Rainmakers, Space Mirrors and Atmospheric Vacuums: A Bibliometric Mapping of Geoengineering Research

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ABSTRACT
This poster presents preliminary results from an informetric study of geoengineering publications. As a field of research geoengineering is loosely defined as the intentional modification of the Earth's environment to stabilize, correct, or ameliorate climate change. A broad overview of the policy and practical implications of geoengineering strategies are discussed, as well as evidence of a growing body of cited scholarly publications. A technique of bibliometric mapping is used to display correlations between keywords attached to a corpus of geoengineering publications. Past studies have shown this technique to be particularly useful for revealing sub-domains that are affecting the evolution of a new field of study. Preliminary results, in the form of keyword co-occurrence clusters are discussed as two-dimensional disciplinary maps. These maps relationally situate the broad sub-domains that both import and export knowledge from the field of geoengineering.

Keywords
Bibliometric mapping, informetrics, scholarly communications.

1. INTRODUCTION
Geoengineering is loosely defined as the intentional modification of the Earth's environment to stabilize, correct, or ameliorate climate change. Given both the uncertainty of it's methods and the ethical dilemma most observe in intentionally manipulating nature, geoengineering is a highly politicized area of scholarship. Further complicating an objective evaluation of geoengineering's potential benefit to combating climate change is the oddity of it's proposed engineering techniques; many of which can be compared to those found in the most elaborate of science-fiction stories. Exemplar strategies for climate modification in geoengineering include albedo enhancement (cloud brightening through balloon seeding), solar refraction (through land and space based mirrors) and carbon sequestering (extracting CO_2 from the atmosphere with enormous vacuum-like technology). Regardless of the novelty of these strategies, it is well recognized by researchers in this field and politicians that engineering the natural world to achieve a 'global cooling' will only take place if all other carbon emissions reduction efforts fail, *and* methods for manipulating the climate are understood well enough to be thought safe, and containable in their effect [4,1].

iConference '12, Feb 07-10 2012, Toronto, ON, Canada
ACM 978-1-4503-0782-6/12/02.

2. BACKGROUND
In 2007 the International Panel on Climate Change (IPCC) issued a research assessment that, for the first time, comprehensively synthesized empirical findings of variations and changes in the Earth's climate [3]. This report has since been recognized as *the* authoritative resource for global climate change scholarship, and it's authors have been prestigiously recognized for their contribution to our knowledge of this phenomenon[1]. IPCC's recommendations for ameliorating negative effects of climate change focused mainly on reducing carbon emissions through policies that better regulate waste management facilities, incentivize sustainable forestry and fishing, and increase efficiency in transportation and energy infrastructures of major urban environments. Many recommendations for combating rising global temperatures were offered, but geoengineering techniques were emphasized as an essential part of any long term disaster avoidance strategy [3; p. 11.2.2].

The term geoengineering was first used in scholarly literature in the 1960's [4], but the field received little attention from both policy makers and climate scientists due to the controversial nature of its proposed engineering techniques. However, being discussed thoroughly by leading climate change researchers in the IPCC report seems to have been a validating mechanism for scholarship in this area. Publications and citations to geoengineering research took a dramatic upturn starting in 2007 and have increased steadily since this date (See Figure 1).

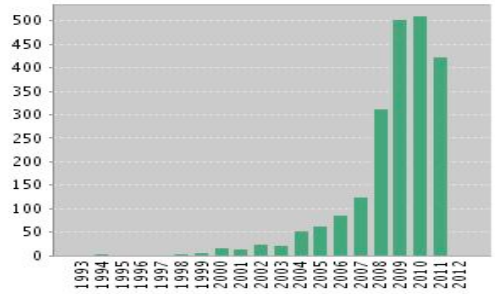

Fig 1. ISI Web of Knowledge Citation report showing citations to geoengineering publications through 08/2011.

2.1 Previous Work
In environmental and geological sciences, climate change research has focused almost exclusively on tracking, measuring and predicting the effect of rising global surface temperatures and sea levels. These investigations are most often realized through the construction of complex data driven simulations and models that leverage information resources from an enormous variety of

[1] http://www.nobelprize.org/nobel_prizes/peace/laureates/2007/

domains and time periods. Locating seminal figures, recognizing the adoption of methods and even identifying the educational backgrounds influencing research strategies in climate change has proven exceptionally difficult due to it's size and the diversity of participants [5,6].

One method of validating the emergence of a new field is to trace it's evolution from more established research disciplines [5]. Previous informetric studies have looked at the evolution of a scientific discipline [8] or a phenomenon of study [6] through techniques such as citation network analysis, bibliographic coupling, co-citation, co-author and co-word analysis. Calero-Medina and Noyons [2] have used a combination of bibliometric mapping and citation network analysis to trace the development of a concept (absorptive capacity) from its fragmented roots to an established interdisciplinary field of research. Bibliometric mapping was shown to be particularly useful for studying interdisciplinary research because it provided a rich overview of the sub-domains contributing to an emergent field by constructing relatedness groupings displayed in a two-dimensional graph (map). Sub- domains that are strongly related to one another get displayed in tight proximity, while weak relations are emphasized by greater relative distance. With this topographic overview, exploring the mapping of a field becomes a matter of drawing inferences from related clusters of concepts and disciplines.

3. METHODS

From ISI Web of Knowledge[2] we retrieved a collection of 232 unique publications with geoengineering in the title, as a word appearing in the abstract, or as a keyword from the year range 1991- 2011. This 'original' corpus consequently received a total of 1214 unique citations, not including author 'self- citations.' From both the original corpus and the citing corpus we extracted two sets of keywords: 1. Author supplied keywords representing the author's selection of concepts, disciplines and the intended audience of interest, and 2. 'Keywords Plus', which are generated by indexers at Thomson and Reuters. Keywords Plus include, 'words or phrases that frequently appear in the titles of an *article's references*, but do not necessarily appear in the title of the article itself.'[3] The combination of these two sets then gives us a depth of relevant keywords that is on the order of three magnitudes; original publication, citing publication, and keywords extracted from the reference list of the citing publications (keywords plus). Of the original corpus and the citing corpus 926 publications had four or more descriptive keywords indexed in their bibliographic data. These 926 publications had 3458 unique keywords in total.

4. PRELIMINARY RESULTS

Each of the 3458 keywords were given a frequency of observation rating based on the number of times that they appeared in the 926 publications. Keywords with eight or more appearances in our corpus were labeled 'frequently observed' (n=116). We then calculated the number of times these frequently observed keywords co-occurred in publications-- that is the number of times frequently observed keywords appeared together in the same publication. Following the method used by Calero-Medina and Noyons [2] we then applied a hierarchical agglomerative complete linkage cluster analysis to our co-occurring keywords matrix. This analysis is still in preliminary stages, but thus far discernible clusters of keyword co-occurrences reveal three very broad sub-domains that we've labeled as atmospheric and environmental sciences, economic/ policy development and oceanography.

5. FUTURE WORK

Future work will include a refined application of the cluster analysis methods, discussed above, in order to better recognize less explicit sub-domain clusters. Additionally, we plan to vet cluster labels through a collaboration with practicing climate scientists. With accurate labels, we can then assign individual articles to a cluster, thus revealing maps of sub-domain clusters. We will also assign overlap to the clusters, so that cosine similarity measures can be calculated for clusters with commonality.This is one in a series of planned informetric studies of geoengineering that includes a comprehensive investigation of the disciplines and researchers contributing to the evolution of this field of research. The data for this analysis and a discussion of the methods planned for future work are available as a CC0 licensed open-notebook at: htttp://www.wiki.nicwe.be/r

6. ACKNOWLEDGEMENTS

This research was funded in part by the Data Curation Education in Research Centers fellowship, IMLS grant # RE 02-10-0004-10. Thank you to Vetle Torvik and colleagues in LIS 590 Informetrics for their insights and recommendations..

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