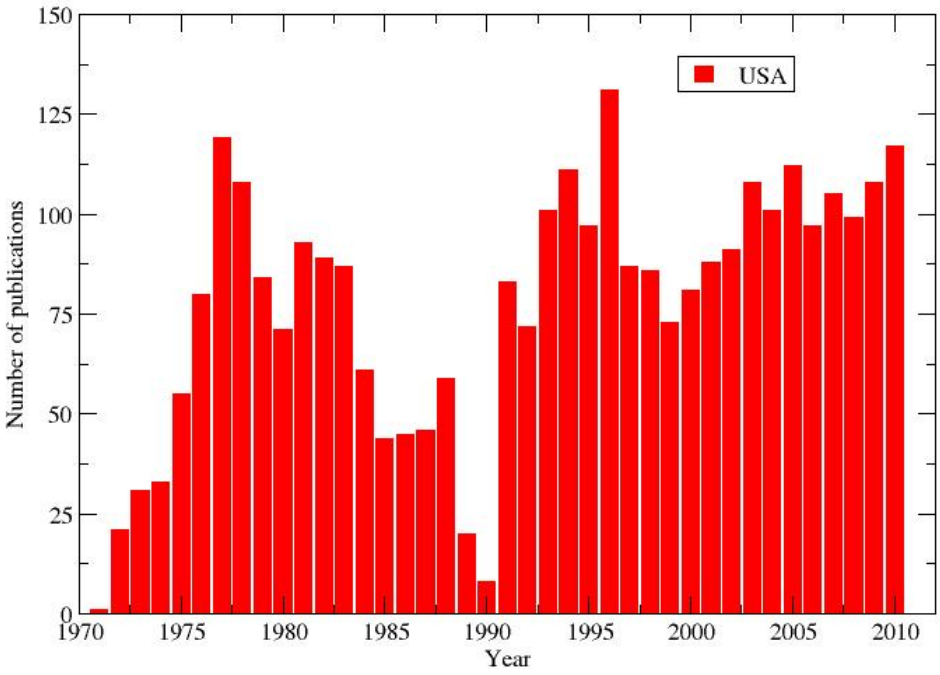

Figure 3: Number of publications in each year since 1970 to present where at least one author has a United States address.

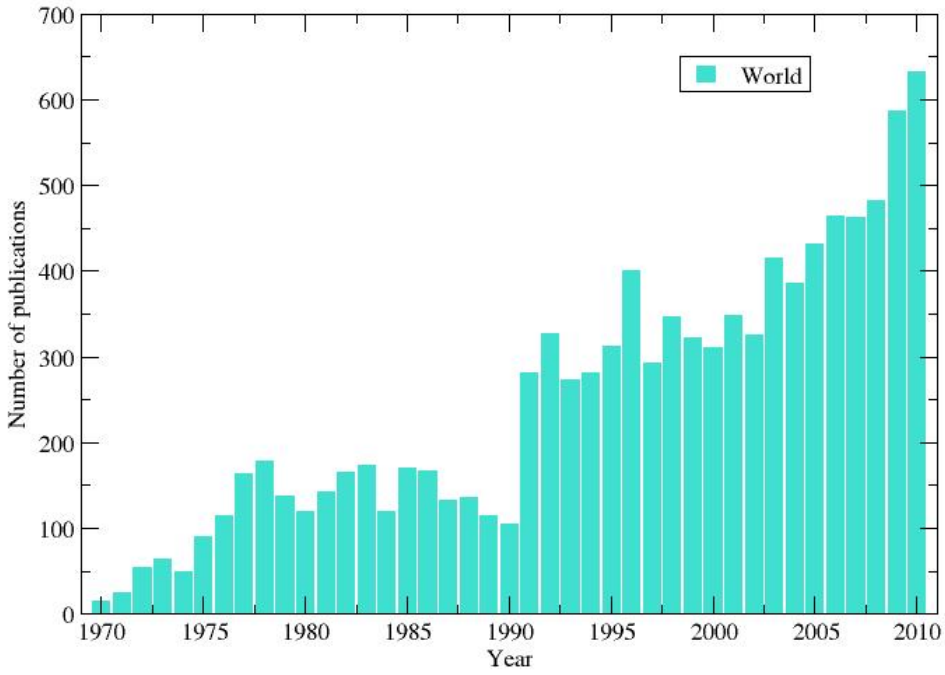

Figure 4: Total number of geothermal publications in each year since 1970 to present.

New Zealand Co-author Networks

In this section we construct co-author networks to give an indication of the amount of collaboration within New Zealand, and to provide information about how well connected researchers are. In the following co-author networks, shown in Figure 5, nodes represent individual authors, while edges between pairs of authors represent those two authors have published a paper together. The co-author networks for New Zealand authors are initially sparse – there are few authors and few connections (co-publications). For example, of the publications in the 1970-1974 period, the largest connected component[1] in the co-author network contains only six authors. For this reason, we only show co-author networks for five-year periods from 1980 onwards.

As the co-author networks increase in size over time, we observe a number of sizable connected components developing. In particular, for the period 2005-2009, most of the authors are included in the largest connected component. However, it is also interesting to note that in the same co-author network, there are a number of secondary connected components, containing a number of authors, and strongly linked, but distinct from the largest connected component. Additionally, numerous authors remain isolated, or poorly connected, which suggests that there are many examples where collaboration is minimal.

[1] The *largest connected component* is the greatest number of nodes (or authors) who are all connected (by a co-author relationship). The connection can be indirect, i.e., it can involve intermediary co-authors.

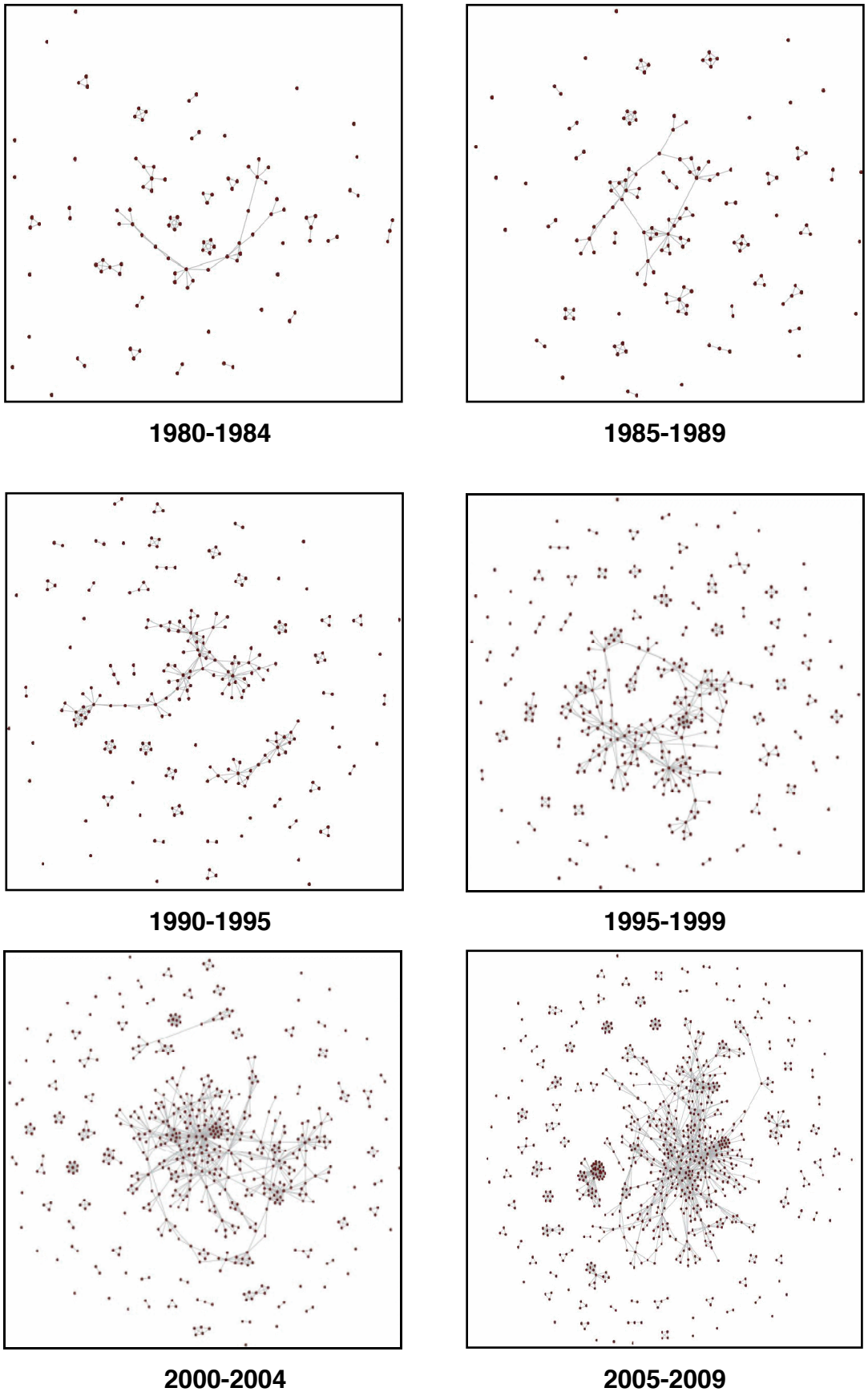

Figure 5: Co-author networks for New Zealand based researchers in five-year bins from 1980 to 2009. The nodes represent individual authors while the lines represent co-author relationships.

World Co-authorship Maps

The co-author networks of the previous section deal only with authors with a New Zealand address. While it would be possible (though computationally very demanding) to produce an equivalent network showing international collaborations, the complexity and detail of such a network would make it difficult to extract useful information. Instead, we reduce the co-author network to a co-author map, showing only high-level information. The co-author maps for the five-year periods from 1970, onwards, are shown in Figure 6.

Such maps are a good measure of collaboration between countries and of how closely we might expect the trends in publication records to correlate between countries. Again, we restrict our analysis to only New Zealand and the five most prolific countries. Each country is represented by a single node, the size of which corresponds to the number of publications from that country. In order to avoid double counting publications, each publication is divided between the co-authors by country. For example, a publication with six authors; three from New Zealand, one from France and two from Canada would contribute 3/6, 1/6 and 2/6 respectively to the total publication count for each of those countries. Each co-author relationship counts as 1 towards the thickness of the edge connecting a pair of countries. However, in order to be able to show all co-author relationships from smallest to largest, it is necessary to scale the edge thickness logarithmically with the number of co-author relationships.

The maps show that New Zealand is relatively well connected from the beginning while some countries (e.g. Japan) remain poorly connected, with very few co-author relationships until the late 1990s. Ultimately, all countries are widely connected, as one might expect with technology making long-distance collaborations easier with time.

While it is unwise to assign too much importance to particular features of the maps, it is perhaps telling that a decline in the connections to New Zealand in the 1985-1989 period is followed by a decline in publications in the subsequent period: 1990-1994. The same pattern can be seen for the United States. This drop-off of in connections and publications matches the trend seen in the volume of publication outputs over time (Figure 2 and Figure 3). When compared with that of countries with significantly larger populations (e.g. France, Japan, Italy and Canada), New Zealand's share of total published output remains strong, relative to population, in all time periods. It is also interesting to note that from 1990 onwards, while the United States has a large, and increasing number of co-author relationships with other countries, its share of the total publications does not increase proportionately. This is perhaps due to a large number of US authors co-authoring publications with several authors from other countries.

Normalised co-author maps, where node size represents the fraction of the total publications in each five-year period, are included in Appendix C.

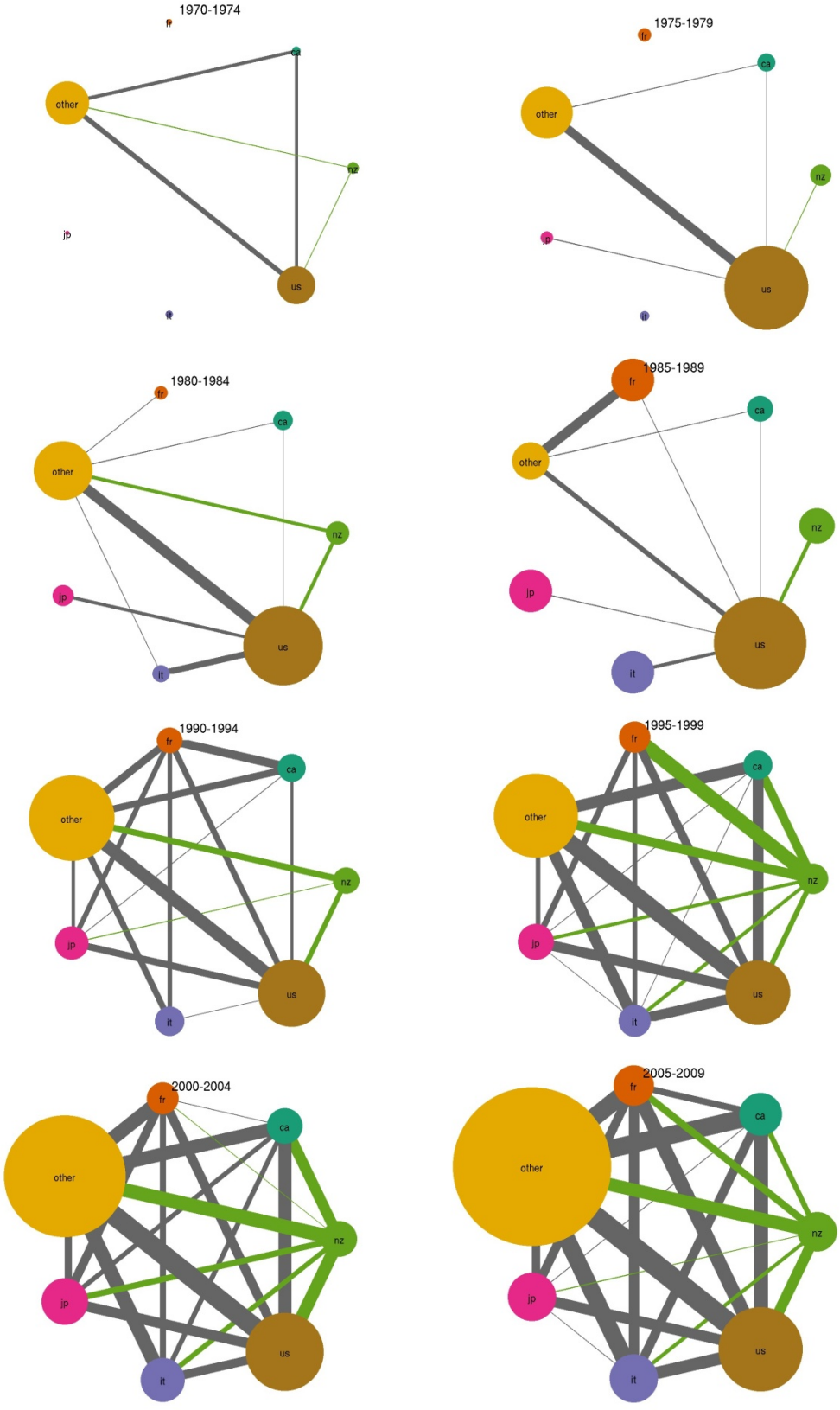

Figure 6: Network maps for the five-year periods from 1970 onwards. The size of each node is proportional to the number of publications for that country for each period.

Conclusions

We are able to make a number of observations from this study:

- The early period of geothermal research in New Zealand is characterised by strong collaborative links with geothermal researchers in the United States.
- New Zealand geothermal researchers have become much more collaborative over time, mirroring the increase in collaboration that has occurred in the rest of the scientific community.
- The volume of published outputs volume peaked in the early 1980s and then declined in both NZ and the US in the late 1980s. This decline was not mirrored in the rest of the world.
- In the late 1980s, the US lost its dominant position in geothermal research which it has not regained. Although the total output in geothermal research in the US and New Zealand recovered, subsequent growth is slower than that for other countries.
- The geothermal community is increasingly dominated by the entry and growth of new players. At the same time, countries are better and better connected, with denser co-author maps.

It may be possible to correlate some of the changes in geothermal bibliometrics with particular events. For example, a large government funded research project in France on Hot Dry Rock geothermal energy in the mid-1980s or the sudden decline in US Dept. of Energy funding for geothermal research in the early 1990s may have left bibliometric signatures. However, a full investigation of this is beyond the scope of this report.

Appendix A: Methodology

Bibliometric data was extracted from the ISI Web of Science database. Geothermal related publications were identified by a search for the keyword “geothermal”. This search resulted in 11,240 publications as of July 10th, 2011. The publication records contain numerous fields, such a publication title, journal title, publication type, date, author names and their corresponding research addresses. In many cases, especially for earlier publications, not all fields have entries: in particular country information is frequently missing for publications prior to the early 1990s. Apart from articles in academic journals, the records include publications from a range of other sources such as proceedings papers, meeting abstracts, reviews and editorial materials. In Table B2 of Appendix B we give a full list of the publication types and the number of publications in each category.

A quick inspection of the publication records indicates that the “geothermal” keyword search also returns a number of publications which are well outside the area of geothermal energy production. Publications relating to extremophiles and astrobiology are a major component of these. In order to limit our search results to a more pertinent set of records, we chose to exclude a number of subject areas from the search results. The list of excluded areas, and the number of publications contained in each, is given in Table B1 of the appendix. After excluding the extraneous results we are left with 10,440 publications.

In addition to publications from New Zealand, we consider publication data for the top five most prolific countries with geothermal publications. These are Canada, France, Italy, Japan and the United States. New Zealand is ranked seventh (behind China) in a table of total geothermal related publications over the entire period for which records are held. New Zealand is followed by Germany, England and Turkey.

Appendix B: Subject areas and document types

Table B1: Subject areas excluded from ISI Web of Science search results.

MICROBIOLOGY (199)	GENETICS & HEREDITY (4)	BUSINESS, FINANCE (1)
BIOTECHNOLOGY & APPLIED MICROBIOLOGY (78)	IMMUNOLOGY (4)	CELL BIOLOGY (1)
PLANT SCIENCES (50)	MYCOLOGY (4)	CHEMISTRY, ORGANIC (1)
MARINE & FRESHWATER BIOLOGY (48)	AGRONOMY (3)	CRITICAL CARE MEDICINE (1)
ECOLOGY (44)	MEDICINE, LEGAL (3)	DEMOGRAPHY (1)
BIOCHEMISTRY & MOLECULAR BIOLOGY (42)	PLANNING & DEVELOPMENT (3)	EDUCATION & EDUCATIONAL RESEARCH (1)
ASTRONOMY & ASTROPHYSICS (27)	VETERINARY SCIENCES (3)	ENDOCRINOLOGY & METABOLISM (1)
BIOLOGY (22)	DERMATOLOGY (2)	FILM, RADIO, TELEVISION (1)
FISHERIES (21)	FORESTRY (2)	HISTORY (1)
ZOOLOGY (16)	LAW (2)	INFECTIOUS DISEASES (1)
PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH (11)	MEDICINE, GENERAL & INTERNAL (2)	INFORMATION SCIENCE & LIBRARY SCIENCE (1)
EVOLUTIONARY BIOLOGY (9)	PARASITOLOGY (2)	MATERIALS SCIENCE, COMPOSITES (1)
IMAGING SCIENCE & PHOTOGRAPHIC TECHNOLOGY (9)	PHYSIOLOGY (2)	NUTRITION & DIETETICS (1)
REMOTE SENSING (9)	SOCIOLOGY (2)	ORNITHOLOGY (1)
ENTOMOLOGY (7)	TOXICOLOGY (2)	POETRY (1)
AGRICULTURE, MULTIDISCIPLINARY (6)	VIROLOGY (2)	POLITICAL SCIENCE (1)
AGRICULTURAL ENGINEERING (5)	AGRICULTURAL ECONOMICS & POLICY (1)	RADIOLOGY, NUCLEAR MEDICINE & MEDICAL IMAGING (1)
BIODIVERSITY CONSERVATION (5)	ART (1)	STATISTICS & PROBABILITY (1)
BIOPHYSICS (5)	ASIAN STUDIES (1)	SURGERY (1)
LIMNOLOGY (5)	BIOCHEMICAL RESEARCH METHODS (1)	URBAN STUDIES (1)
FOOD SCIENCE & TECHNOLOGY (4)		

Table B2: Publication types included in the data set. The number of publications for each type is given in brackets.

ARTICLE (7,358)	NOTE (94)	BOOK REVIEW (21)	ABSTRACT OF PUBLISHED ITEM (1)
PROCEEDINGS PAPER (2,214)	LETTER (82)	CORRECTION (16)	DATABASE REVIEW (1)
MEETING ABSTRACT (825)	NEWS ITEM (34)	BIBLIOGRAPHY (5)	SOFTWARE REVIEW (1)
REVIEW (400)	DISCUSSION (32)	CORRECTION, ADDITION (4)	TV REVIEW, RADIO REVIEW, VIDEO (1)
EDITORIAL MATERIAL (160)			

Appendix C: Normalised World Co-authorship Maps

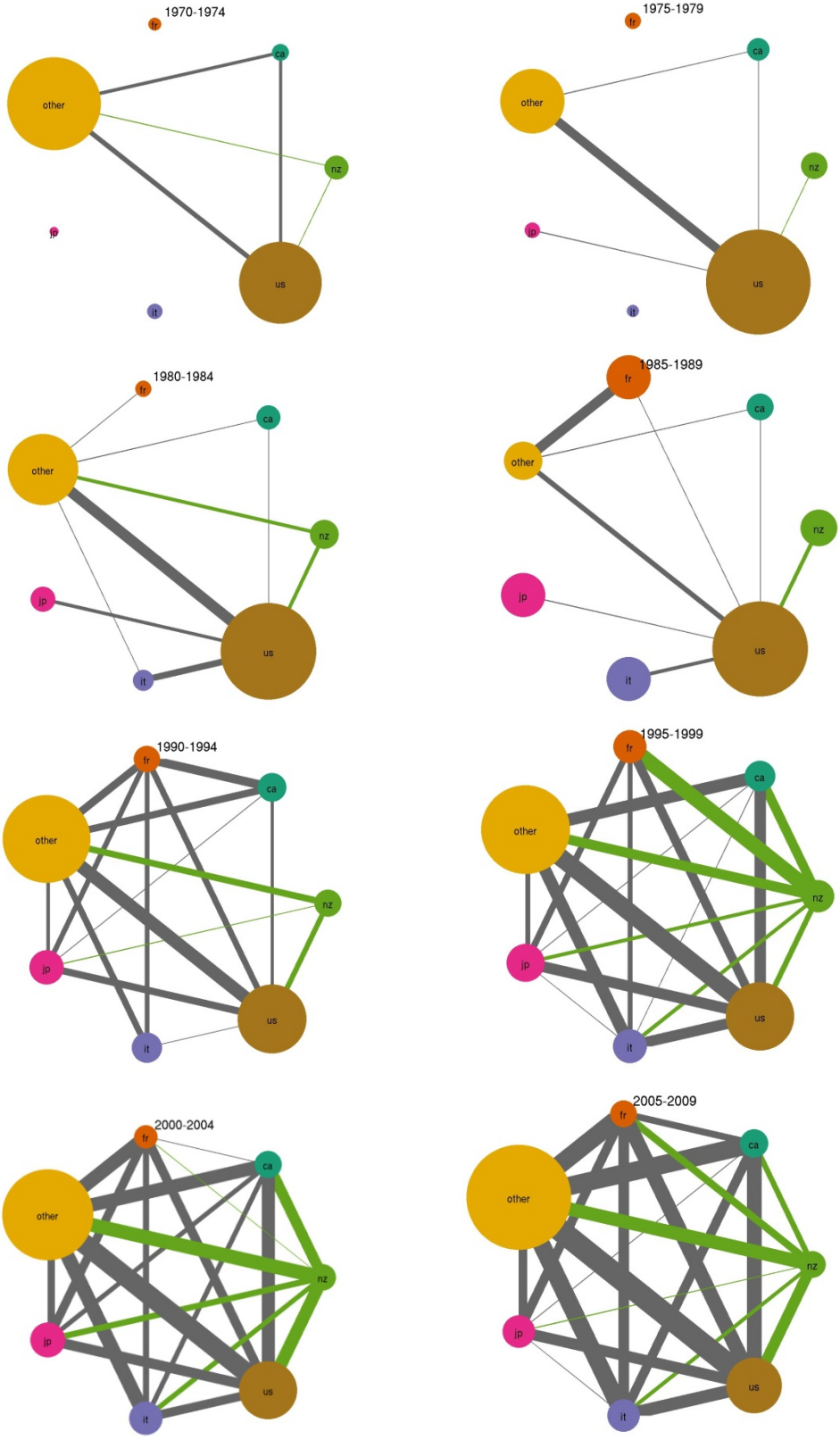

Figure C1: Normalised network maps for the five-year periods from 1970 onwards. The number of publications has been normalised such that the total size of the nodes is the same for each five-year period.

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I accept that this report satisfies the project deliverable, namely: A report on the growth and decline of capability in geothermal power engineering.

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