Representations of Glacial Ice in National Geographic Magazine's Coverage of Climate Change between 1978 and 2018

A Grounded Theory Analysis

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Abstract

When working within the photo-essay format used by National Geographic Magazine (NGM) journalists and editors face challenges in engaging audiences with complex issues such as climate change. This study investigates the changing representations of glacial ice within NGM's coverage of climate change between 1978 and 2018. A theory, grounded in the data and integrated with existing literature, was developed to explain the findings.

Qualitative analysis of twenty seven articles and seven editorials showed how NGM's representations of glacial ice, in the context of the magazine's coverage of climate change, evolved through three distinct phases. The mix of content, communication modes, explanatory frames and multi-modal representations characterising each phase reflected: NGM's changing, but often tacit, synthesis of the state of climate science; limitations of the magazine's photo-essay format; and the social practices within NGM (such as reporting norms) during the relevant period. Analysis shows that NGM's framing of climate change and the representations of glacial ice became aligned with accepted climate-science only after 2003.

This study extends previous research results on how popular science magazines, such as NGM, present climate-change issues using multiple modes of communication. It suggests a growing role for infographics in print magazines to compensate for inherent limitations of photographic images when communicating about causal relationships. The developed theory explains the study results and suggests science communicators will benefit from matching their choices of frame and modalities to characteristics of the underlying science and the associated social, economic and political systems being reported on.

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1 Introduction

PEW Research Center (2019) shows the public is belatedly recognising anthropogenic climate change as a significant threat for society, and the urgency of effective policy action is growing (Intergovernmental Panel on Climate Change, 2018). Although the history of climate change science began in the 1880s, 1978 is seen as the milestone year where scientific opinion converged on global warming as the chief climate risk facing society (Weart, 2019). Glacial ice (glaciers, the ice sheets formed from them, and the icebergs "calved" from those sheets) became a global metaphor for the societal challenge of global warming with the use of retreating glaciers as the backdrop for political activity (Gore, 1997; Carey, 2007; Doyle, 2007). Growing international concern for the threat of flooding caused by sea-level rise as the Greenland and Antarctic ice sheets melt (McGranahan, Balk, and Anderson, 2007) has ensured glacial ice continued to play a significant role in both climate science (Vaughan et al., 2013; Intergovernmental Panel on Climate Change, 2019) and climate change communication (Smith and Joffe, 2009; Leonn and Erviti, 2015; Lam and Tegelberg, 2019).

Communicating about climate change involves complex, and often conflicting, social and political ideas and represents an ongoing challenge for science communicators (Nisbet and Markowitz, 2016). Manzo (2010) argues that engaging the public with climate change requires a communicator to address three factors: cognition (knowledge and understanding of climate science), affect (interest in and concern about the issue), and behaviour (personal engagement and motivations to act). Visual material, with its ability to evoke emotive reactions (Joffe, 2008) and communicate information in a memorable way (Evans, 2010) led climate communicators to adopt photographic imagery when attempting to change the public's understanding and attitudes towards climate change (O'Neill and Nicholson-Cole, 2009). While the interpretation of visual material is subject to perceptual processes shared by all viewers (Messaris, 1994) there remain social factors which influence the emotional response and interpretations of images (Chapman et al., 2016).

Research on the representation of glaciers in the English-speaking press by O'Neill et al. (2013) and by non-governmental organisations (NGO) campaigns as analysed by Doyle (2007) confirmed the uncertain effects of using emotive imagery in climate change communication when seeking to generate

public engagement. Further research (Chapman et al., 2016; Nurmis, 2015) has codified practitioner focused guidance for selecting images in climate change communication (Wang et al., 2018). The challenge of understanding the interplay between the various meanings generated through images, text and other forms of communication when they appear together on the page remains an ongoing research area for climate change communication.

Research into the representation of environmental issues in print media (DiFrancesco and Young, 2011; Wozniak, Lack, and Wessler, 2015) and the imagery of climate change used in TV news programmes (Leonn and Erviti, 2015) demonstrate it is often the combination of images with associated content e.g., captions, narrative text which establishes the meaning of an image for audiences. The different forms of content are referred to as "modes" and studies of visual culture, such as Rose (2016), demonstrate how the meaning of an image is heavily influenced by its associated content. The wider cultural trend towards increased visuality in many forms of popular communication Mitchell, 1994; Hariman and Lucaites, 2007 as well as in popular science magazines reinforces the need for images, captions, and text to be analysed both individually and in combination to understand their cumulative messaging and potential impact.

There has been limited research on climate change communication in popular science magazines despite the genre attracting an educated and influential audience (Born, 2015). In particular, National Geographic Magazine (NGM) provides a significant route for scientific knowledge to reach millions of people across the globe with each issue (National Geographic, 2019a). National Geographic (2019) claims ten million copies of each issue are sold, reaching around 30 million people globally. NGM established a unique reputation and market position using photography as an important part of its approach to communication (Hawkins, 2010). NGM's ability to create visual icons [1] is described by Lutz and Collins (1993) and Beaudreau (2002). The problematic nature of NGM's historical coverage of non-western cultures (Lutz and Collins, 1993) led the current editor to acknowledge the magazine's often racially-biased and stereotyped portrayals (Goldberg, 2018). Despite criticism, NGM has grown its market presence and remains unique among popular science magazines for its market position and ongoing ability to establish visual icons within environmental and climate discourse as demonstrated by the magazine's polar bear coverage discussed by Mittermeier (2018) and Born (2018).

The multimodal nature of NGM's content is influenced by different people having the roles of ar-

[1] Repeated images found across media types, representing significant events, and activating strong reactions (Hariman and Lucaites, 2007)

ticle writer, caption writer, illustrator and photographer who operate semi-independently and provide differing perspectives for the article (Souza, 1998; Mendelson and Darling-Wolf, 2009). Pflaeging (2017) describes the evolution of NGM's magazine layout towards increased dependency between caption and images, reinforcing the importance of a multimodal approach to analysis of NGM content. In the context of environmental topics, Whitley and Kalof (2014) showed how image captions play a key part in establishing the meaning of the photographic images used in NGM articles about animals and climate change.

Given the iconic nature of glaciers and ice sheets in news media coverage of climate change (O'Neill, 2019), there is surprisingly limited extant research on the representation of glacial ice in popular science magazines. This study, by undertaking an empirical analysis of how NGM represented glaciers between 1978 and 2018 within their coverage of climate change, contributes to the practice of climate change communication. The analysis will identify and describe how multimodal representation of glaciers within NGM has changed over time. A theory to explain the findings about the representation across images, infographics, captions, and article text will be developed using Grounded Theory Method (GTM) (Urquhart, 2013). The theoretical model and its integration with existing theories and best practice recommendations aims to provide insights for the practice of multimodal communication about climate change in popular science magazines.

2 Background

2.1 Glacial Ice, Climate Change and Consequences

The role of glacial ice in establishing the evidence for climate change was initially highlighted to the public through political campaigns linking glaciers and climate change (Gore, 1997) and NGO campaigns to highlight their disappearance (Lam and Tegelberg, 2019; Doyle, 2007). Their iconic role (Carey, 2007) was based on the drama of significant geological change, the societal dangers associated with sea-level rise caused by their physical melting (Kaser et al., 2006) and the scientific importance of the climatic records of temperature and atmospheric composition stored in the annual layers of mountain and polar glaciers which confirmed the links between CO_2 levels and global temperatures. By the mid 1980s, glacial core samples were providing 150,000 years of climate history covering complete glacial cycles (Lorius et al., 1992) and, by 2004, ice cores from Greenland and the Antartica provided over 740,000 years of climate history (Oerlemans and EPICA community members, 2004). The physical dangers of extreme altitude and accidents faced by the scientists involved in collecting ice-cores featured in several popular science books released in the mid-2000s e.g., (Bowen, 2006).

Loss of mountain glaciers risks disruption to the agricultural water supplies needed by a significant proportion of the world's population (Barnett, Adam, and Lettenmaier, 2005). The likely sea-level rise caused by melting of the West Antarctic ice sheet (Mercer, 1978; Vaughan, 2008) is an example of the dangers documented by IPCC reports (Intergovernmental Panel on Climate Change, 2018). Sea levels will continue to rise for many centuries as a result of the ongoing glacial melting. Should the global average temperature rise by the expected three degrees then sea levels are expected to be around six meters higher than today (Dutton et al., 2015) and submerge cities and coastlines with a current (2019) population of hundreds of millions. The Intergovernmental Panel on Climate Change (2019) report on the impact of global warming on the cryosphere suggests sea-level rise in the short term will be greater than previously expected.

2.2 Climate Change: Communication for Engagement

While the science of climate change itself developed quickly after 1978 (see Appendix B), effective communication of the issues lagged behind for a number of reasons: reporting practices, media-biases, and belated development of best practice for effective communication of the complexities associated with global warming.

2.2.1 Environmental Reporting Practices

Revkin (2005) argues that during the 1970s and early 1980s media coverage of climate change focused on dramatic aspects of stories, sometimes leading to misleading coverage e.g., the "myth" there was a scientific consensus for global cooling in the 1970s (Peterson, Connolley, and Fleck, 2008). After a rapid growth in coverage in 1988, driven by a combination of political factors and weather events, there was a lowering of interest (Ungar, 1992). In an analysis of US press coverage of global warming between 1988 and 2002 Boykoff and Boykoff (2004) argued that a wish for journalistic balance, with its equal treatment of opposing views independent of scientific merit or weight of opinion among experts, "...contributed to a significant divergence of popular discourse from scientific discourse" (Boykoff and Boykoff, 2004, p. 125) and that the "...press's adherence to balance actually leads to biased coverage of both anthropogenic contributions to global warming and resultant action." (Boykoff and Boykoff, 2004, p. 125) The importance of specialist reporters in avoiding these confusions was highlighted by Wilson (2000) who identified that much reporting was being done by non-specialists. and argued:

> "Quality reporting on climate change needs to portray the scientific consensus and dissent accurately. ...reporters were confused; they exaggerated the debate ... misunderstanding of debate is exacerbated by many reports' inaccurate understanding (of the science)." (Wilson, 2000, p. 11)

With an IPCC-led consensus being established by 2001, analysis by Bruggemann and Engesser (2017) showed from the mid-2000s "... climate journalism has moved beyond the norm of balance towards a more interpretative pattern of journalism. " (Bruggemann and Engesser, 2017) This change is consistent with the evolution of practice within environmental journalism as a whole. Palen (1999) describes attempts since the mid-90s to provide support for environmental journalism as a specialist field and ensuring journalistic independence from vested interests concluding: "... experience demon-

strated the continuing, although limited, utility of journalistic objectivity as a standard around which practitioners could organise themselves" (Palen, 1999, p. 156). By the mid-2000s environmental journalists found themselves seeking more effective ways to persuade, as opposed to simply informing, audiences of the importance of the issues facing the natural world (Mittermeier, 2005; Ward, 2008; Gervais, 2016). This shift towards an advocacy-led approach (Fisher, 2016) led a number of the leading photographers who had worked for NGM to create new NGOs to support their vision. One example is James Balog, who in 2006 established the Extreme Ice Survey to monitor glacier retreat using time-lapse photography (Kleibeor, 2013; Lam and Tegelberg, 2019). The work of other NGM staff who shifted their work towards advocacy is described in (Ward, 2008; Nurmis, 2017).

2.2.2 Framing of Climate Change

A preferred meaning is assigned when selecting a particular interpretation of a complex issue and then using that "framing" to communicate about the issue to a particular audience. Entman (1993) defines framing as:

> To frame is to select some aspects of a perceived reality and make them more salient in a communicating text, in such a way as to promote a particular problem definition, causal interpretation, moral evaluation and/or treatment recommendation for the item described. (Entman, 1993, p. 52)

Nisbet (2010) shows how this framing is used by audiences, journalists and politicians to shape communications about climate change. O'Neill et al. (2015) analysed the dominant frames in legacy and social media coverage of the Fifth IPCC Assessment report and demonstrated how the editorial policy of particular UK and US print media organisations led each to different selections of frames around the extent of scientific consensus, political conflicts and predictions of dire consequences.

2.3 Factors Influencing Audience Perceptions

The historically low level of public attention to global warming is partially explained by Ungar (1992) who argues that audience receptiveness to political and scientific claims about environmental issues are often driven by events e.g., extreme weather events, rather than the claims on their own. It takes

"dramatic events to transform underlying dread into social scares and thereby enhance attention to claims-making appeals" (Ungar, 1992, p. 486).

Communication about climate change science shares many of the challenges seen with other geological science issues caused by reliance on observation and modelling of the past and future as opposed to empirical testing. Effectively representing climate events over long timescales using photography (Doyle, 2007) and visualisations (Nicholson-Cole, 2005) are known to be challenging. Gibson (2016) discusses how cognitive models used to understand the timescales and scope of geological issues differ between experts and lay-people and hence form a significant barrier to communication.

2.4 Success Factors in Multimodal Communication

Dahlstrom (2014) argues for the ongoing importance of textual narrative structures in communication to non-expert audiences. However, the complex scientific, emotional and political issues typical of climate change often require combinations of images and text to present a coherent story. DiFrancesco and Young (2011) demonstrate this for press coverage. A similar need for aligned image and text content within TV coverage is analysed by Leonn and Erviti (2015). Both studies discuss negative impacts on engagement when different modes present conflicting or confusing messages. The use of infographics when communicating complex issues is an emerging practice within both news journalism and science communication. In their study of climate change coverage in Western media Painter et al. (2016) found "Infographics are usually produced by specialised journalists. " (Painter et al., 2016, p. 64) Within science communication Lazard and Atkinson (2015) showed that: "individuals engage in greater levels of issue-relevant thinking when shown infographics compared to messages that rely just on text or just on illustration". The review of best practice recommendations in the design of climate change related infographics and other forms of data visualisation for non-specialist audiences by Harold et al. (2016) highlights the cognitive benefits of closely integrating graphics with their associated text and avoiding misleading mappings between visuals and textual language used.

Appendix C presents a review of research on the combined influence of image and text. There is evidence for enhanced learning from multimodal material, and how the emotional impact of an image overriding the textual message if they are not congruent. However, when the image and text messaging are aligned:

> ... inclusion of an attention-grabbing image increased the salience of, and attention

> to, the accompanying text, whose structure in turn guided participant's interpretation and support for [political] intervention (Zillmann, Knobloch, and Yu, 2001). For opinion formation, it seems that images are important but words "still exert defining power". (Entman, 1993, p. 104). (Powell et al., 2015, p. 1011)

2.5 Implications of NGM's Photo-Essay Format

The photo-essay, characterised by a combination of text and visuals with both carrying significant narrative information is a defining characteristic of NGM (Mendelson and Darling-Wolf, 2009). The complex process of producing photo-essays at NGM, with separate teams of photographers, article writers and caption writers, is described in (Lutz and Collins, 1993; Darling-Wolf and Mendelson, 2008; Mendelson and Darling-Wolf, 2009; Wheelersburg, 2017). Those studies identify the complexity of the process as a risk factor for disconnects between images, captions and textual storylines. The risk is compounded because audiences process text and images differently: the response to images is often immediate and emotional, with responses to text involving more cognitive processing (Messaris, 1994; Messaris, 1996; Mitchell, 1994). Disconnects become more likely when many readers of the magazine focus on the images and captions, rather than the text (Allner, 2000). Pflaeging (2017) argues that NGM has evolved its magazine design approach towards the use of articles with less text and use of image-caption clusters to support the narrative structure of the photo essay form, and as a response to the increasingly multi-media approach of NGM as media landscapes evolve.

There has been an extensive body of academic work on NGM's representation of cultural and social issues in a stereotyped and formulaic way (Hawkins, 2010; Lutz and Collins, 1993; Beaudreau, 2002; Mendelson and Darling-Wolf, 2009). These analyses often used image content analysis together with other forms of multimodal analysis (Rose, 2016, Ch. 5). Illustrating the potential constraints of the photo-essay format Beaudreau (2002) used image content analysis together with thematic analysis of captions and article text and historical sources on the economy and culture of Canada to examine NGM's evolving representation of Canada between 1960 and 1990, concluding:

> ... it is clear that the need to "exoticize" Canada through its choice of photographic content meant that National Geographic could only be partly relied upon to convey complex economic, political, and cultural changes in any given society. (Beaudreau, 2002, p. 541)

2.6 Previous Research on NGM's Environmental Messaging

A literature search for academic research on NGM's approach to coverage of environmental coverage identified a limited number of papers.

Peterson, Connolley, and Fleck (2008) examined journalistic coverage climate warming issues in the 1970s and presented a critique of NGM as misrepresenting scientific consensus while seeking "false balance" in its reporting on future climate changes.

Remillard (2011) presents a case study of the images and text in a 2009 NGM photo essay about Canadian oil sands integrated with the particular social and commercial context of the topic. The research examined both how aspects of environmental risk were represented visually in the original article and how the press and politicians reacted to the content and timing of its publication. The article may not have substantially raised levels of reader engagement, despite:

> "...the images presented the particular geographical location and distinct industrial process vividly and beautifully. The images also undeniably documented extensive environmental degradation." (Remillard, 2011, p. 127)

Whitley and Kalof (2014) analysed the representation of animals in NGM's climate change coverage between 1990 and 2001 using thematic analysis of both images and their captions. Relevant findings to this study were, firstly, about how NGM's animal imagery matches the criteria for effective communication about climate change but often "distances" the problem:

> ... we can indicate how well national geographic's images of animals in articles on climate change match some of the key characteristics of climate change visual communication identified by (Nicholson-Cole, 2005, p 267) as likely to motivate behavioral change...
>
> Our research establishes that National Geographic visuals of climate change were often of animals in distinctly distant and remote environments, exacerbating the perception that climate change is an obscure and far-off problem that has no cause or connection to humans. (Whitley and Kalof, 2014, p. 27)

Secondly, the analysis showed that: "Captions simultaneously serve to situate and construct the visual narrative" (Whitley and Kalof, 2014, p. 12).

Peck (2014) published a critique of the pre-2006 visual coverage of glaciers by NGM photographer Jim Balog as being overly focused on aesthetic issues. Balog changed his views on the importance

of climate change in 2006 because of his work with NGM (Kleibeor, 2013) and established a NGO focused on showing the impact of global warming on glaciers through a world-wide network of time lapse cameras (Lam and Tegelberg, 2019).

Born (2018) investigated how polar bears emerged as an icon for climate change within NGM's articles about climate change over the period 1992 to 2012. The analysis used content analysis together with multimodal analysis of text and images to demonstrate a sequence of representations over time. "... anthropormorphised depictions first established polar bears as subjects of identification [key topics]. Then, polar bears were visibly connected to the endangered Arctic. Finally, they emerged as ambassadors of a threatened ecosystem and icons of climate change." (Born, 2018, p. 1).

These studies of environmental representation suggest, in light of NGM's unique role and audience reach, and with limited studies of the topic in other popular science magazines (Born, 2015), there exists a gap in the research literature investigating NGM's climate change communication practices.

2.7 Research Questions

This study aims to address the identified gap in the research landscape by inductively building a theory about the multimodal representation of glacial-ice within the climate change coverage of NGM between 1978 and 2018. Objectives are to:

- analyse the content of relevant articles and editorials from editions of the magazine published between 1978 to 2018 to establish the types and extent of glacial-ice coverage;
- undertake multimodal analysis of the representation of glacial-ice using analysis of images, identification of visual themes, identification of narrative themes within the text of the article, and comparison between textual and visual themes;
- inductively develop a theory about NGM's representation of glacial-ice;
- compare the themes and theory identified from the analysis with those identified in the wider science communication literature;
- recommend further research areas.

The research questions identified are presented below.

Research Question 1: How has glacial ice been represented within NGM's climate-change coverage between 1978 and 2018?

Research Question 2: How has the framing (of articles and images) and narratives employed in the articles varied over time?

Research Question 3: How have the subject and composition of the visual imagery of glacial ice changed over time?

Research Question 4: Are the representations of glacial ice consistent within articles across the different modes?

Research Question 5: What theory emerges from the analysis of NGM's representation of glacial ice and its integration with existing literature?

Research Question 6: How do the identified themes and theory compare and contrast to practice and recommendations within the wider science communication literature discussing the representation of climate change?

Analysis findings used to answer questions 1 through 4 are described in Chapter 4 and discussed further in Chapter 5. A theory developed to explain the results is described and discussed in Chapter 5. Discussion on comparison of NGM's approach with best practice within science communication is presented in Chapter 5.

3 Method

3.1 Method Selection

The literature discussed in the previous sections revealed limited research to date on the representation of glacial ice in popular science media and highlighted the general importance of multimodal analysis of climate change communication. Given limited existing material multi-modal analysis of popular science magazines, Grounded Theory Method (GTM) (Urquhart, 2013) was selected as the research method to provide both detailed analysis guidelines and support for the identification of "emergent" ideas. This study used the Glasserian form of GMT, characterised by its sequence of coding stages, because of its track-record of research into combined social, science and technology questions (Urquhart, 2013). The integration of visual data within GTM is relatively new (Mey and Dietrich, 2016), and coding approaches from Konecki (2011) were adapted to support coding of visual data. Although GTM often seeks to build theory without reference to existing literature and concepts, this study incorporated a set of codes developed to document the influence on the coding process of existing literature on glacial-ice (e.g., (Carey, 2007)) and researcher prior knowledge (e.g., coding approaches based on (Rose, 2016, Ch. 4) as recommended by (Glasson, 2004). The selected approach using GTM is illustrated in Figure 1.

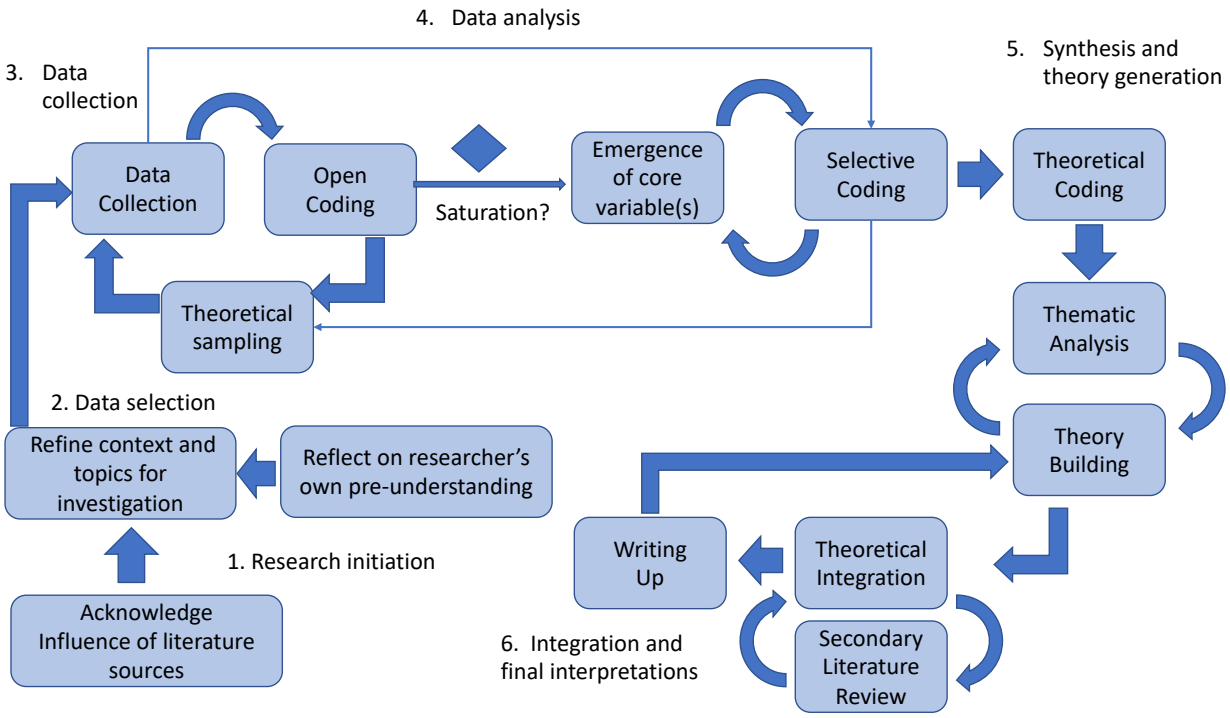
3.2 Theoretical Sampling

GTM seeks to identify and analyse content relevant to the research questions (termed theoretical sampling) and suggests data collection stops when "gathering fresh data no longer sparks new theoretical insights, nor reveals new properties of your core theoretical categories." (Charmaz, 2006, p. 113) For this analysis, theoretical sampling involved two additional forms of content. First, when initial analysis of the NGM articles showed there were significant changes in coding patterns across time e.g., emergence of dominant new codes such as sea-level rise, questions about the origin of these changes were addressed by adding relevant NGM editorial and opinion pieces to the data to be analysed. Secondly,

Figure 1

Glasserian Grounded Theory Method

Process model adapted from (Urquhart, 2013) and (Glasson, 2004).



the inclusion of codes suggested by relevant literature was used to integrate analysis of NGM articles with existing knowledge.

3.3 Data Selection and Collection

The project analysed the National Geographic Magazine's representation of glacial ice between 1978 and 2018 in the context of climate change. The online repository of National Geographic Magazine (National Geographic, 2019b) provides access to all magazine content for the required years and a keyword based search mechanism for text and images.

3.3.1 Article Selection

The mandatory selection criteria for article inclusion were

- articles published after December 1977 and before January 2019;

- articles classified by NGM's textual keyword search as being related to ((“GLACIER” OR "ICE SHELF" OR "ICE SHEET") and “CLIMATE”) or (“GLOBAL WARMING” OR “CLIMATE CHANGE”);
- articles found using NGM's image keyword search as related to (“GLACIER” or “ICE”);
- containing one or more paragraphs discussing the impact of climate change on glacial ice (identified by researcher review and recorded for analysis);

All the keyword selected articles were reviewed and only those (approximately two-thirds) containing one or more paragraphs discussing the relationship between climate change and glacial ice were retained for further analysis. The majority of other coverage within the period focused on wildlife conservation, and recreational activities. Synonyms for climate change such as “global warming” were allowed in the manual review. These articles formed the initial basis of the study.

3.3.2 Editorial and Opinion Piece Selection

Editorials, and opinion pieces discussing climate change (with or without specific mention of glacial ice) between 1978 and 2018 were included as part of the theoretical sampling to support analysis of NGM's editorial position on climate change.

3.3.3 Article Details

26 feature and short articles were selected, together with seven editorial or opinion pieces. The selected articles are described in Tables 1, 2 and 3.

3.4 Data Management

The NGM portal (National Geographic, 2019b) was used to convert the selected articles to electronic files which were then printed for review. The article text was converted to text files using an Optical Character Recognition (OCR) utility and edited by the researcher where the OCR process had not produced well-formed text. Photographic images were reviewed using the paper copies without reference to surrounding text and written descriptions produced as text files. The image descriptions focused on subject matter, composition, the presence of humans or animals and any open questions or emotional

Table 1

NGM Content for Analysis: 1978 to 2003

Year of publication, title of article, reference and unique article id

Year	Title	Reference	Id
1985	Kluane: Canada's Icy Wilderness Park	Lee and Mobley, 1985	17
1987	Ice on the World	Matthews, 1987	20
1990	Antarctica: A Land of Isolation No More	Hodgson, 1990	15
1992	Tales of Climate Change Held Deep in the Ice	NGM, 1992	23
1998	From the Editor	Allen, 1998	6
1998	Unlocking the Climate Puzzle	Suplee and Pinneo, 1998	1
2001	Rising Tide of Concern	NGM, 2001	22
2001	Frozen Under	Stenzel and Smith, 2001	24
2003	Alaska's Giant of Ice and Stone	Lanting and J.G., 2003	4

reactions felt by the researcher when considering the image. The image captions were copied to text files from the OCR'ed text.

The software tool NVivo (QSR International, 2018) was used to store the text of the articles, captions, and the written description of the images prior to coding. Codes (known as Nodes in NVivo) were assigned to text within the files and analysed in Nvivo Excel (Microsoft, 2019) was used for time-series analysis of codes and to summarise results.

3.5 Coding Processes

3.5.1 Development of Initial Codes

Within GTM, coding is defined as "... attaching conceptual labels to data" (Urquhart, 2013, p. 35). The printed versions of the articles were reviewed (in random order) and annotated to identify ideas and subjects that frequently recurred. These constructs formed a list of tentative initial codes. Review of background literature suggested a further set of potential codes for text e.g., descriptions of a glacier as threatened or as a resource (Carey, 2007) and images e.g., descriptions of composition (Rose, 2016). These codes allowed the inclusion of pre-existing theories within the coding analysis. Examples of the

Table 2

NGM Content for Analysis: 2004 to 2014

Year of publication, title of article, reference and unique article id

Year	Title	Reference	Id
2004	GeoSigns: The Big Thaw	Glick and Essick, 2004	5
2004	Signs From Earth: Heating Up...Melting Down	Appenzeller et al., 2004	10
2004	TimeSigns: Now What?	Essick and Morell, 2004	14
2004	From the Editor	Allen, 2004	30
2006	Meltdown: The Alps Under Pressure	Olsen et al., 2006	28
2007	Glacier-Waterton: Crown of the Continent	Chadwick and Melford, 2007	27
2007	Cover Page Title: The Big Thaw	NGM, 2007	29
2007	The Big Thaw	Balog and Appenzeller, 2007	33
2008	Guts of a Glacier	Carroll, 2008	31
2009	South Georgia: Resurrection Island	Nicklen and Brower, 2009	19
2010	The Big Melt	Larmer and Bendiksen, 2010	2
2010	The Changing Face of Greenland	Jenkins and Balog, 2010	16
2010	The Power of Patagonia	Klinkenborg and M., 2010	18
2012	Antartica Undercut	Walters and Grob, 2012	13
2013	Prove: Glacial Meltdown	Kunzig and Balog, 2013	11
2013	Exploration: Risk Takers	Walters and Grob, 2013	12
2013	Rising Seas	Folger and Steinmetz, 2013	21

Table 3

NGM Content for Analysis: 2015 to 2018

Year of publication, title of article, reference and unique article id

Year	Title	Reference	Id
2015	From The Editor: Of Coverage and Covers	Goldberg, 2015	7
2015	Climate Change is Here	NGM, 2015	25
2016	From the Editor: Our Changing Role in Parks	Goldberg, 2016	8
2017	The Crisis on the Ice	Fox and Seaman, 2017	9
2017	7 Things You Need to Know: Climate Change	NGM, 2017	32
2018	A Crack in the World	Welch et al., 2018	26
2018	Climate Change: The More things Change	Revkin, 2018	3

initial codes are shown in Table 4.

Table 4

Examples of initial open codes

changing glacier	sea-level	threatened	green-house gases
static glacier	flooding	caption	time-lapse
consensus	struggle	ice-core	ice-sheet
theory	conflict: intra-science	rate of change	infographic
model	conflict: political	historical	agriculture

At this stage in the project, the tentative codes and initial analysis results were reviewed with the project supervisor to provide a check on the coding approach.

3.5.2 GTM Coding: Open, Selective and Theoretical Codes

The version of GTM described by Urquhart (2013) uses three coding stages to support the inductive construction of a theory. Open Coding is the process of assigning codes to data, item by item in an iterative and reflective process, analysing the data as opposed to describing it. The list of tentative codes (including those derived from existing literature) was used as the starting point for open coding of the separate files containing the text and captions in each article. The written description of the

image (developed as described above) was then coded (using guidelines for the open coding of textual image descriptions from (Konecki, 2011)), to identify concepts expressed by the images. Examples of the development of open codes are shown in Table 5. To explore the connection between concepts

Table 5

Examples of open coding from text

Text source	Assigned open code(s)
researchers use poles to find crevices on ice sheet	risky activity
such a rise today would swamp coastal cities	threat, sea-level rise
freezer holds an ice core from Perus' Quelccaya ice cap	ice core, resource
must have melted in a few hundred years	rapid change
no more glaciers in Glacier National Park	resource, wilderness
if recent changes caused by humans.	doubt, human influence

expressed by the images and their associated captions the written description of the images and the associated caption text were integrated into "image-caption-cluster" (ICC) textual files. Key points of difference were noted and open coding of the ICC file was then undertaken.

In Selective Coding the open codes were organised into core categories (clusters of open codes which express a more abstract "concept") of the theory. The initial stages of selective coding generated a large number of potential codes. In order to focus on the "core" categories relevant to the theory building those codes describing similar concepts or processes were combined, and then named for the abstracted process they represented as suggested in (Bazeley, 2013, Ch. 8). Ideas about potential categories for the codes were documented in written memos and illustrative examples of selective codes and their associated open codes are shown in Table 6. Figure 2 shows how a number of selective codes originated during analysis stages of the study.

Theoretical Coding (also known as "finding relationships between categories") developed semantic relationships between the selective codes. The approach taken to develop the theoretical codes was iterative. Each of the selective codes were grouped by possible connections and a set of potential theoretical codes based on recommendations from (Spradley, 1979, p. 111) (presented in Table 7) and (Urquhart, 2013, p. 109-110) were used as a checklist to prompt and refine the analysis.

The relationships between the categories were abstracted to become theoretical codes. Once the relationship definitions stabilised after a number of iterations, a graphical representation was produced

Table 6

Examples of selective codes

Selective code	Open codes contributing to the selective code
scientific resource	ice core, satellite, time-lapse photo history
societal impact	sea-level rise, flood, heat wave, drought
balance	many say, other side, caveat, inter-scientist debate
multi-modal alignment	image-caption alignment, image-caption-text alignment

Table 7

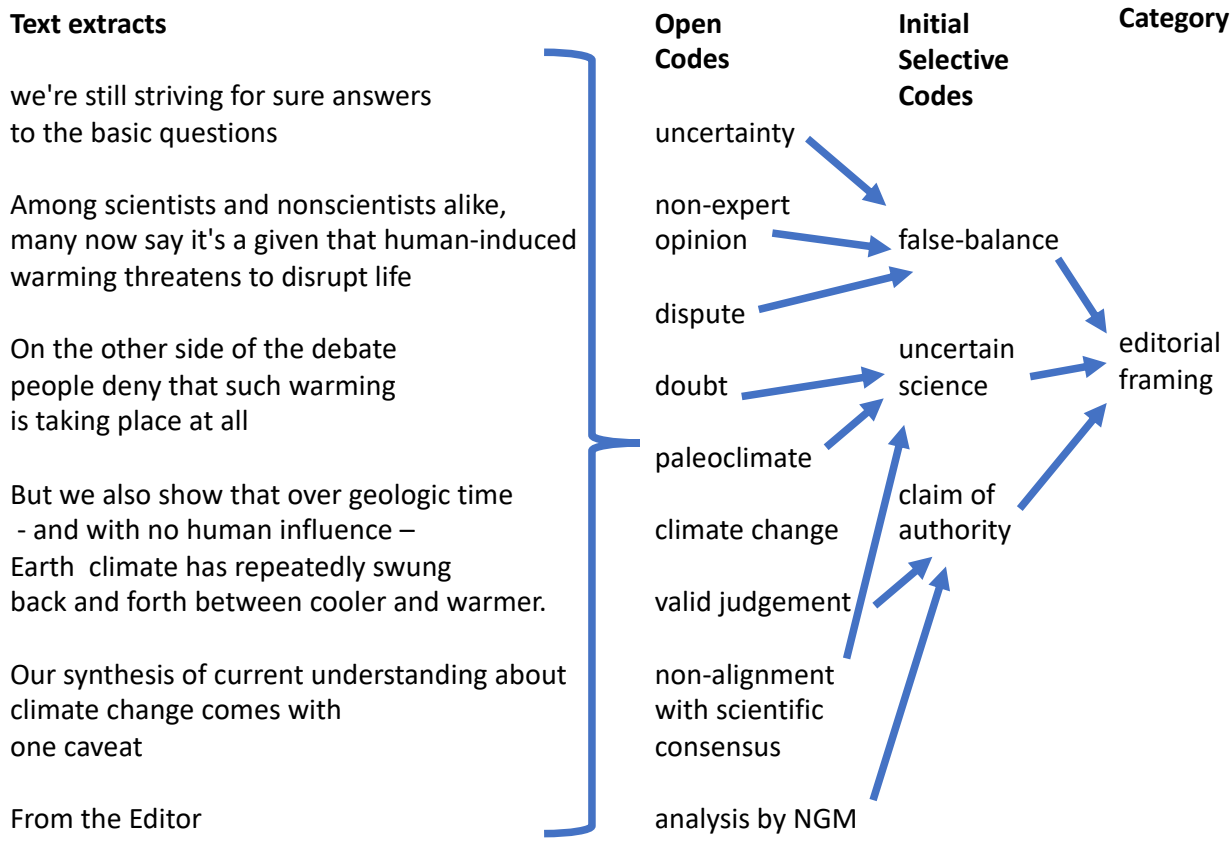
Symantic relationships

Relationship analysis approach adapted from (Spradley, 1979, p. 111)

Type of relationship	Meaning
Inclusion	X is a kind of Y
Spatial	X is a place in Y, X is a part of Y
Cause-effect	X is a cause of Y
Rationale	X is a reason for doing Y
Location for action	X is a place for doing Y
Function	X is used for Y
Means-end	X is a way to do Y
Sequence	X is a stage in Y
Attribution	X is an attribute of Y

Figure 2

Example showing development of selective codes from NGM articles.



to summarise the analysis.

Themes, defined as "... cognitive principles , tacit or explicit, recurrent in a number of categories and serving as a relationship among subsystems of meaning" (Spradley, 1979, p. 115) were then identified by iterative review of coding patterns and the articles themselves while developing potential relationships between the categories. Themes formed links between external theories and the categories and selective codes emerging from analysis of the NGM content and became a key input into the process of theory building.

3.5.3 Theoretical Integration

In parallel with coding of the NGM data, background literature was reviewed to identify potential external theories which would be related to the emerging theory. Notes on relevant theories were summarised in text files, and then categories and themes were identified by review. An example of the

analytic notes developed using this approach is Appendix B's analysis of the history of climate science. The selected theoretical categories and source literature is presented in Table 8.

Table 8

Literature used for theoretical categories

External Theoretical Category	Reference(s)
Criteria for effective engagement	(Manzo, 2010)
Journalistic Norms: balance	(Boykoff, 2007)
Journalistic Norms: interpretative journalism	(Bruggemann and Engesser, 2017)
Climate Science	(Weart, 2019), (Mason, 2013)
Limitations of photographic images	(Messaris, 1996; Messaris, 1994)
Framing	(Entman, 1993)

3.6 Process of Theory Development

Through an iterative process of combining and abstracting identified themes into possible causal relationships between categories, and then seeking evidence supporting those relationships within the analysis results of NGM content and external theories, a grounded theory capable of explaining the analysis results was developed.

3.7 Relating Theory to Wider Literature

The emerging theory was compared to other theories and observations in the literature described in the background section and covering the topics of: visual methods (Rose, 2016), multi-modal framing (Geise and Baden, 2015; Wozniak, Lack, and Wessler, 2015), quantity of coverage (Mazur, 2009), public arenas (Ungar, 2014), evolution of environmental photo-journalism practice (Ward, 2008; Gervais, 2016); the time-line of climate science and politics (Mason, 2013; Weart, 2019) and (Black, 2018); cultural representation of glaciers (Carey, 2007). Literature used to provide insight into the editorial practices of NGM included (Allner, 2000; Beaudreau, 2002; Pflaeging, 2017). The social system within NGM is described in (Souza, 1998; Darling-Wolf and Mendelson, 2008; Wheelersburg, 2017).

3.8 Data and Analysis Validity

3.8.1 Data Selection

The process of article selection was reliant on the search mechanism provided by the NGM portal. Use of other search engines with access to online versions of NGM content did not find other NGM articles meeting the criteria that they contained a paragraph about glacial ice and climate change. The number of articles (26), editorial material (7) and images analysed (165) are larger than those used in other published papers about the representation of environmental issues by NGM e.g., (Born, 2018).

3.8.2 Quality Control

Qualitative analysis involves subjective aspects (Madill, Jordan, and Shirley, 2000) especially as visual analysis of environmental communication involves a complex set of of perspectives and potential interpretations (Hansen and Machin, 2013). To address possible subjective influences on the researcher this study checked that choices made during analysis were not purely subjective and could be generalised through:

- development of an initial coding scheme reflecting researcher's initial knowledge;
- reviewing results from coding of the images from the articles with an independent reviewer to minimise subjective influences;
- presentation and discussion of preliminary results with project supervisor and peer-group as part of the project evaluation process;
- systematic use of journaling and self-reflexivity (Bolton, 2014) to identify biases introduced by the researcher as recommended in (Glasson, 2004).

The independent review of results from image coding identified significantly different coding results between researcher and checker for two important selective codes. This ambiguity was addressed through discussion and amalgamating the concepts into one code.

3.8.3 Reflection on Coding

Svobodova et al. (2104) illustrates the difficulty of developing methods for compositional analysis of landscape images such as those found within NGM. Open coding within GTM aims to provide an initial analytic coding and many of the codes related to the possible purpose(s) of the images, and questions raised about possible meanings rather than compositional features. A sample written description and the associated open codes developed when describing an image were: "Visually arresting aerial image of swirling striations in glaciers as it snakes back towards sunlit white sharp mountain peaks. Multiple glaciers meeting." The open codes applied here were: glacier, visual, attention-grabbing, sublime-wilderness. The adopted approach provided an opportunity to integrate codes based on prior-knowledge (e.g., time-lapse) with those established though the process of "bottom-up" coding from the image descriptions. In contrast to coding of images, analysis of the article and caption text used fewer codes derived from prior-knowledge. The combined approach allowed for the development of rich insights into the material.

4 Results

4.1 Core Categories and Selective Codes

The inductive examination of the NGM articles developed a number of core categories relevant to the representation of glacial ice. A typology of the categories and the selective codes making up those categories is shown in Figure 3. Examples and commentary on how the core categories and codes relate to material from the NGM articles is provided in Appendix A.

4.1.1 Representations of Glacial Ice

The identified selective codes representing glacial ice were:

- **as threatened by global warming** became the dominant representation of glacial ice post-2003;
- **as driving sea-level rise** was the dominant description of the impact of melting glaciers;
- **as a source of ice-cores** reflected the scientific importance of the historical studies of climate provided by the cores;
- **as a water source for agriculture** was used in a limited number of articles;
- **as an economic resource** used in later articles to describe the impact of disappearing non-polar glacial ice;
- **as wilderness** was the dominant description pre-2004, associated with aesthetic imagery and adventure narratives;
- **as research-site**, used when discussing research not involving ice-cores, represented the danger and effort of scientific research as well as linking to wilderness descriptions.

The dominant representations within the feature articles are presented in Tables 9 and 10.

Figure 3

Core Categories and Selective Codes: across all articles, 1978 to 2014

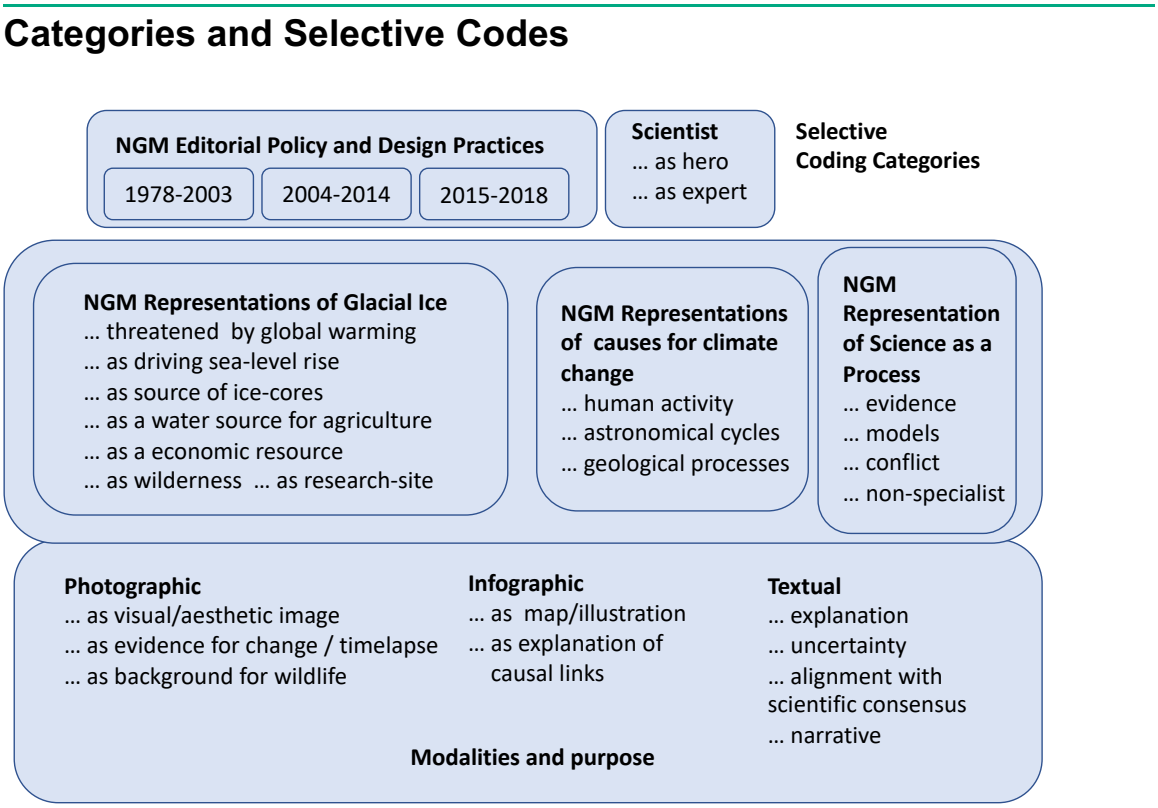


Table 9

Dominant representations per article: 1978 to 2013

Article Year	Id	Representation(s)
1985	17	as wilderness, as source of ice core
1987	20	as source of ice core
1990	15	as wilderness, as source of ice core
1992	23	as source of ice core
1998	1	as source of ice core
2001	24	as wilderness, as research site
2001	22	as driving sea-level rise
2003	4	as wilderness
2004	5	as threatened, as driving sea-level rise
2004	14	as threatened, as driving sea-level rise
2004	10	as threatened, as driving sea-level rise
2007	27	as wilderness, as threatened,
2007	33	as threatened, as driving sea-level rise
2010	18	as threatened, source of flooding
2010	2	as threatened, as water source for agriculture
2010	16	as threatened
2012	13	as threatened, as driving sea-level rise
2013	11	as driving sea-level rise
2013	12	as threatened, as source of ice core
2013	21	as threatened

Table 10

Dominant representations per article: 2015 to 2018

Article Year	Id	Representation(s)
2015	7	as threatened
2015	25	as threatened
2017	9	as threatened, as driving sea-level rise
2017	32	as threatened, as driving sea-level rise
2018	3	as threatened, as economic resource
2018	28	as threatened,

4.1.2 Modalities - Photographic Images

Coding of photographic images showed the dominant visual representations of glacial ice as being: visual/aesthetic; as evidence for change e.g. collapsing ice or time-lapse; and as background for wildlife.

as visual/aesthetic NGM's history shows its extensive use of aesthetically pleasing and dramatic imagery in its coverage of many environmental issues (Lutz and Collins, 1993; Hawkins, 2010; Whitley and Kalof, 2014). The imagery is used to support a framing of glacial ice as "sublime wilderness" and forms a significant part of the coverage pre-2004. Later articles shift to using visually striking images to engage the reader.

as evidence for change From 2004, photographs in the form of timelapse images were consistently used as evidence for change. The timelapse images and their content is described in Table 11. NGM's use of images as evidence is supported by extracts from articles such as:

> "A photograph is powerful proof. It's indisputable evidence." - Brian Skerry (Kunzig and Balog, 2013, p. 65)

> "We know the climate is changing, but wrapping our minds around that fact can be difficult. The Extreme Ice Survey makes the changes tangible. Through nearly a million time-lapse photographs, we now have indisputable, gut-wrenching proof that ancient glaciers are disappearing." - James Balog (Kunzig and Balog, 2013, p. 68)

background for wildlife Glacial ice was used as a background for wildlife images in a number of articles across the whole time-period.

Table 11

NGM Use of timelapse images

Year	Id	Number of Time-lapse	Purpose(s)
1987	20	1	to show glacier change
1998	15	1	to show glacier change
1998	1	1	to show glacier change
2004	5	1	to show ice-shelf collapse
2007	33	3	to show glacier loss
2010	2	1	to show glacier loss
2010	16	1	to show ice-sheet melting
2013	11	1	to show glacier retreat
2017	9	1	to show ice sheet melting
2017	32	1	to show ice-sheet collapse

4.1.3 Modalities - Infographics

Selective codes for infographic representation distinguished between usage as map/illustration; or as explanation of causal links. NGM's use of infographics and their purpose is described in Table 12.

4.1.4 Modalities - Text

In the text outside captions, glacial ice references were coded as: explanation, uncertainty, alignment with scientific consensus; narrative. All the articles up to 2003 expressed significant levels of uncertainty about the process and results from climate science. The lack of clarity often made the text harder to understand and impacted on possible motivation for action. Text in the articles was mainly used to provide background and descriptions. The narrative elements of the article text are described using theoretical codes adapted from (Wozniak, Lack, and Wessler, 2015), and described in Tables 13 and 14. The analysis suggests a change in tone about climate change after 2003, moving away from a neutral point of view. A limited range of narrative types were employed to bring drama to the articles.

Table 12

NGM Use of Infographics

Year	Id	Number of Infographics	Purpose(s)
1987	20	2	history of Antarctic icecap
1990	15	2	map of Antartica, ice core history
1998	1	2	ice structure, ice core history
2001	22	2	impact of sea-level rise
2003	4	1	map of national park
2004	14	1	CO_2 concentration over time, ice cycles
2007	33	2	extent of global ice loss, mechanism of ice loss
2008	31	1	map
2010	2	1	map of Tibetan glaciers
2010	16	2	explanation of ice sheet meting
2017	9	1	explanation of Antarctic ice sheet melting
2018	26	2	explanation of warming causes and impact

4.2 Codes and Inter-Category Relationships

The important selective codes and their relationships changed over the analysis period as shown in Figure 5 for 1978 to 2003, Figure 5 for 2004 to 2014 and Figure 6 for 2015-2018.

Between 1978 and 2003 the dominant representations of glacial ice was as wilderness, research-site and as a source of ice-cores which are positioned as providing evidence for past changes in climate. There is an emphasis of the visual aesthetics of the images used mainly as illustration. The role of the astronomical and geological processes dominated discussion of the causes for climate change, with coverage often focused on conflicts within the scientific community.

2004 marked a significant change as shown in Figure 5 with new codes and relationships. NGM focused the representation of glacial ice as being threatened by climate change with the introduction of human causes and the impact of rising of sea levels. The scientists who undertook the often heroic expeditions to collect ice-cores featured heavily in interviews and discussion of their work. Article text, while based on consensus views of the science, presented significant uncertainties on the speed and extent of impact of sea-level rise. Photographs were used as "proof" for change rather than simply

Table 13

Coding for relevant narrative elements 1987 - 2014

Coding of feature articles related to climate change 1987 to 2014

Year	Id	Tone	Narrative Genre(s)
1985	17	neutral	triumph over adversity
1987	20	neutral	science conflict
1990	15	neutral	triumph in difficult research
1992	23	neutral	triumph in difficult research
1998	6	neutral	science conflict
1998	1	neutral	science conflict
2001	22	pessimistic	struggle over destiny
2001	24	neutral	triumph over difficult research
2003	4	neutral	science conflict
2004	5	neutral	struggle over destiny
2004	10	pessimistic	struggle over destiny
2004	14	pessimistic	political conflict
2004	30	pessimistic	political conflict
2007	27	neutral	political alignment
2008	31	pessimistic	triumph in difficult research
2009	19	pessimistic	nature returns after exploitation
2010	2	pessimistic	political conflict, inter-science conflict
2010	16	pessimistic	struggle over destiny
2010	18	neutral	political conflict
2012	13	pessimistic	struggle over destiny
2012	11	pessimistic	struggle over destiny
2012	12	pessimistic	triumph over difficult research
2013	21	pessimistic	struggle over destiny

Table 14

Coding for relevant narrative elements 2015 - 2018

Coding in feature articles related to climate change 2015 to 2018

Year	Id	Tone	Narrative Genre(s)
2015	7	pessimistic	struggle over destiny
2016	8	pessimistic	struggle over destiny
2017	9	pessimistic	triumph over difficult research
2017	32	pessimistic	struggle over destiny
2018	3	pessimistic	historical conflicts, science, politics
2018	26	pessimistic	unclear
2018	28	pessimistic	struggle over destiny

visually attractive images. Infographics presenting causal arguments began to appear.

From 2015, Figure 6 shows scientists became an authority figure as NGM aligned with the science. Aesthetic images were used to attract attention to articles, but the causal arguments were made using infographics, with the narrative used for explanations and to introduce narrative elements focused on the activity of scientists and to describe the risks and uncertainties of the impacts of climate change. Scientists were presented as experts with minimal debate about climate science.

Figure 4

Core Categories and Relationships 1978 - 2003

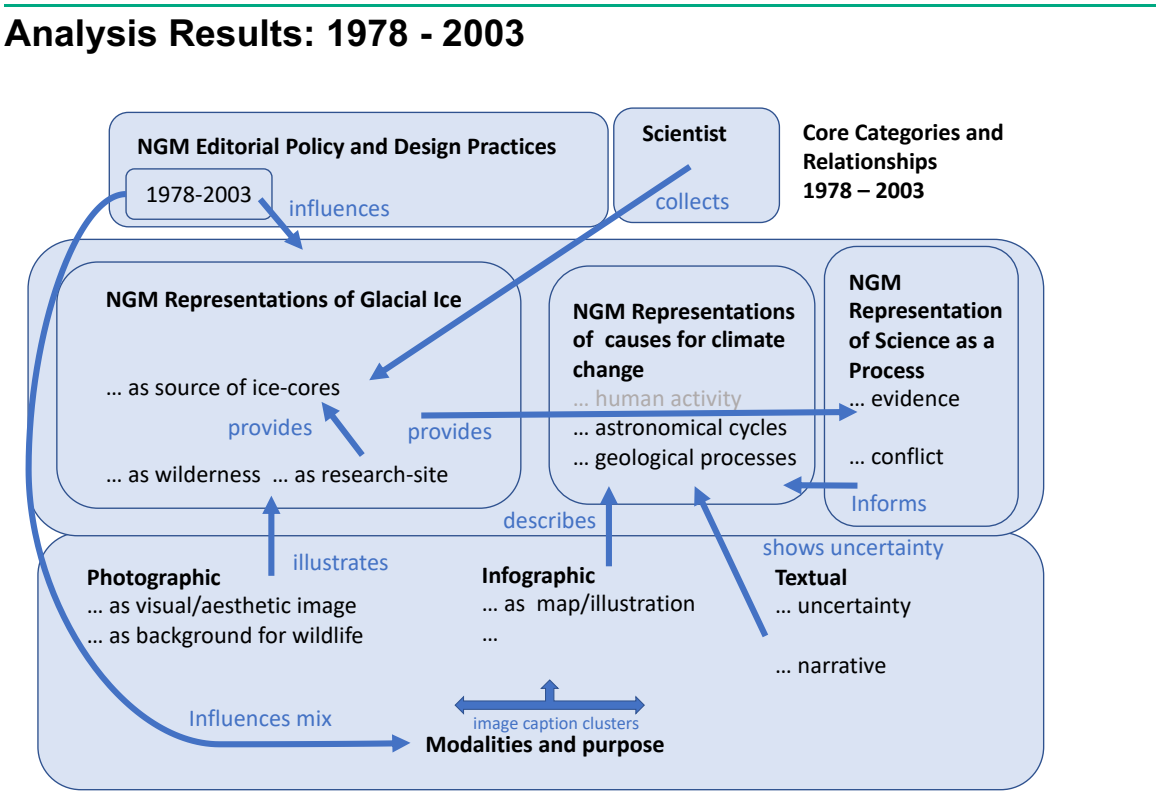


Figure 5

Core Categories and Relationships 2004 - 2014

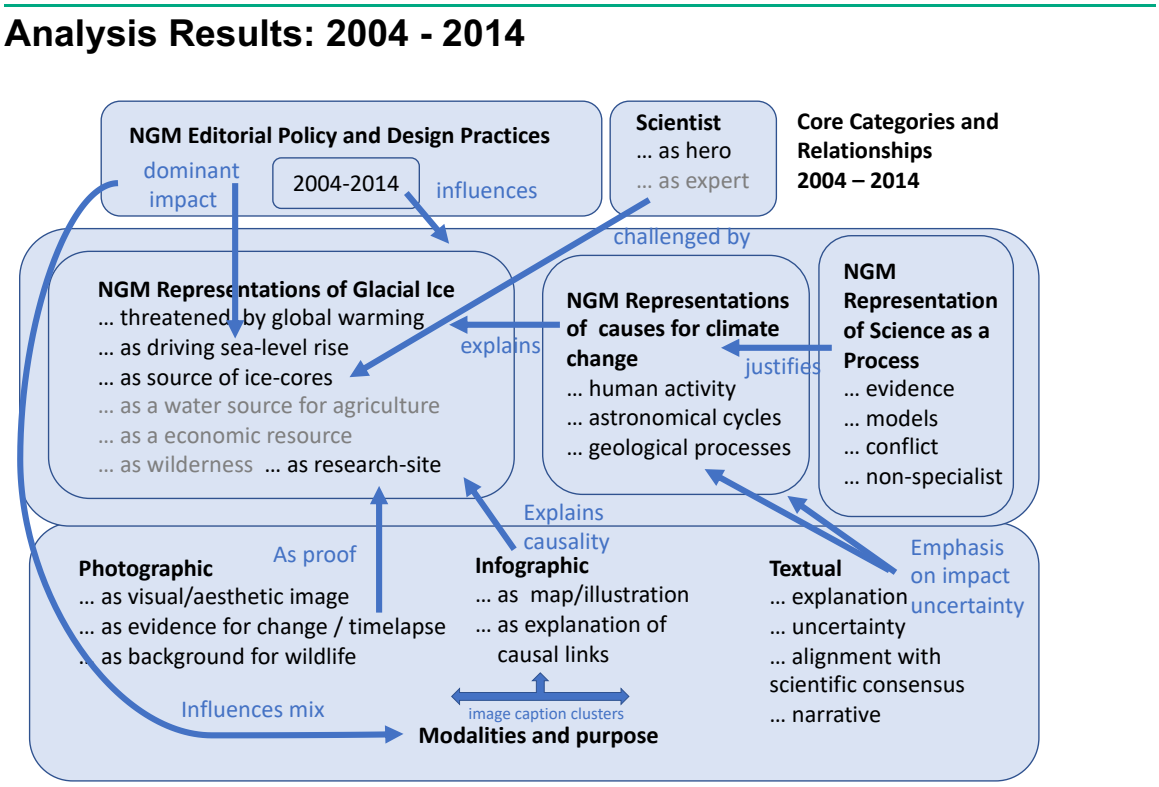
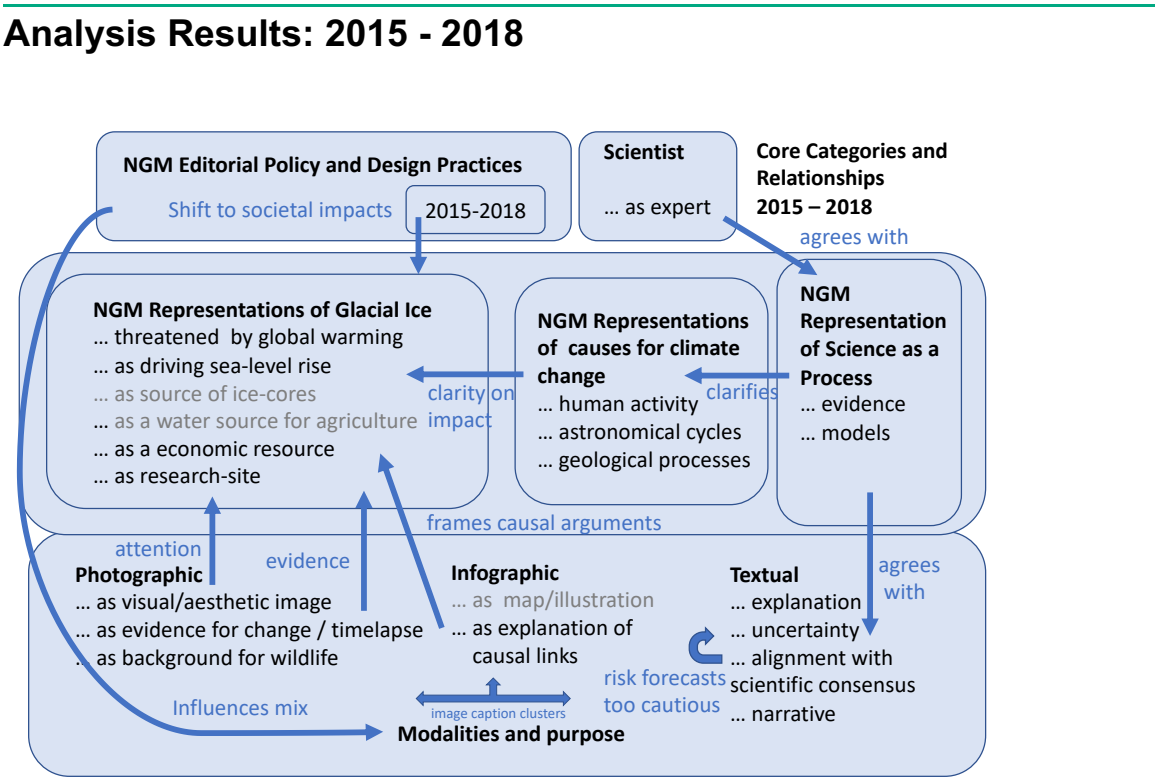


Figure 6

Core Categories and Relationships 2015 - 2018



4.3 Categories and relationships with external theories

Figure 7 shows categories developed from theories found in the literature (Table 8) and the associated themes linking categories developed from NGM's representations to important ideas from the external theories.

Entman's media frames, described in Entman (1993), are present but expressed across multiple modes via the combined effect of text, images, captions and infographics.

NGM representations only partially support the three criteria for audience engagement described by Manzo (2010): knowledge, importance and motivation to act. NGM's choice of both imagery, infographic and text elements addresses the need for knowledge, the focus on sea-level rise as impact demonstrates the potential importance of the issue. However the language used, lack of clarity on timescales and the limited discussion of suggested actions suggests the glacial-ice articles were relatively weak on the third criteria.

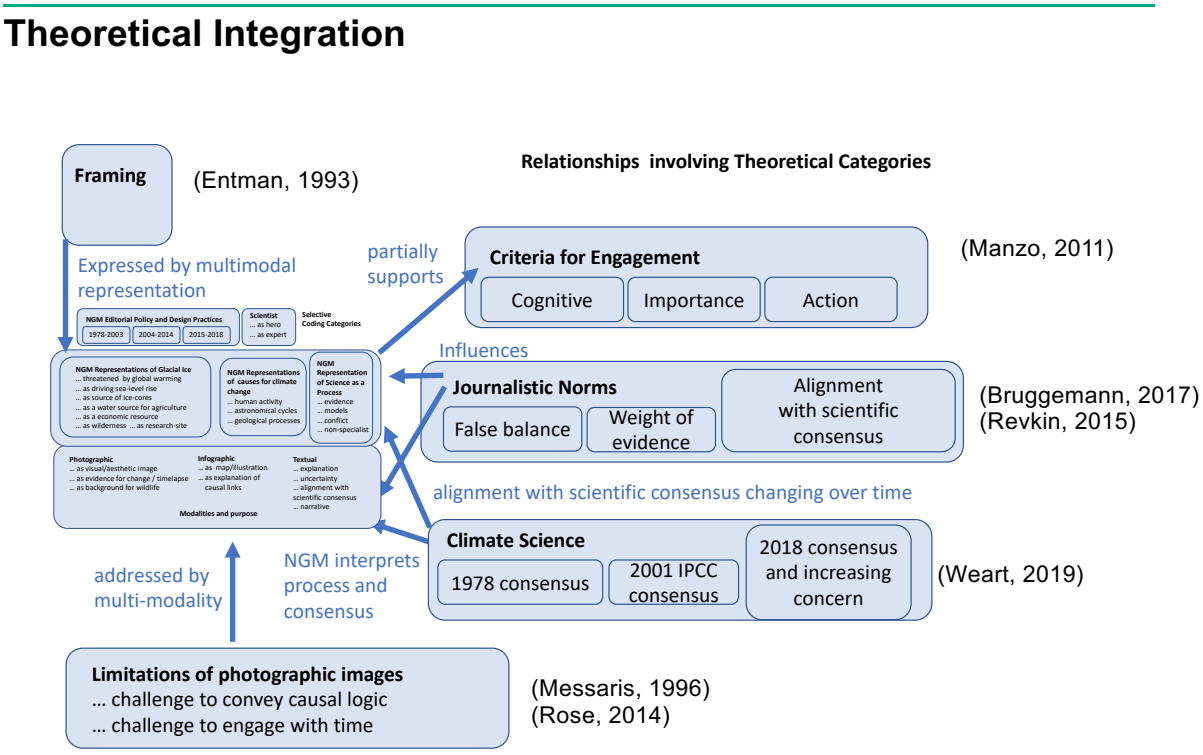
The identified studies of journalistic norms associated with environmental reporting give context to changes in NGM's approach. The early misalignment with scientific consensus and a late transition to weight of evidence reporting are important categories to consider when evaluating NGM's editorial policies.

The process and consensus of climate science from 1978 to 2018 is described in Appendix B. NGM's interpretation of that science established editorial policies and the preferred representations clearly changed over time. The important role of ice-cores in the analysis of paleoclimatology was reflected in NGM's coverage but the content and editorial positioning indicated that, at least until 2003, NGM reserved a right to present its own synthesis of climate science rather than rely on the output of bodies such as the IPCC.

The field of visual studies has explored limitations of photographic images (Messaris, 1994; Messaris, 1996; Rose, 2016), especially how images struggle to convey causal logic or to show change over long time scales. NGM addressed these limitations though adoption of other modes i.e., using image-caption combinations and infographics. Appendix C presents further theoretical background on how multi-modality effects potential levels of engagement.

Figure 7

Categories and relationships with external theories



4.4 Answering RQ1: Representation of Glacial Ice

Research Question 1 asked how has glacial ice been represented within NGM's climate-change coverage between 1978 and 2018? The changes of representations and relationships across modes are shown in Figures 4, 5, 6. In summary, NGM's dominant representation shifted from glacial-ice as wilderness to glacial-ice being threatened by climate change and as the source of sea-level rise from 2004. Since then, it has maintained that argument, and further strengthened its alignment with scientific consensus on the relationship between warming and human-generated greenhouse gases.

4.5 Answering RQ2: Framing within articles

Research Question 2 asked how has the framing (of articles and images) and narratives varied over time? In summary, the frames used to summarise the articles match the multi-modal representations discussed above. Using the approach from (Entman, 1993) to frame issues at the level of the complete article gives results shown in Tables 15 and 16. The problems and causes are described in Tables 17 and 18, and are consistent with those derived from the coding analysis.

Consistent with their limitations (Messaris, 1994), images were difficult to analyse using the framing approach described above. Instead, analysis of the types of image most often found in each article is shown in Tables 19 and 20. Changes over time suggest that images became a more specialised form of communication, with a focus on evidence for change, while maintaining a role in presenting visually pleasing images.

4.6 Answering RQ3: Subject and Composition of Visual Imagery

Research Question 3 asked how the subject and composition of the visual imagery of glacial ice changed over time? The subject matter of images were most commonly coded as in Figure 8.

The prevalence and purpose of time-lapse and infographic images are described in Table 11 and 12. Image analysis using "compositional interpretation" (Rose, 2016, Ch. 4) (e.g, perspective, colour, spatial organisation) gave inconclusive results.

Table 15

Article Framing Analysis: Issues 1987 to 2014

Year	Id	Frame Issue
1985	17	wilderness preservation
1987	20	impact of ice on world
1990	15	Antartica no longer isolated
1992	23	search for historical evidence for CO_2 warming
1998	6	human contribution
1998	1	climate as puzzle
2001	22	rising sea levels
2001	24	Antartic wilderness as research site for climate
2003	4	wildlife in Northern climes
2004	5	thawing of ice
2004	10	Warning signs from a warming Earth
2004	14	Future path of global warming
2004	30	truth of impact of human caused warming
2006	28	ice loss in Alps
2007	27	impact on environment of climate change
2008	31	"The Big Thaw"
2009	19	glacier melt and sea-level rise
2010	2	wildlife threatened by climate change
2010	16	glacier loss in Asia
2010	18	changing Greenland as ice melts
2012	13	wilderness preservation
2012	11	undercutting of Antartic ice
2012	12	proof of glacial melting
2013	21	ice collection for science

Table 16

Article Framing Analysis: Issues 2015 to 2018

Year	Id	Frame Issue
2015	7	rising sea levels
2015	25	reality of climate change
2016	8	loss of glaciers in US National Parks
2017	9	"Crisis of Antarctic Ice Loss"
2017	32	warming world
2018	3	History of climate change
2018	26	Antarctica changing in single generation

Figure 8

Photographic images: coding occurrence by image subject

Year	Id	changing-glacier	static-glacier	iceberg	icesheet/shelf	ice core	research-site	scientist	citizen	plant/animal
1985	17	2			1	1	1	4	1	1
1987	20	2	2	1	1			1		
1990	15	1	1	1		1	3	3		2
1992	23					1		1		
1998	1	2								
1998	30				1					1
2001	24			1	2					2
2003	4	3	4							
2004	5		2							
2004	10		1							
2004	14					1				
2007	29	1								
2007	33	6			1					
2008	31							1		
2009	19			3						3
2010	2	2								
2010	16	4						1		
2010	18		2							
2012	13	1								
2013	21	2		1						
2013	11	2	2							
2013	12							1		
2015	25	1								
2017	32	1			1					
2017	9	5		4						
2018	26		2	3						2
2018	28	1							1	

Table 17

Article Framing Analysis Problem and Cause 1987 to 2013

Year	Id	Frame Problem	Frame Cause: who/what
1985	17	dangers to visitors	no blame on human pollution
1987	20	uncertainty on climate science	unclear
1990	15	now connected, impacts from rest of world	human pollution
1992	23	possible impact of greenhouse gases	connection to greenhouse gases
1998	6	science conflict	political - science debates
1998	1	"unlocking the climate puzzle"	uncertain
2001	22	societal risks from sea-level rise	warming from pollutants
2001	24	changing climate in alarming ways	unclear
2001	4	not covered	not covered
2003	5	climate changes and ice retreating	human produced CO_2
2004	10	warming of the Earth	human produced CO_2, political delays
2004	14	scientific forecasts alarming	human produced CO_2
2004	30	impact of warming environment	human causes
2006	28	damage limitation	unclear
2007	27	climate change impacts on environment	human causes
2007	29	ice thawing, sea-level rise	unclear
2008	31	lack of clarity on how glaciers melt	unclear
2009	19	wildlife dependency on krill	global warming, no cause
2010	2	human impact of loss of Asian glaciers	warming accepted, debate on cause
2010	16	faster melting of ice-sheets	warming of ice sheet, no blame
2010	18	changes threaten wilderness	commercial exploitation
2012	13	warmer water meting Antarctica from below	no attribution
2012	11	fast changes	human causes
2012	12	need to access ice cores before gone	people not acting
2013	21	societal risks	warming - lack of planning

Table 18

Article Framing Analysis Problem and Cause 2015 to 2018

Year	Id	Frame Problem	Frame Cause: who/what
2015	7	need for another future	unclear
2016	8	powering planet without worsening situation	human implied
2017	9	impacts of climate change	unclear
2017	32	extreme weather, wildlife impact	human caused warming
2018	3	delayed response	multiple human culprits
2018	26	changing Antarctic ecosystem	human fossil fuel use

4.7 Answering RQ4: Representation across modes

Research Question 4 asked whether the representations of glacial ice are consistent within articles across the different modes? The coding of text files combining a description of the image with the NGM captions showed no evidence of conflict between images and captions - rather a varying degree of description and context setting. The text based framing of articles was often supported by the meaning derived from image-captions and infographics especially after 2003. Conflict between modes was avoided, even when the meanings from different modes were not strongly related (as often seen before 1998). Unlike conflicts seen in NGM articles discussing cultural topics (Mendelson and Darling-Wolf, 2009), the sampled articles avoided conflicting meanings across modalities, rather becoming more coherent across the modes from 2003 onwards.

Table 19

Coding instances per dominant image type, 1987 to 2014

Year	Id	aesthetic	as evidence for change	backdrop for wildlife
1985	17	4		
1987	20	5	2	
1990	15	8	1	1
1992	23			
1998	30			1
1998	1	1	2	
2001	24	2	6	
2003	4	7		
2004	5	4	2	
2004	10		1	
2004	14	1	1	
2004	30	4	2	
2007	29	1	0	
2007	33	2	6	
2008	31	1		
2009	19			3
2010	2		2	
2010	16	4	2	
2010	18	4		
2013	21	1	2	
2013	11	1	2	
2012	12			

Table 20

Coding instances per dominant image type, 2015 to 2018

Year	Id	aesthetic	as evidence for change	backdrop for wildlife
2015	25	2		
2017	32		2	
2018	26	3		2

5 Discussion

5.1 Results Summary and Comparison with Previous Research

Glacial ice was used as a metaphor for the impact of climate change and featured in over half of NGM's climate coverage between 1978 and 2018. The representation of glacial ice within NGM's coverage of climate change showed three distinct phases: 1978 to 2003, 2004 to 2014, and 2015 to 2018. NGM's editorial position changed significantly in 2004, and to a lesser extent in 2015, as the magazine shifted towards closer alignment with climate science, and avoided false-balance reporting. The representations across multiple modes emphasised that glacial ice was threatened by human-generated greenhouse gases and its melting would lead to significant sea-level rise and (with lesser levels of coverage) other significant societal impacts. The magazine increasingly used photographic images (e.g., in time-series) as evidence for change and introduced increasingly complex infographics to present detailed causal arguments about changes to ice and climate.

NGM was, until 2004, presenting the issue of global warming in a way that did not match the scientific consensus of the time about human causes of global warming. This result extends analysis by Peterson, Connolley, and Fleck (2008) which showed NGM's coverage of the impact of climate change in the 1970's was subject to misleading levels of "false balance" about global warming. The analysis findings are consistent with results from Born (2018) where analysis of NGM's representation of polar bears between 1998 to 2012 identified a significant shift in NGM viewpoint on climate change in 2004.

> ... anthropogenic climate change is presented as rather uncertain and it will take until 2004, over the course of eight feature articles [from 1998], for climate change to be regarded as discursively established within the magazine (Born, 2017).
>
> ... in the very same issue, an article about the global carbon cycle finally draws a clear connection between the burning of fossil fuels and climate change (Born, 2017). (Born, 2018, p. 6-7)

This study confirms the role of captions in defining meaning of photographic images within NGM,

consistent with conclusions in (Whitley and Kalof, 2014). The meanings derived from photographic images and captions were not found to conflict with each other. The role of these "image-caption clusters" in establishing meaning is consistent with the NGM design trends described in (Pflaeging, 2017).

NGM's shift, after 2003, away from aesthetic imagery of glacial ice and towards a more deliberate focus on sea-level rise as the major cause for concern, coincides with a wider shift in journalistic norms when reporting on climate change. O'Neill (2019), in a study of UK and US newspaper use of climate imagery between 2001 and 2009 noted:

> Ice imagery usage begins to decline (as a percentage of annual coverage) from around 2005 onwards. This ice imagery is beautiful and awe- inspiring, and rarely depicts people. Analysis of the images, together with the article's headlines, main text and caption shows how this visual synecdoche[1] works to create feelings of distant wonder and threat of climate risk (see (O'Neill et al., 2013)). (O'Neill, 2019, p. 7)

NGM's choice of glacial photographic imagery described in Figure 8 emphasised the remote nature of the melting ice, with limited images featuring non-scientists. This effect is consistent with the "distancing" effect of animal images from remote environments described in (Whitley and Kalof, 2014). The challenges faced by NGM when representing a complex system such as climate change within a photo-essay based medium were similar to those faced by NGO's who had selected photographic imagery to highlight climate change issues as shown by Doyle (2007).

> Where Greenpeace have been committed to communicating the reality of climate change since 1990 they have also been committed to the use of photography as a privileged form of environmental documentation and communication. By identifying the representational problems encountered in communicating a temporal, and not always visible, environmental risk such as climate change, my intention in this paper has been to examine how Greenpeace negotiated these problems in their own climate change communication. Attention has been focused upon how Greenpeace sought to make real the potential and invisible risks of climate change, in light of their commitment to photographic communication. (Doyle, 2007, p. 146)

[1] defined as where part of image-caption cluster is made to represent the whole

NGM's representations of glacial ice between 1978 and 2007 are similar to the "sublime wilderness" and "endangered" themes discussed by Carey (2007) in his analysis of the historical role of glaciers in Western culture.

5.2 RQ5: Building Theory from Analysis and Literature

Research Question 5 asked what theory emerges from the analysis of NGM's representation of glacial ice and its integration with existing literature? Such a theory needs to explain key results from the analysis: the three distinct phases of representation, the use of particular representations, the change of NGM's editorial worldview in 2004, the choices made in the selection of different modalities and how NGM evolved its use of the photo-essay format.

5.2.1 Integrating with Literature

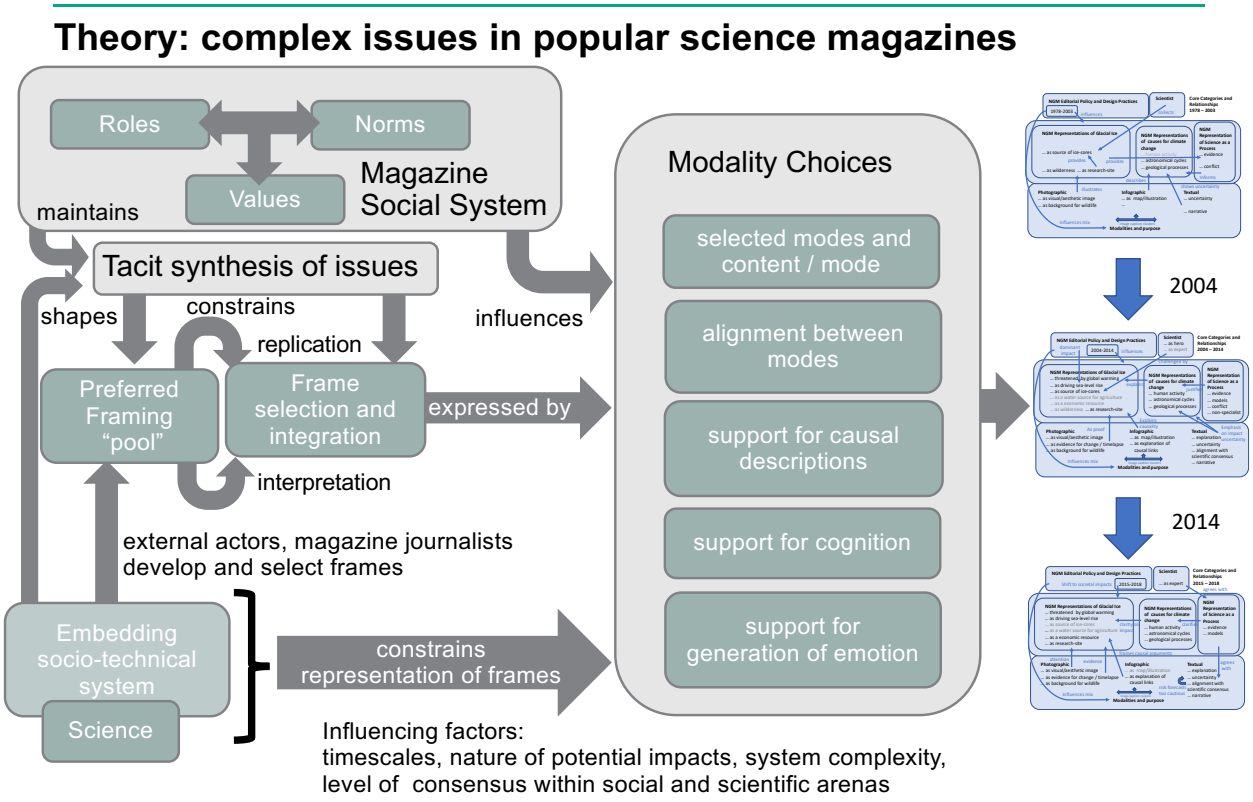
(Allner, 2000; Beaudreau, 2002; Souza, 1998; Lutz and Collins, 1993; Mendelson and Darling-Wolf, 2009) all describe the process by which NGM's articles are produced as a complex interplay between different organisational roles and mode-specific approaches to story-telling. Photographers, writers and editors interact during development of the article within a context set by NGM's journalistic norms e.g., the internal debate about advocacy versus journalism described by (Ward, 2008, p.61).

A NGM article can be analysed as a multi-modal form of communication. Literature on multi-modality in science communications (Harold et al., 2016; Linden et al., 2014; Mol, 2011; Lazard and Atkinson, 2015) suggests the avoidance of conflict between the meanings of text and images in the articles, together with use of infographics to explain complex causal relationships, benefits issue-specific cognition by readers.

The presented analysis and literature review demonstrates NGM articles contain multiple frames and partial frames represented across multiple modes. By defining frames as "... patterns of interpretation rooted in culture and articulated by the individual" (Bruggemann, 2014, p. 61), the selection and combination of frames by the NGM journalists can be used to describe the construction of a NGM article. The reuse and adaption of frames selected from a pool of possible frames by journalists constructing an article is supported by the analysis of how framing is actually used by climate journalists in the studies (Engesser and Bruggemann, 2016; Bruggemann, 2014).

Figure 9

Theory developed from NGM data and integrated literature



5.2.2 Theory Description

Figure 9 describes the theory developed to explain the analysis results. NGM was seeking to manage an evolving tension between its traditional world-view and changing journalistic norms as the scope and scale of the implications of climate warming emerged. While managing that tension it sought ways to represent complex, long-timescale issues within the limitations of its favoured photo-essay format. NGM's adoption of a restricted set of frames in representing glacial ice, especially from 2004 onwards, allowed for consistent use of specific image-types for particular purposes: e.g., time-lapse photographic images of glaciers as evidence of change.

The magazine's social system is modelled using the elements of: roles i.e., a social position with a set of associated responsibilities (e.g., editor, writer); the expected behaviours or norms (e.g., balance versus weight of evidence reporting); and performance measures for the roles set by local standards

or values (Checkland and Poulter, 2006). This social system maintains an often tacit synthesis of the issues (social, economic, scientific) which constrains both the selection of frames and how they can be integrated within an article. The norms within the magazine influence how a particular frame is expressed using the magazine's preferred selection of modalities.

The underlying science and the associated social, economic and political systems changing the science into real-world technologies and impacts are understood by external actors and magazine journalists in varying ways and are adopted, analysed and discussed through an evolving set of frames maintained in a "pool" of frames by the NGM social system. The pool is shaped by the magazine's tacit models of the underlying science and associated real-world implications of that knowledge. The staff involved in frame selection and integration for a particular article adopt particular frames from the pool, and both replicate and possibly re-interpret those selected frames, before making choices about how to express them within the constraints of the NGM preferred modes.

The nature of the underlying science and the social systems it influences effect both the frames themselves (Engesser and Bruggemann, 2016; O'Neill, 2019) and how they can be effectively represented using the modalities available within a photo-essay based magazine. Literature suggests, and this analysis confirms, NGM's use of different modalities can be summarised as: visual items are used to command higher attention and to induce emotions, cognitive understanding (especially of causal relationships) is supported by infographics, with text used to provide description, context setting and narrative structures (Joffe, 2008; Wozniak, Lack, and Wessler, 2015; Geise and Baden, 2015).

Characteristics of the social, economic and political system constrain effective multi-modal representation of a particular frame. The levels of consensus in relevant arenas (Hilgartner and Bosk, 1988) about a topic, the complexity of the system being framed, the nature of the social and political impacts, and the timescales involved all influence effectiveness of a particular choice of modality. Propositions connecting expected patterns of framing and multi-modal representations to the nature of the underlying science and its impacts in the real-world are presented below. The source of supporting evidence for each proposition from NGM data and literature is presented in Table 21.

1. When there is a high degree of consensus in the magazine's social system, and the scientific arenas around a topic, a restricted set of frames and mix of modalities aligning to the optimum purpose of each type of content are used. Visuals were used to attract attention and provide evidence, infographics were used for descriptions of causal logic and text provides description and context along with a narrative skeleton for the article. The material in each mode is complemen-

tary and reinforcing the overall framing rather than conflicting.

2. A lower degree of consensus is associated with a wider range of frames, less emphasis on causal descriptions (in text and infographics), more emphasis on conflict based narrative structures, and a wider range of subjects and styles for photographic images.

3. As the level of complexity in the underlying science and scale of changes in social, economic or political systems increase a wider range of modalities need to be employed for effective communication.

4. Photographic images of geological subjects provide limited causal explanations, and rely on captions to frame the meaning of the image.

5. The emotive power of photographic images within photo-essays is limited when representing geological or other scientific topics associated with complex mental models removed from reader's day-to-day experience.

6. When the emotive power of images in a photo-essay is low e.g., pre-2004 landscape images, the framing of the photo-essay is dominated by the text or infographics (if well produced).

7. Time-lapse imagery provides evidence for change when the causal factors are not too complex e.g., for geological processes such as ice-sheet collapse, in contrast to changes in human social systems.

8. Changes with long timescales within social, economic or political systems are associated with the use of infographics to explain causal relationships rather than reliance on textual description.

5.2.3 Research Contribution

The contributions of this study are described in Table 22. The developed theory extends previous work in identifying connections between characteristics of the underlying science and associated social and political systems and selected modes. The study highlights the role of the tacit synthesis of issues maintained by the social system within NGM's organisation.

Walsham (1995) suggests the creation of a theory integrated with existing literature would justify tentative application of the developed concepts to different contexts e.g., other popular science magazines. While based on analysis of NGM's glacial-ice coverage, Tables 22 and 24 suggests applicability

Table 21

Sources of support for theoretical propositions

Proposition	Support from NGM analysis and literature
1, 2	NGM's post-2004 alignment with climate science
	limited representations of glacial-ice post-2003
	pre-2004 featured a wider variety of photo-subjects and topics
	post-2003 changes in image types and purposes
	post-2004 increase in use of infographics to present causal arguments
	increasing alignment between text and infographics over time within sample
	increasing alignment between editorial position and article text post 2003
	supported by literature on NGM content development processes e.g.
	(Allner, 2000; Beaudreau, 2002)
	(Souza, 1998; Mendelson and Darling-Wolf, 2009)
3	comparison between types and sophistication of modes used pre- and post-2004
4	review of image-caption clusters describing geological subjects
	supported by (Todd, 2010; Peck, 2014)
5	review of coding for geological-related subjects e.g., glacial-ice, ice-age
	supported by discussions within (Gibson, 2016; Doyle, 2007; Peck, 2014)
6	review of image and infographic coding versus article frames
	literature discussion in Appendix C
7	review of time-lapse images
8	review of articles and infographics in articles post-2003

Table 22

Research contribution

Contribution characterised using typology of analytic generalisations from Walsham (1995)

Characteristic	Contribution
Development of Concepts	multi-modal analysis of NGM representations
	role of magazine social system and tacit models
	adaption of GTM to multi-modal analysis
Generation of Theory	nature of underlying science effecting modalities
	relationship between framing and modality
	role of tacit models and magazine social system
Drawing of specific implications	growing importance of infographics
	weakness of traditional photo-journalism
Contribution of rich insight	explanation of changes in NGM's coverage
	importance of visualisation

to other print magazines in the popular science genre. In contrast to print media, social media platforms support a variety of complex usage patterns by the public (French and Bazarova, 2017) and digital media organisations adopt a wide variety of platform specific modes when reporting on climate change (Painter et al., 2016; Wang et al., 2018). Both factors suggest the theory developed in this study will require extension to be applicable outside popular science print media.

5.3 RQ6: Compare and Contrast to Best Practice

Research Question 6 asked how do the identified themes and theory compare and contrast to practice and recommendations within the wider science communication literature discussing the representation of climate change?

5.3.1 Role of the Visual

Recommendations for best-practice in the use of visuals in climate change communication are identified by (Corner, Webster, and Teriete, 2015; Chapman et al., 2016). Table 23 compares the NGM approach versus best practice. It is important to note that this study confirmed the meaning of visual content cannot easily be separated from the other modes.

Table 23

NGM's use of visual communication best-practice

Comparison between NGM analysis results and best-practice recommendations for visual communication (Corner, Webster, and Teriete, 2015; Chapman et al., 2016)

Recommendation	NGM Comparison
Show "real people"	images of scientists used, no political figures
	images of people affected by flooding
Tell new stories	NGM changed "default" storyline in 2004 and 2015
Show climate causes at scale	shown as world-wide issue from 2004
	use of infographics for causal arguments
Show local climate impacts	focused on sea-level rise in western world
Minimise protest imagery	avoided use of this type of image
Understand your audience	imagery changed between phases of coverage as editorial position changed, limited challenge to audience until 2004

NGM's approach of using few images showing how climate change affected humans before 2015 was highlighted as a weakness in visual coverage of climate change by Metag et al. (2016).

5.3.2 Role of multi-modality

Analysis of NGM articles demonstrates how the framing (as defined in (Entman, 1993)) of the main issues in the articles is achieved by a combination of content expressed using particular modes rather than a single mode as often found in news media. Multi-modality was shown to be essential in understanding how NGM frames issues.

The theory developed in this study suggests that practitioners need to consider the specific characteristics (e.g., levels of consensus, timescales) of the core science and its potential social, political impacts when choosing the modality to express a particular frame. The inherent limitations of photographic imagery suggests consistent adoption of multi-modality as a strategy for optimising the design of materials in popular science magazines. The analysis results show infographics are an important mode for magazines dealing with uncertain and complex topics such as climate-change; a direction reinforced by arguments in (Mol, 2011; Spiegelhalter, Pearson, and Short, 2011).

5.3.3 Articulating an internal synthesis of issues

The role of the social system within the magazine and how the organisation develops and then maintains a tacit model of the underlying science and its potential impacts on social, economic or political issues is an under-explored area in science journalism (Engesser and Bruggemann, 2016). It may be that popular science magazines would find it useful, as NGM did with the issue of its historically racist coverage (Goldberg, 2018; Lutz and Collins, 1993), to seek to be seen as transparent and trustworthy when reporting on difficult issues by articulating their current synthesis of the issues (Fiske and Dupree, 2014).

5.4 Learning Points and Limitations

Qualitative analysis involves subjective aspects as the visual and textual analysis of environmental communication requires the researcher to integrate a mix of perspectives and interpretations (Hansen and Machin, 2013). To address subjective influences on the researcher, this study checked choices made during analysis were not purely subjective and could be generalised by: using open codes reflecting initial knowledge gathered from literature review, reviewing results from coding the images with an independent reviewer to minimise impact of subjective influences; presentation and discussion of pre-

liminary results with supervisor and peers, together with use of journal notes to identify potential biases introduced by the researcher.

If time and scope had allowed, interviews and/or participant observation with NGM staff would have been a valuable source of data to further refine and validate the proposed theory rather than relying on integration with previous literature. As argued by Low (2019) demonstrating "saturation" or completeness of a qualitative GTM analysis depends on arguments about the levels of rigour adopted and development of an emergent theory that explains, rather than simply describes, data. This study meets recommended criteria for saturation as described in Table 24.

Table 24

Justification for completeness of analysis

Criteria for completeness of analysis based on justifications in (Low, 2019, p. 137). Does the developed theory:

Criteria	Justification
... address how and why ?	discussion of Figure 9
	see Table21
... address social processes?	discussion of Figure 9
... "make sense given previous theory"	via theoretical integration of Figure 7
... generate concepts ?	see Table 22
... generalise?	social processes not NGM-specific
	integrated theories not NGM-specific
... enable testing?	through further study of relevant NGM social processes
	through further work using NGM social-media
	through studies of other popular-science magazines

6 Conclusions and Implications

This study contributes to literature on the representation of environmental issues within popular science magazines. Despite their potential role in the debate, representation of climate change in popular science magazines has received little research attention. This study establishes how glacial ice was described by NGM in its coverage of climate change between 1978 and 2018 and derives a theory to explain the findings.

NGM's representations of glacial ice evolved through three distinct phases. The mix of content, modes and frames characterising each phase reflected NGM's understanding of climate science and social structures (roles, norms and values) prevalent within NGM during each period. NGM's framing of climate change and the role of glacial ice became aligned with then current scientific consensus only after 2003. The study confirms earlier work by Whitley and Kalof (2014), and Born (2018) on the important role of multi-modality in environmental communication within NGM. The results demonstrate the growing importance of infographics to NGM as a specific mode in the communication of complex issues, and confirming the recommendations of (Mol, 2011; Lazard and Atkinson, 2015).

The developed theory shows how the social-system within the magazine and characteristics of the underlying science and associated societal effects of climate change influenced NGM's choice of representations and modalities over time. It can be concluded that NGM:

- shifted from a position of limited alignment with scientific consensus and extensive "false balance" reporting to strong alignment with climate science over the period of the study;
- changed representations of glacial ice as the magazine's position on the science and associated social impacts of climate change evolved;
- increasingly used photographic images as evidence for change and infographics to communicate causal links within selected frames; and
- evolved their use of the photo-essay format over the timescale of the study by increasingly tailoring content to particular modes and using (post-2003, and especially post-2014) more sophisticated infographics to provide causal explanations.

This study was undertaken by a single researcher, limiting the scope to a document based analysis of NGM articles selected by keyword search mechanisms provided by NGM. External review provided quality control on image analysis to minimise subjective influences. The interpretative approach enabled an understanding of relationships between the analysed concepts and external literature as well as supporting development of a theory about the role of multi-modality within popular science magazines.

The analysis results suggest that science communicators within print-based popular science magazines should seek to fully exploit the use of multiple modes and continue to build the skills and magazine design knowledge needed to represent complex causal relationships using visualisation as well as using both images and text. Given the growing importance of social media to NGM and its audience (Goldberg, 2017b; National Geographic, 2019a), a study of how NGM uses multi-modality within its social media coverage of glacial ice and climate change is recommended as an initial next step. An important extension to the methods used in this study would be to include tests for audience engagement with different text-image combinations and infographics across the different media platforms.

A Categories and Selective Codes

A.1 NGM's Multimodal Representations of Glacial Ice

Analysis of the developed a number of selective codes representing glacial ice. The examples below illustrate how the selective codes relate to the relevant source material.

as threatened by global warming became the dominant representation of glacial ice post 2003.

> It's no surprise that a warming climate is melting the world's glaciers and polar ice. But no one expected it to happen this fast. (Balog and Appenzeller, 2007, p. 56)

as driving sea-level rise was the dominant coding for the impact of the melting of glaciers

> For now, the best estimates suggest that Antarctica will sweat off enough ice to raise global sea-levels by 1.5 to 3.5 feet by 2100, depending on how quickly humans continue to pump out greenhouse gases. Throw in Greenland and other rapidly melting glaciers around the world, and sea level could plausibly rise three to seven feet by 2100. (Fox and Seaman, 2017, p. 47)

> Geologists studying ancient shorelines have concluded that 125,000 years ago, when the Earth was only slightly warmer than today, sea levels were 20 to 30 feet higher. Some, three million years ago, the last time atmospheric carbon dioxide was as high as it is today, and the temperature was about it's expected to be in 2050, sea levels were up to 70 feet higher than today. (Fox and Seaman, 2017, p.47)

as a source of ice-cores

> The cores come from glaciers crowning summits in the Andes, the Himalaya, and Alaska and Mount Kilimanjaro. (Essick and Morell, 2004, p. 69-72)

as a water source for agriculture used in a limited number of articles

> With nearly 37,000 glaciers on the Chinese side alone, the Tibetan Plateau and its surrounding arc of mountains contain the largest volume of ice outside the polar regions... All told, some two billion people depend on rivers fed by snow and ice of the plateau region...These warming rates make them especially sensitive to shifts in climate. (Larmer and Bendiksen, 2010, p. 66-67)

as an economic resource used in later articles to describe the impact of disappearing non-polar glacial ice

> Peru's Quelccaya ice cap is the largest in the tropics. If it continues to melt at its current rate - contracting more than 600 feet a year in some places - it will be gone by 2100, leaving thousands who rely on its water for drinking and electricyu high, dry, and in the dark. (Glick and Essick, 2004, p. 14)

> ... if you are the owner of a ski resort on a glacier, four months of melting is a major concern. (Olsen et al., 2006, p. 99)

as wilderness the dominant description pre-2004, associated with aesthetic imagery and

> Poised for a fall, ice at the Lowell Glacier's toe menaces kayakers on the Alsek River. Unsurpassed among Canada's national parks for wildness and beauty on a stunning scale, Kluane is a realm of big ice, bigger mountains , large challenges, and great rewards. (Lee and Mobley, 1985, p. 631)

> Andean peaks crest the clouds above the Northern ice field. At once severe and sublime, this icy wilderness is ruled by elemental forces that cause it to remain for the most part, a blank spot on scientific maps. (Klinkenborg and M., 2010, p. 98)

as research-site representing the danger and effort of scientific research as well as the linking to the wilderness descriptions.

> The fifth largest continent [Antartica] is a giant outdoor laboratory where scientists strive to decipher clues to our planet's history and detect early warning signs of global pollution (Hodgson, 1990, p. 3)

A.2 NGM representation of causes of climate change

The selective codes developed were: human activity, astronomical cycles, geological processes.

human activity became the dominant cause for warming and hence loss of glaciers post 2004.

> "people don't realise how dramatic these changes will be," says Tett. "But we expect to see a two- to five-degree warming over the next hundred years." ... Can we do anything to stop the change? "No," says Tett. "We'd need to get to zero emisssions to stabilize the CO_2 that's already in the atmosphere. And that's not the path we, as societies, have chosen. Even if we were to stop CO_2 emissions now, we are committed to warming." (Essick and Morell, 2004, p. 75)

astronomical cycles were consistently used to explain the Earth's natural glacial cycles

> Like a wobbling top, the spinning Earth does not keep a constant position in relation to the sun. In the 1930s Serbian mathematician Milankovitch declared that three basic variations in earth's movement affect global climate. A 100,000-year cycle of the planet's orbit, a 41,000-year cycle in the tilt of the Earth's axis, and a 23,000-year cycle in the wobble of the axis. According to these cycles we should be in the midst of a long period of cooling. (Suplee and Pinneo, 1998, p. 51)

geological processes were invokes as a complicating factor in understanding climate change in the early articles but were later de-emphasised.

> The effects of the Pinatubo eruption went far beyond the country, however, as some 20 million tons of sulphur dioxide were hurled into the stratosphere and circulated around the globe, cooling the planet's surface for two years. (Suplee and Pinneo, 1998, p. 63)

A.3 NGM representation of science as a process

Codes developed to analyse NGM's represenation of the process of science research were: the forms of evidence, the computer models, conflicts within science and with political issues, and the role of non-specialist views.

evidence for change and as input to scientific debate. Forms of evidence: ice cores, satellite, warm water measurement, radar, satellite based technologies.

> The rise and fall of temperatures over the past 750,000 years in what is now Tibet is revealed in a thousand-foot-long ice core... (Suplee and Pinneo, 1998, p. 58)

> ... Rignot reported satellite radar measurements showing that most glaciers draining the southern half of the Greenland ice sheet have accelerated. (Balog and Appenzeller, 2007, p. 61)

models

In 1998

> But how credible are current projections? The computer models used to project green house effects far into the future are still being improved to accommodate a rapidly growing font of knowledge. (Suplee and Pinneo, 1998, p. 46)

By 2004 ...

> What do you get when you compare hundreds of thousands of years of climate data from glaciers, caves and coral reefs with climate projections modelled by the world's most powerful supercomputers? Factor in a heavy dose of greenhouse gases, and you get a harrowing forecast. (Essick and Morell, 2004, p. 56)

conflict: Intra-science conflicts were used as a narrative device in many articles as shown in Tables 13 and 14. The pre-2004 coverage emphasised the lack of certainty, e.g.:

> The Alaskan glaciers have recently been puzzling and bemusing scientists with unexpected, even startling, activity. (Matthews, 1987, p. 84)

This approach was found in many of the early articles on short term behaviour of glaciers:

> But other glacioligists disagree, many of them see little connection between local weather or short-term climate changes and the behaviour of the these great ice streams that end in the sea. (Matthews, 1987, p. 103)

By 2004, the debates between scientists were being described in a more detailed and positive way:

> Not everyone is convinced that the North Atlantic Ocean conveyer is the only switch for the Earth's sudden climate changes. "Maybe that's true fro the higher latitudes, but it's

> not for the tropics," says Lonnie Thompson, whom many credit with retrieving the best paleoclimate records from the torrid zone - ... Indeed until research by Thompson and others showed something different, most scientists regarded the tropic as a place where little climate change had ever taken place - not even during the ice ages. "There's a bias in our view of of climate change that sees events in the Northern Hemispheres as the most important, ... but its a data collecting bias: That's where we have the most records from." (Essick and Morell, 2004, p. 69)

conflict: scientific and policy debate

From 1998 editorial

> Among scientists and non-scientists alike, many say it's now a given that human-induced warming threatens to disrupt life on Earth. On the other side of the debate people deny that such warming is taking place at all. One thing seems certain: The debate will rage as long as the evidence is in any way equivocal. (Allen, 1998, p. 13)

non-specialist views and denial plays a significant role in NGM's reporting before 2004. As per the criticism of non-specialists reporting on complex issues by Wilson (2000) we find arguments which conflict with the scientific consensus e.g.,

> The Ice Age, which has really not left the planet for two million years, is reasserting itself. The warm time, which has lasted less than 12,00 years, is over, the next great return of ice has begun. (Matthews, 1987, p. 84)

In this article (Matthews, 1987) NGM presented a view of global cooling being possible (almost 10 years after the scientific consensus for warming) - which was by the same author as the NGM article (Mathews, 1976) critiqued in (Peterson, Connolley, and Fleck, 2008) for false representation of the scientific consensus.

The 1998 editorial showed that NGM sought to maintain its own interpretation of the science and emphasised doubts:

> Our synthesis of the current understanding about climate change comes with one caveat: Every day it seems, scientists publish some new insight into the complexity of the climate system, which despite the explosion of knowledge in recent years remains, frustratingly, mysterious. (Allen, 1998, p. 13)

A.4 Modalities - Photographic Images

Coding of photographic images showed the dominant visual representations of glacial ice as being: visual/aesthetic; as evidence for change e.g. collapsing ice or time-lapse; and as background for wildlife.

as visual/aesthetic NGM's history shows its extensive use of aesthetically pleasing and dramatic imagery in its coverage of many environmental issues (Lutz and Collins, 1993; Hawkins, 2010; Whitley and Kalof, 2014). The imagery is used to support a framing of glacial ice as "sublime wilderness" and forms a significant part of the coverage. Later articles shift to using the interest raised by visually striking images to engage the reader.

as evidence for change From 2004, photographs were consistently used as evidence for change.

> "A photograph is powerful proof. It's indisputable evidence." - Brian Skerry (Kunzig and Balog, 2013, p. 65)

> "We know the climate is changing, but wrapping our minds around that fact can be difficult. The Extreme Ice Survey makes the changes tangible. Through nearly a million time-lapse photographs, we now have indisputable, gut-wrenching proof that ancient glaciers are disappearing. I started this project in 2007 thinking it would last two years. We deployed 25 solar-powered cameras alongside glaciers in Greenland, Iceland, Alaska, teh Alps and the Rocky mountains. I never expected to see such huge changes in such a short period of time. The photographs show glaciers breaking apart and melting faster than we had imagined. So now the survey will go on indefinitely, expanding into South America and Antarctica. Someone must bear witness to these monumental changes. We can't ever stop. People need to see that climate change is real." - James Balog (Kunzig and Balog, 2013, p. 68)

background for wildlife Glacial ice was used as a background for wildlife images, with an example caption:

> ... icebergs like this one, calved from glaciers on land, provide critical resting places for animals. (Welch et al., 2018, p. 117)

A.5 Modalities - Infographics

Selective codes for Infographic representation distinguished between the use: as map/illustration; or as explanation of causal links.

A typical illustration of the use of illustrations to provide information is the graphic and minimal associated text showing the Amundsen polar base is moving with the ice as the ice at the South pole moves 10 meters a year (Hodgson, 1990, p. 15).

An example of how NGM evolved the use of infographics to provide explanation of causal links is the text of an infographic from (Balog and Appenzeller, 2007).

> Ice sheets covering Greenland and West Antarctica are shrinking unexpectedly fast, and the outlet glaciers that carry inland ice into the sea are accelerating. Multiple processes are speeding the loss of ice.
>
> 1 Surface melting begets more melting. Snow reflects the sun's light and heat, keeping ice below it from melting. Where it melt, exposed dark ice absorbs heat. As glaciers thin, their surfeace sinks to lower altitudes where temperatures are higher.
>
> 2 Meltwater fractures ice and lubricates the bottom, speeding flow. Summer meltwater pools on the ice surface and forms lakes. Meltwater plunges into open crevices and moulins,, breaking up the ice and lubricating its base, which accelerates flow.
>
> 3 Thinner ice has a weaker grip on the land and can't hold the accelerating glacier. The biggest outlet glacier in Greenland flows twice as fast as in 1995. The ice moves fastest at the front.
>
> 4. Warmer oceans erode floating ice at its base. Some glaciers end in a floating ice tongue, which buttresses the land ice behind it. As the ocean warms, it erodes the ice tongue from below, weakening it and causing it to break up. Warm currents eat away the grounding line, where the floating ice meets the bedrock. Pressure at depth lowers the ice's melting point, making it even more vulnerable to warmer water. (Balog and Appenzeller, 2007, p. 64)

A.6 Modalities - Text

In the text outside captions, glacial ice was coded as: explanation, uncertainty, alignment with scientific consensus; narrative.

All the articles up to 2015 tended to use language about science referring to uncertainty on the process and results from climate science. The lack of clarity often made the text harder to understand and impacted on motivation for action.

Text in the articles was used to provide background and description. The narrative elements of the article text are described in Tables 13 and 14.

A.7 Image Caption Clustering

For almost all the images there was a very strong alignment between the information and meaning in the image captions and the photographic image itself. There were no clusters with conflicting information found - just more or less coherent levels of support.

A.8 Scientists and Glacial Ice

The article described scientific work being done in the face of challenges e.g.,

> ... lowers himself into a crevasse on the Brunt Ice Shelf. Despite the obvious danger they pose for researchers, crevasses serve science - their walls contain climatatological data similar to that in ice cores. (Hodgson, 1990, p. 35)

From 2004 onwards a number of scientists are represented as undertaking heroic activities.

> "Lonnie Thompson has been climbing to mountaintop glaciers from Peru to Chile for the past 38 years, pulling crucial climate data from deep inside the ice. A glacier that's hundreds of feet thick can contain thousands of years of information: layers of snow and dry-season dust. Some say Thompson has spent more time above 18,000 feet than anyone alive - 1,099 days, at last count. His data show the planet is warming as a historic rate. As a result the ice is melting - and his vital, dangerous work is taking on new urgency." (Walters and Grob, 2013, p. 62)

From 2015, NGM increasingly presented scientists as experts: with clear forecasts, arguments presented without false balance, and relying on the scientists authority, e.g.:

> "These are the fastest retreating glaciers on the face of the Earth," says Eric Rignot, a glaciologist at the NASA Jet Propulsion Laboratory in Pasadena, California. Rignot has studied the region for more than two decades, using radar from aircraft and satellites, and he believes the collapse of the West Antartic Ice Sheet is only a matter of time. The question is whether it will take 500 years or fewer than a hundred - and whether humanity will have time to prepare. "We have to get these numbers right, " Rignot says. "But we have to to be careful not to waste too much time doing that." (Fox and Seaman, 2017, p. 41)

A.9 NGM's Editorial Policies

The appointment of Bill Allen as editor in 1995 continued the magazine's previous emphasis on "journalistic balance" about climate change through to 2003. A shift in the magazine's editorial direction towards being more strongly aligned with the science of climate change is suggested by his 2004 editorial comment about negative audience reaction to NGM's climate change coverage:

> "...we are going to take you all over the world to show you the hard truth as scientists see it. I can live with some cancelled memberships, I'd have a harder time looking at myself in the mirror if I didn't bring you the biggest story in geography today." (Allen, 2004, p.4)

Chris Johns (editor from January 2005 to April 2014) continued to modernise the design of the magazine but published little on climate science. The biggest change in editorial policy has been seen under Susan Goldberg (April 2014 to present) who challenged the historical cultural biases of the organisation in a rejection of previous racist coverage (Goldberg, 2018) and has raised the importance of NGM's climate change coverage as illustrated in 2017's editorial:

> "At National Geographic we are proudly nonpartisan. But there are a few matters on which we do take sides: we are on the side of facts, we are on the side of science, we are on the side of the planet. We promise that we will continue to report – factually and fairly – on how climate change is altering the Earth." (Goldberg, 2017a, p.4)

Andrew Revkin, a long serving environment reporters in the US (Revkin, 2016) and a recognised public commentator on policy approaches to climate change (Nisbet, 2014), joined the National Geo-

graphic Society as "strategic adviser, environmental and science journalism" during 2018 and presented his historical perspective on climate change reporting in Revkin (2018). He describes climate change as being:

> ... unlike any environmental problem we've ever faced. We can't "fix" it the way we've started to fix smog or the ozone hole, with circumscribed regulations and treaties and limited technological changes. Climate change is too big in space, time, and complexity; the emissions that cause it are too central a consequence of the effort of some 7.5 billion people now, and some 10 billion within several decades, to prosper on Earth (Revkin, 2018, p. 20)

The commentary can be interpreted as a belated recognition by NGM of the significant societal impacts implied by climate change and the article describes errors made in coverage of the topic by NGM and others.

B Climate Science and Politics: 1978 to 2018

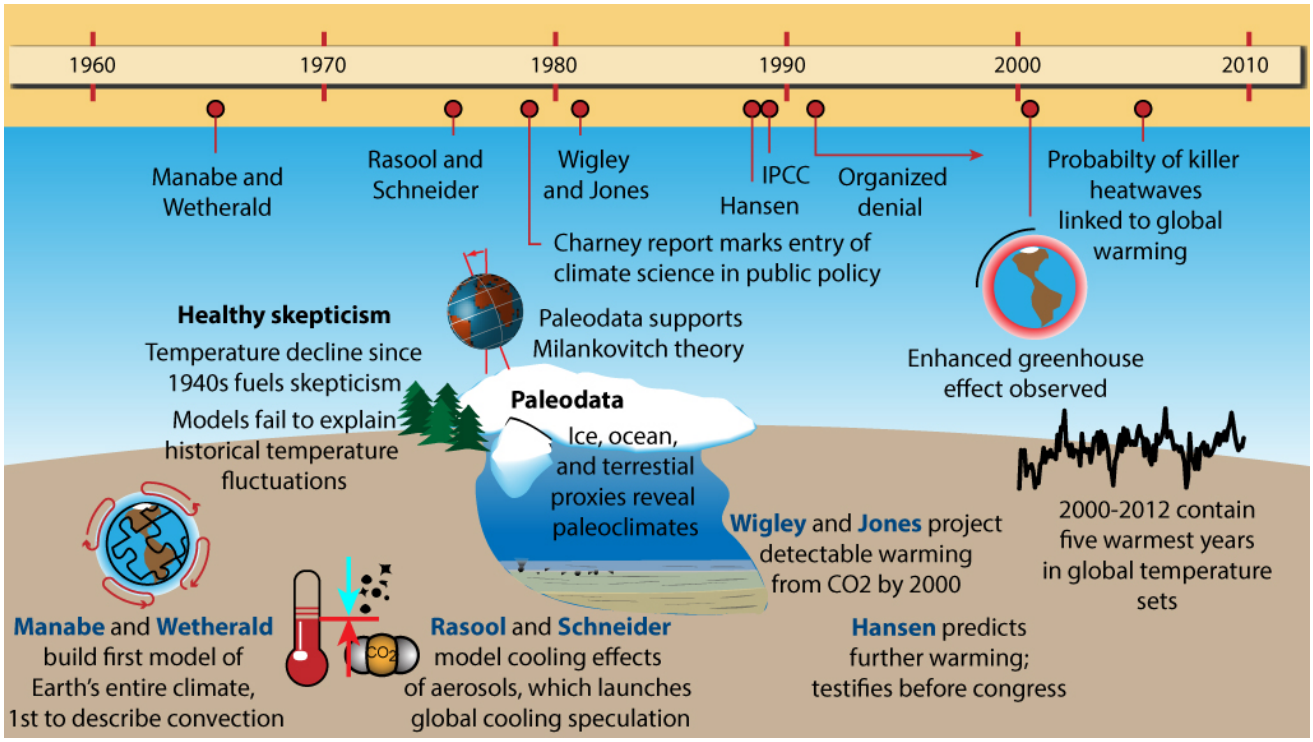
To provide context for the analysis of climate change and glacier coverage in NGM a timeline of climate science and related external events based on Weart (2019) and Mason (2013) was developed.

B.1 Emergence of the Consensus for Global Warming

Study of the climate from 1880s to the middle of the 1970s was a fragmented field, described by Peterson, Connolley, and Fleck, (2008) "... as separate threads of research pursued by isolated groups of scientists. Atmospheric chemists and modellers grappled with the measurement of changes in carbon dioxide and atmospheric gases, and the changes in climate that might result. Meanwhile, geologists and paleoclimate researchers tried to understand when Earth slipped into and out of ice ages, and why." The detailed history of climate science is provided in Weart (2019) and Mason (2013) explains how, by the end of the 1960s, there was a growing understanding that the planet's climate system was subject to feedback loops that could cause significant climate changes on the timescale of centuries. The short term cooling trend since the 1940s in the Northern Hemisphere, later shown to be caused by the cooling effects of industrial particulate air pollution, led to uncertainty in the early 1970s amongst scientists, the public and politicians about climate trends. Media coverage asked whether society should expect a new ice-age or catastrophic flooding as the icecaps melted, however research activity accelerated and by mid-decade the dominant forecast in peer-reviewed journals was for a future warming of the climate (Peterson, Connolley, and Fleck, 2008). From 1977 onwards, media coverage of scientific uncertainty about the cooling versus warming forces was replaced with reporting on the risk of significant future warming probably caused by human activity (Weart, 2019). Revkin (2005) argues this pattern of news coverage was driven by the media's need for newness and drama as opposed to a nuanced discussion of a complex and uncertain issue. The landmark report, "Carbon Dioxide and Climate", by the US National Academy of Sciences Charney et al. (1979) summarised the new scientific consensus that with the then rate of carbon use, human produced carbon dioxide would warm the global surface by around 3 degrees Celsius, causing dramatic impacts on the Earth's climate because of the expected

Figure 10

Climate Science Timeline (from (Mason, 2013), Attribution 3.0 Unported (CC BY 3.0)



doubling of atmospheric carbon dioxide content by 2030.

A summary of the timeline showing the importance of ice-cores to paleoclimate research and the timeline of key policy events is presented in Figure 10.

B.2 Climate change becomes political: 1978 to 1987

Despite increased scientific concern, and unlike in the mid 1970s, there was limited press coverage of the issue with the annual number of articles about global climate change printed in major US newspapers at zero in 79-80, rising to around 2 per newspaper per year through to 1987 (Weart, 2019). During the Reagen presidency a wide range of environmental issues became political issues and concerns about climate change were overshadowed by concerns such as "acid rain", "nuclear winter"' and the discovery of the "hole" in the Ozone layer. Climate change also became entangled with the question of energy policy in many countries. The science of climate change however continued to progress and showed the sensitivity of many ecosystems to relatively small changes in temperature. The improved computer models alongside initial results from analysis of ice core's in Greenland and Antarctica confirmed the

links between CO2 levels and global temperatures. By the mid 1980s glacial core samples were providing 150,000 years of climate history covering complete glacial cycles and provided further support for the strong link between temperature and carbon dioxide levels (Lorius et al., 1992).

With limited public attention being paid to their warnings, scientists who wished to influence government policies started to adopt advocacy based approaches and actively sought media attention and cooperation of professional science writers as well as directly engaging policy makers. Jim Hansen, who was among the first climate scientists to achieve a public profile, worked on climate modelling at NASA. His early research on warming prepared him to testify to Congress in 1987 that he could

> ... confidently state that major greenhouse climate changes are a certainty ...the global warming predicted in the next 20 years will make the Earth warmer than it has been in the past 100,000 years. (Hansen et al., 1987)

B.3 Drama and the path to the Kyoto Climate conference: 1988 to 1997

The summer of 1988 marked a turning point for public awareness. Hansen shifted to a position of overt advocacy (Donner, 2014) and took advantage of a political sponsor and the ongoing heat waves and drought in the USA to generate significant media coverage when he testified to Congress that: he was 99% confident a long term warming trend was underway, that the greenhouse effect was likely to be the cause, and warming would bring more frequent weather problems (Hansen, 1988). Thirty years on Hansen's forecasts are proving to be remarkably accurate, but it was the timing, his combative style, and the hard-hitting message that climate change was a threat to everyone that generated the initial press interest. The coverage continued because

> "Whether regarded as a warning signal or a metaphor of a possible future, the weather events unleashed a surge of fear that brought concentrated attention to the greenhouse effect." (Ungar, 1992, p. 10)

Press coverage jumped by a factor of ten in 1988 compared to 1987 and the greenhouse effect became a strong public concern - requiring a political response.The fossil-fuel industries began well funded lobbying operations to avoid the threat of regulations to curb warming. Environmental groups aligned

behind the issue and together with calls for restrictions on emissions by the scientific community: because of the combination of press opportunity, content and external events climate warming became a global policy issue (Ungar, 2014). The UN coordinated creation of the Intergovernmental Panel on Climate Change (IPCC) and its 1990 report confirmed the ever-growing scientific consensus that warming was underway.

Despite the growth of organised lobbying by fossil-fuel and other US industrial and political groups (Otto, 2016) the reports of changes in the Arctic and that Antarctic ice shelves were starting to breakup began to affect public opinion. Growing understanding of historical climate changes based on ice-core analysis showed that major climate changes can happen in the space of a few decades - much faster than previously thought likely. The second IPCC conference in 1995 confirmed the evidence for warming and in 1997 the Kyoto conference attempted to set targets for industrialised nations to reduce their greenhouse gas emissions.

B.4 Organised denial and slow progress towards action: 1998 to 2007

Organised denial organised by vested interests increased the levels of political polarisation and distorted media reporting of the issues Brulle, 2018; Black, 2018. In contrast the scientific community was increasingly aligned. The 2001 National Academy panel sees "paradigm shift" in scientific recognition of the risk of decade-scale climate change and the Third IPCC report in 2001 effectively showed an end to the debate within the science community: significant warming is underway. By 2003 divergence between European and US public opinion became evident, despite the impact of collapsing ice sheets on rising sea levels being highlighted in press. In 2005 the Kyoto Treaty went into effect without US, with the media belatedly reporting that the science was settled. The decade was marked by intensive efforts to improve the date collection and computer modelling of the major ice systems in Greenland and the Antarctic driven by growing concerns about the instability of the glaciers caused by small changes in average temperature. By the mid-2000s studies such as Kaser et al. (2006) had measured the total global mass of ice and was showing a net loss since the 1970s in every region of the globe. The Greenland and Antarctic ice sheets (and the Arctic Ocean sea ice cover) were all found to be shrinking faster than expected.

When the 2007 IPCC report confirmed that serious impacts of warming were already happening, and suggested the cost of reducing emissions would be less than the damage they will cause, the US public concern about warming returned to levels of 1989 with an associated peak of press coverage about the issues.

B.5 Growing public awareness: 2008 to 2018

However, even when the failure of the 2009 Copenhagen conference to agree binding targets suggested the world was not going to avoid dangerous future climate change, public interest fell again. Despite the severe weather events in 2012, and in a significant contrast to 1988, there was only a limited increase in interest in global warming caused by political leaders avoiding the topic, reduced levels scientific advocacy and the ongoing influence of organised denial networks (Ungar, 2014).

In the background, the cryosphere continued to drive scientific concerns leading to some continued media coverage. By 2015 researchers demonstrated the collapse of the west Antarctic ice sheet is irreversable and will bring metres of sea-level rise over future centuries. In 2016 a new analysis suggested satellite measurements had underestimated recent melting of Greenland ice by some 40%. The Paris agreement of 2015 was seen as a politically feasible was for nearly all governments to set targets for reduction in greenhouse gases. Since that agreement, there has been further evidence that damage from the changed climate in the form of droughts, floods, cyclones, hurricanes, wildfires and wildlife extinctions are happening sooner and at lower CO2 levels than expected. 2018 ended with the mean temperature and the level of CO2 in the atmosphere the highest since the evolution of Homo Sapiens.

C Multimodality

This appendix provides an example of the material developed to document the researcher's understanding of a candidate area for analysis and the "theoretical integration" with the categories and themes from analysis of NGM material.

In commercial advertising, the text associated with images plays a key role in providing causal claims that images struggle to express (Messaris, 1996). Is there evidence that careful combination of text and images would improve audience engagement with communications about climate change? On the cognitive side, there is evidence from educational contexts that well designed combinations of images and text improves learning from multimedia content (Mayer, 1997; Eitel, Scheiter, and Schaeler, 2013; Schnotz, 2002). Combinations of text and image with aligned messages have been shown to be effective in initiating behavioural change with fund-raising activity by charities (Kogut and Ritov, 2005), and in increasing reading times for articles in general news magazines (Zillmann, Knobloch, and Yu, 2001). Analysis of audience responses to descriptions of social conflict by Powell et al. (2015) showed the emotional impact of an image overrides the textual message if they are not congruent but that, when the image and text messaging are aligned:

> ... the inclusion of an attention-grabbing image increased the salience of and attention to the accompanying text, whose structure in turn guided participant's interpretation and support for [political] intervention (Zillmann, Knobloch, and Yu, 2001). For opinion formation, it seems that images are important but words "still exert defining power" (Entman, 1993, p. 104). (Powell et al., 2015, p. 1011)

A case study describing problems when integrating text and images in a NGM article about Saudi Arabia is analysed by Mendelson and Darling-Wolf (2009). The study investigated

> ... how participant's perceptions of Saudi Arabia differed when they were exposed only to the text of the article, only to its photographs, or to both text and photographs, using focus group interviews. Participants exposed only to the text saw it as a cohesive narrative. The 'photos only' groups tended to jump between photographs without a linear pattern.

> The 'text and photos' group perceived the photo story as composed of two competing narratives, which made them uncomfortable. (Mendelson and Darling-Wolf, 2009, p. 798)

The complex scientific, emotional and political issues typical of climate change often requires combinations of images and text to present a coherent story: as shown for press coverage by DiFrancesco and Young (2011); and in TV coverage by Leonn and Erviti (2015). Both studies emphasise the negative impact on engagement when different modes present conflicting or confusing messages.

The use of infographics when communicating complex issues is a relatively new area for science communication. Lazard and Atkinson 2015 showed that: "individuals engage in greater levels of issue-relevant thinking when shown infographics compared to messages that rely just on text or just on illustration". The rationale for the suitability of infographics in science communication is further discussed by (Mol, 2011) and (Linden et al., 2014). The review of best practice recommendations in the design of climate change related infographics and other forms of data visualisation for non-specialist audiences by Harold et al. (2016) highlights the cognitive benefits of closely integrating graphics with their associated text and avoiding misleading mappings between visuals and the language used.

The evidence discussed suggests why a multimodal photo-essay could be an effective vehicle for improved engagement across the areas identified by Manzo (2010): knowledge, interest, and motivation to act.

Supporting the approach in this study a review of how science communication research is adapting to the shift from visual to multimodal communication is presented by Hansen and Machin (2013). The benefits of a multimodal approach to analysis include capturing multiple potential meanings of images, ability to compare and contrast meanings expressed in different modes, and understanding how text elements constrain the meaning of an associated image.

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