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STANCE IN CLIMATE SCIENCE: A DIACHRONIC ANALYSIS OF EPISTEMIC STANCE FEATURES IN IPCC PHYSICAL SCIENCE REPORTS

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ABSTRACT

This diachronic corpus-based analysis investigates the use of epistemic stance devices in reports from the United Nations' Intergovernmental Panel on Climate Change (IPCC) from the date of its first report on the physical science of climate change in 1990 to its sixth contribution in 2021. Applying the framework of stance (Biber & Finegan, 1989), the study focuses upon changes in the use of the epistemic stance markers of modal verbs and adverbs across the approximately 30-year period. To empirically measure the strength of trends in the use of these stance devices, Kendall's Tau correlation coefficient was calculated for each item using their normalized frequencies from the six reports. Analysis displayed that the use of modal verbs has consistently decreased across this period of time in which the scientific consensus regarding the anthropogenic origins of climate change expanded and solidified. Additionally, of the greater than twenty stance adverbs displaying consistent use trajectories across the period, the majority of these items were emphatic adverbs declining in use.

KEYWORDS

climate change discourse, stance, diachronic analysis, discourse analysis, IPCC

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Stance in climate science: A diachronic analysis of epistemic stance features in IPCC physical science reports

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1. Introduction

Climate change discourse has been a frequent site of investigation for researchers from a range of disciplinary orientations in recent years. However, and somewhat surprisingly, ‘the issue [climate change] has so far given rise to little linguistically oriented research’ (Fløttum & Dahl, 2012, p. 14) as the majority of studies into climate change discourse emanate from communication and media studies which rarely pursue ‘micro-textual or corpus-driven research’ (Dormer, 2020, p. 1130). Halliday once asserted that the climate crisis and its myriad consequences ‘are problems of the applied linguistic community’ (Halliday, 1990/2001, p. 199), yet the community has extended limited attention to the discourse of the crisis. As applied linguistics aims ‘to improve the lives of individuals and conditions in society’ (AAAL.org), then addressing ‘our contemporary ecological crisis certainly qualifies’ as a problem deserving attention across the many sites in which applied linguistics is pursued (Lamb, 2020, p. 923).

One applied linguistic approach that could contribute to the study of climate change discourse is stance analysis, which enables the exploration of the ‘attitudes, feelings, judgments, or commitment concerning the propositional content of a message’ (Biber & Finegan, 1989, p. 93). In recent years, the approach has been productively applied in multiple discourse spaces, particularly in the corpus-aided analysis of academic registers (e.g. Aull & Lancaster, 2014; Biber, 2006; Gray & Biber, 2012; Hyland, 1996, 1998, 2005) but also business (Poole, 2017; Samson, 2004), health (Staples & Biber, 2014), science (Poole, Gnann, & Hahn-Powell, 2019; Hyland, 1996, 1998; Moskowich & Crespo, 2014), political (Simaki, Paradis, & Kerren, 2019), and legal communication (Chaemsithong, 2017; Gales, 2015). As climate change and measures to address the crisis continue to generate controversy in the U.S. and elsewhere, corpus-aided stance analysis can provide insight into how individuals and groups discursively represent climate change and argue either for or against the anthropogenic origins of the climate crisis. Additionally, diachronic analyses of stance use in climate science research broadly and the IPCC reports specifically can shed light on how the use of stance features evolves within a discourse community as knowledge solidifies and consensus emerges.

In light of these gaps in the research — 1) the relative dearth of linguistically-oriented research on climate change discourse, and 2) limited application of stance analysis (and diachronic stance analysis) in this discourse space — the present study investigates the use

of stance markers in the reports of the United Nations' Intergovernmental Panel on Climate Change (IPCC) and how these markers are variably deployed from the date of the first report in 1990 to the sixth offering in 2021. The following briefly introduces the stance framework (Section 2.1) and surveys studies of climate change discourse (Section 2.2) with a focus on studies that explore the language of certainty/uncertainty in climate change communication. Additional information regarding the IPCC, its reports, and the corpus constructed for this study is detailed (Section 3.0) before findings are discussed (section 4.0).

2. Stance and climate change discourse

2.1. Stance

Stance analysis explores the linguistic features which function to convey a speaker or writer's 'attitudes, feelings, judgments, or commitment concerning the propositional content of a message' (Biber & Finegan, 1989, p. 93). In recent years, researchers have offered extensive attention to the study of stance within language use in a variety of registers, genres, and discourses through related frameworks such as appraisal (Martin, 2000), evidentiality (Chafe, 1986), evaluation (Thompson & Hunston, 2000), and metadiscourse (Hyland, 2005), amongst others. Though each framework has distinct characteristics, they all broadly share an interest in exploring how speakers and writers 'encode opinions and assessments' with their language use (Gray & Biber, 2012, p. 15).

In studies of stance, linguistic features are typically categorized by the semantic meaning they convey; the category which has garnered attention in climate change studies is epistemic stance markers. Features of this class concern 'the status of information and its level of certainty or factuality' (Charles, 2007, p. 206). Devices serving this epistemic function reflect 'speaker comments on the status of information in a proposition' and indicate the 'degree of certainty (or doubt), actuality, precision, or limitation' (Biber, Johansson, Leech, Conrad, & Finegan, 2000, p. 972). These features enable writers/speakers to 'annotate their texts to comment on the possible accuracy or credibility of a claim, the extent they want to commit themselves to it, or the attitude they want to convey to an entity, a proposition, or the reader' (Hyland, 2005, p.178). For example, epistemic adverbs such as *certainly* and *probably* convey varying levels of certainty or likelihood while modals verbs such as *may*, *might*, or *could* likewise reflect the level of commitment one extends to the information/proposition.

As noted, stance research has proliferated in recent years to a broad range of discourse spaces. However, diachronic studies of changes in the use of stance are somewhat rare. Thus, while this study primarily seeks to explore realizations of stance in climate change research, it also investigates how the use of stance features changes diachronically in one register of science writing — the IPCC assessment report — as knowledge grows and consensus strengthens within a community.

2.2. Climate change discourse

The volume of research into climate change discourse in media exceeds any other space in which communication of the crisis has been explored. Most commonly, such media-focused research explores the frequency with which phrases such as *climate crisis* and *global warming* or their language-specific equivalents (e.g., *cambio climático* (Spanish) (Dotson, Jacobson, Kaid & Carlton, 2012), *changement climatique* (French) (Aykut, Comby, & Guillemot, 2012), *kiko hendo* (Japanese) (Sampei & Aoyagi-Usui, 2009), *klimatför* (Swedish) (Shehata & Hopmann, 2012), etc.) appear in the media of a particular national context, often comparing their frequencies of use to an additional national context. In likely the most comprehensive of such studies, the use of *climate change* and its related terms were tracked in major newspapers of twenty-seven countries from 1996-2010 in greater than 150,000 articles (Schmidt, Ivanova, & Schäfer, 2013). Such frequency-based studies are guided by the underlying assumption that the frequency of mentions of *climate change* in the national media reflects and contributes to public attention and that more frequent use indicates greater likelihood of political action. Illustrating this point, Schmidt Ivanova, & Schäfer (2013) discovered ‘strong correspondence between the pressure to engage in climate action and media attention’ (p. 1246) as media in nations committed to the Kyoto Protocols mentioned *climate change* more frequently than in nations uncommitted to its requirements and goals.

Studies exploring climate change in national media are valuable, yet they also reflect the aforementioned critique of the absence of linguistically-oriented research in this space (Fløttum & Dahl, 2012). While these media studies do typically base their analyses on data present in rather large, specialized corpora, they rarely implement analytic methods of corpus-assisted discourse studies such as collocation analysis, keyword analysis, and semantic annotation analysis; Grundmann & Scott (2012) is a noteworthy exception for its implementation of cluster and keyword analysis. These studies report frequency of use of *climate change* and related n-grams — in other words, they answer ‘How often does the media in a certain context mention *climate change*?’ but they less frequently query ‘How is climate change and climate science discursively framed and represented?’ or ‘How have the stances of certain organizations and key stakeholders, as reflected in their deployment of stance devices, evolved over time?’

There are, however, studies which explore climate change beyond its use in media through a more discourse analytic approach. For example, Collins & Nerlich (2015) implement a semantic tag analysis in order to investigate user comments posted to articles published online on *The Guardian* website as they seek to identify themes present in user engagement. Additionally, Fløttum, Gjesdal, Gjerstad, Koteyko, & Salway (2014) perform cluster and concordance analysis of future-oriented lexical items (e.g., *future*, *threat*, *must*) to a corpus of climate-related blogs to investigate how users conceptualize the future amidst the cascading effects of the climate crisis. Additional studies have investigated the

emergence of collocations in which *carbon* has productively emerged such as *carbon credit*, *carbon footprint*, *carbon emissions*, and *carbon indulgences* (Koteyko, 2010; Nerlich & Koteyko, 2009).

The linguistic mechanisms construing certain stances toward climate change and climate science have also been investigated. In one such study, Bailey, Giangola & Boykoff (2014) explored epistemic markers and hedges — devices which lessen the level of commitment to a proposition — in a selection of articles from two U.S.-based newspapers and two from Spain. The study revealed a greater frequency of negatively-toned epistemic markers in US newspapers and an overall tendency to project uncertainty despite the advancing scientific consensus on climate change. In a similar investigation of stance in media, a corpus of 19,000 articles sourced from greater than twenty news sites was analyzed to discern how the modals *will*, *must*, *should*, and *would* were used by news outlets of varying political orientations (Abney, Gann, Huetten, & Matlock, 2019). The analysis revealed that progressive news sources (e.g., *Think Progress*, *Mother Jones*, and *Slate*) use ‘a greater proportion of certainty language’ through modals such as *will* and *must* while conservative sites (e.g., *The American Conservative* and *Fox News*) express uncertainty through their use of modals *should* and *would*.

Studies have also explored the texts of organizations such as the UN’s IPCC and the Heartland Institute’s Non-Intergovernmental Panel on Climate Change (NIPCC) whose positions regarding climate change are diametrically opposite; the Heartland Institute is a leader of climate change denial and skepticism in the US. In a comparative analysis of the IPCC’s *Fifth Assessment Report* and the NIPCC’s *Climate Change Reconsidered II*, the use of tentative words (e.g., epistemic adjectives such as *possible* and *probable* and epistemic modals such as *might*), emotional words (e.g., *alarmist*, *wrong*) as well as several measures assessing the degree of formality of the two texts (e.g., modifiers per noun phrase, presence of passive voice, etc.) were analyzed (Medimorec & Pennycook, 2015). The IPCC employed a more formal, neutral, and conservative style of representation reflective of the conventions of science discourse while the NIPCC discursively projected greater certainty in a style and approach that Taylor-Neu (2019) labels ‘agonistic’ (p. 13). These findings regarding the use of tentative language in IPCC reports reflects research elsewhere that displays the tendency in academic and science writing to frequently use devices that lessen commitment to a claim or proposition (Hyland, 1998, 2005). It has been further shown that IPCC authors tend to be more conservative with their presentation of climate science as they aim to avoid controversy and politicization while adhering to science conventions of objectivity, moderation, and restraint (Brysse, Oreskes, O’Reilly & Oppenheimer, 2013; Freudenberg & Muselli, 2013).

As the review demonstrates, there have been studies in climate change discourse which explore the discursive representation of climate change through the stance framework, yet this area remains underexplored. In cases where stance features have been in-

cluded in the analysis, these studies have generally been restricted to a rather limited number of epistemic stance features, primarily modal verbs. Additionally, the present study adds a diachronic dimension as it aims to reveal how stance use in IPCC texts has evolved during a period in which the empirical evidence for anthropogenic climate change became increasingly incontrovertible. While diachronic research of climate change research has been pursued (e.g., Carvahlo, 2005; Boykoff *et al.*, 2015), these studies have focused upon representations of climate change in popular media. This study instead pursues a diachronic analysis of stance features within the approximately 30-year span of IPCC reports to provide insight into how the use of stance features evolves within a discourse community and how stance features operate within these influential IPCC texts.

3. Method

3.1. *The IPCC*

The United Nations' IPCC was created in 1988 to 'to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options' (ipcc.ch). It is the leading organization disseminating climate change research, and each report they publish receives global attention. The body released its first assessment report in 1990 and has published subsequent reports approximately every five years with various updates and focused reports in intervening years. The comprehensive assessment includes the reports of Working Groups I, II, and III. Working Group I produces a report focused upon the physical science basis of climate change; Working Group II creates reports on impacts, adaptation, and vulnerabilities; Working Group III focuses upon climate change mitigation. The reports are the product of collaborations from hundreds of international scientists to synthesize and summarize research on climate change into a comprehensive and accessible form for policymakers and the global public. While the reports are intended to inform policy, they refrain from forwarding specific policy suggestions.

3.2. *The IPCC Corpus*

The present analysis focuses specifically on the reports of Working Group 1 as these publications deal narrowly with the physical science basis of climate change. Thus, the specialized corpus compiled for this analysis consists of the publications from Working Group I for each of the six assessment reports produced by the IPCC since 1990. The six Working Group I reports were downloaded from the IPCC's website, converted, cleaned, and tagged with the Stanford Part of Speech Tagger (Toutanova, Klein, Manning, & Singer, 2003) to facilitate identification and retrieval of stance items. The size of the IPCC Corpus is 5,160,980 words.

The academic sub-corpus of the Corpus of Contemporary American English (Davies, 2012) was used as one reference corpus. This sub-corpus, hereafter referred to as COCA-A, contains approximately 120 million words from articles published in more than 100 peer-reviewed journals. Additionally, a sub-corpus focused upon Climatology created from the English EcoLexicon Corpus (León-Araúz, Martin, & Reimerink, 2018) was also used for comparative purposes. The EcoLexicon Corpus is a 23-million word corpus of texts such as journal articles and books from 1973-2016 from areas such as oceanography, biology, climatology, ecology, etc. The Climatology sub-corpus is 4,285,644 words. The COCA-A and Climatology sub-corpus provide useful comparative data to help contextualize findings from the IPCC corpus.

	Word Count
AR1: Climate Change: The IPCC Scientific Assessment	183,036
AR2: The Science of Climate Change	311,140
AR3 Climate Change 2001: The Scientific Basis	629,723
AR4 Climate Change 2007: The Physical Science Basis	786,071
AR5 Climate Change 2013: The Physical Science Basis	1,219,740
AR6 Climate Change 2021: The Physical Science Basis	2,031,270
Average text length:	860, 163
Total word count:	5,160,980

Table 1: IPCC Corpus

3.3. Stance features

The stance features analyzed in the present study are modal verbs and adverbs. The nine central modal verbs are divided into three semantic classes: 1) possibility/permission/ability: *can, could, may, might* 2) necessity/obligation: *must, should* 3) prediction/volition: *will, would, shall* (Biber, 2006). In the analysis, the frequencies of *shall* and *can* are included in the table but not discussed. In the case of *shall*, it is omitted due to its rather low frequency in the texts across the six periods. For the modal *can*, it does not carry epistemic meaning, but rather it encodes ability and/or possibility in its root meaning (Coates, 1983). The remaining seven central modals carry a range of often overlapping meanings which makes determining the frequency of each particular meaning conveyed in each instance in a corpus of this size quite difficult. Discussion is informed by previous corpus-aided studies of modals and statements of their function in these reports are supported by examples drawn from the corpus.

As noted, adverbs were identified after the corpus was annotated for word class. Such a process captures many items which do not index stance meanings (e.g., *here, now, too, thereafter*); these items were manually removed from the data. Stance adverbs can be cat-

egorized into three groups: epistemic, attitudinal, and style, with the present analysis focused on epistemic features, though one attitudinal adverb is included in the discussion. The epistemic adverbs are broadly presented in two groups: 1) those that express certainty, and thus, function to heighten level of commitment to a proposition (also known as boosters [Hyland, 2005]), and 2) those which indicate a degree of uncertainty and lessen the level of commitment to a proposition (also referred to as hedges [Hyland, 2005]). All frequencies reported in the tables are normalized per one million words. This rate enables comparisons across corpora and related studies.

3.4. Analysis

The diachronic analysis was aided by the implementation of the Kendall's Tau correlation coefficient. Kendall's Tau is a correlation measure which yields a figure between -1.0 and +1.0. Negative values correspond to negative correlations (decreasing frequencies over time); positive values correspond to positive correlations (increasing frequencies over time). Kendall's Tau is particularly well-suited for identifying broad level changes in diachronic investigations due to its insensitivity to extreme values. This metric is also suitable for measuring nonlinear, monotonic relationships, meaning unidirectional trends (always increasing or always decreasing) are easily identified. In this study, thresholds were set at +/- 0.80 for the Kendall's Tau and a corresponding p-value of 0.05. These thresholds translate to a 95% confidence level that the correlations are not due to chance alone and ensure that the selected stance features are statistically significant, often with confidence levels of 97.8% or higher in our study.

4. Results and discussion

4.1. Modal verbs in IPCC texts

The use of modal verbs in the IPCC texts was the first focus of the analysis. The data reveal that frequency of use for all nine of the central modals is declining over time.

However, only those items meeting the previously discussed thresholds are explored in the subsequent discussion. Five modals meet these thresholds: *may*, *should*, *must*, *would*, *could*.

	1990	1995	2001	2007	2013	2021	Tau	P-value
may	1792.00	1571.64	1340.27	938.85	905.11	543.50	-1.000	0.003
should	540.88	353.54	238.20	185.73	112.32	67.45	-1.000	0.003
must	513.56	269.97	222.32	124.67	45.09	27.08	-1.000	0.003
would	1130.93	800.28	509.75	517.76	491.91	295.38	-0.867	0.017
could	956.10	536.74	408.12	477.06	362.37	217.60	-0.867	0.017
might	284.10	318.18	115.92	138.66	102.48	61.54	-0.733	0.056

shall	5.46	3.21	3.18	0.00	1.64	0.98	-0.733	0.056
can	2190.83	1642.35	1640.40	1432.44	1961.89	1178.08	-0.600	0.136
will	2065.17	784.21	606.62	436.35	1447.03	868.91	-0.200	0.719

Table 2: Modal verbs in IPCC reports

First, the modal *may* resides in the semantic class functioning to express possibility, permission, and ability. Approaching 2,000 instances per million (pm) in 1990 at the time of the first report, it possesses one of the highest usage rates of any modal in any of the six periods. In COCA-A, its pm frequency is greater than 1,500 pm while in the Climatology Corpus, it appears at almost 1,400 pm. Thus, while the first three reports use the term at comparable rates to the reference corpora, it begins to decline with its most substantial pm fall occurring between the fifth and sixth reports. By the 2021 iteration of the report, its pm frequency has fallen 70% from its rate in 1990 (1792 pm to 543.50 pm) to a frequency well below COCA-A and the Climatology Corpus.

It is revealing that the use of *may* has so significantly declined over the period in which the IPCC has published reports. One plausible conclusion is the consensus regarding the science of climate change has grown as techniques and models have grown more sophisticated and data more varied. In a sense, the function of *may* to indicate probability is utilized less frequently by the authors who now present data and claims more declaratively without the modulation provided by the modal. In example 1 from the first IPCC report in 1990, the use of *may* hedges quite overtly whether climate change can be attributed to human action. The statement is cautious and tentative, even speculative, as the IPCC releases its first report on the crisis—such rhetorical uncertainty regarding human action and climate change is absent by the final report. Similar uncertainty is reflected in example 2 regarding the possibility of sea level rise in the second report in 1995. As time passes, such explicitly coded uncertainty connecting human action to climate change is absent.

- (1) There is concern that human activities *may* be inadvertently changing the climate of the globe through the enhanced greenhouse effect, by past and continuing emissions of carbon dioxide and other gases which will cause the temperature of the earth's surface to increase... (IPCC, 1990)
- (2) ... the warming and consequent expansion of the oceans *may* account for about 2 to 7 cm of the observed rise in sea level. (IPCC, 1995)

In cases where *may* persists in more recent iterations of the reports, it generally concerns the possibility of certain future climate-related outcomes which existing models cannot easily predict. For instance, example 3 is rather measured in its assertion of when 'predicted increases' may be experienced while example 4 acknowledges the difficulty of forwarding predictions on such a complex matter as global climate. These instances, as well

as examples 5 and 6, demonstrate that the language of uncertainty remains in the discourse of climate change, but the focus of such uncertainty has seemingly changed. On one hand, such cautious language use seems prudent as inaccurate predictions of climate change outcomes would weaken the credibility of the IPCC. However, it is possible too that the cautious stances produced by the patterning of possibility modals such as *may* enable skeptics to propagate a message that climate science is unsettled. Nonetheless, the data for *may* suggests that as consensus for anthropogenic climate change has increased since 1990, the rhetorical need to frequently modulate claims with *may* has declined.

- (3) Bender *et al.* (2010) supports this argument and suggests that the predicted increases in the frequency of the strongest Atlantic storms *may* not emerge as a statistically significant signal until the latter half of the 21st century. (IPCC, 2007)
- (4) Even with arbitrarily accurate models and observations, there *may* still be limits to the predictability of such a Nonlinear system. (IPCC, 2021)
- (5) Rapid dynamical change *may* be initiated by a Climatic trigger, such as incursion of warm ocean water beneath an ice shelf, or thinning of a grounded Tidewater terminus, which may lead to reactions within the glacier system, that may result in rapid ice loss. (IPCC, 2021)
- (6) Permafrost *may* persist when Near-Surface Permafrost is absent. (IPCC, 2021)

Should and *must* produce semantic meanings of obligation and/or necessity (Biber, 2006). In the IPCC Corpus, *should* opens at greater than 500 pm but falls to below 100 pm in 2021; contrastingly, it appears at approximately 850 pm in COCA-A and 380 pm in Climatology. The decline between 1990 and 2021 represents an 88% decrease in use. Its early use rate is in the range of the two reference corpora before it declines to a much lower frequency in later reports. As examples 7-9 exhibit, *should* engages the reader quite directly as its use prompts reader action to recall, use, or note something of importance. Its use generally abides by the conventions of science writing in which an ostensibly absent author disseminates information to be consumed and interpreted by others, as its use does not provide policy directives that dictate actions to be taken. Its declining use—a rate of use much lower than its frequencies in comparable corpora—reflects the policy-neutral orientation of the documents. Another explanation for its low frequency is that the modal *should* can encode attitudinal meanings in a manner that more epistemic-oriented modals do not. As the scientist authors of these reports likely try to avoid the contention and controversy that typically follows these reports, the low frequency of the modal in later reports may be attributed to an interest by the authors to extricate themselves from the politicization and controversy these documents at times engender.

- (7) The global pattern is dominated by large pole to Equator gradients which models simulate well (figure 4.8) though it *should* be recalled that in most of the models shown, the ocean surface temperatures are maintained. (IPCC, 1990)
- (8) These results suggest that the Multi-Model ensemble *should* be used with care when estimating probability forecasts or the uncertainty of the mean predictions. (IPCC, 2013)
- (9) It *should* be noted, however, that Multi-Hazard Dependencies can also decrease risk, for instance when hazards are negatively correlated. (IPCC, 2021)

The modal *must* follows a similar use trajectory as the previously discussed modals, but its decline is even more significant as it falls from greater than 500 pm in the first report to fewer than 30 pm in 2021—this is a 95% decrease in use over the approximately 30-year timespan. In comparison, it appears at nearly 600 pm in COCA-A and greater than 350 pm in the Climatology Corpus. Again, its initial usage ranges between these two figures before declining quite rapidly in subsequent iterations of the reports.

The modal *must* provides a greater illocutionary force than other modal verbs. In the reports, *must* functions in contexts where a command is expressed for actions that must be completed or for logical deductions. While other modals provide the author space to reserve full commitment to a proposition, *must* is rather emphatic in its ascription of certainty. However, while it provides illocutionary force in example 10, it does so in a context in which caution is demanded as limitations on understandings of climate change are acknowledged—such cautioning uses of *must* are frequent in the IPCC texts. Many instances align with its more prototypical function in which a logical deduction is made. In examples 11-13, *must* asserts undeniable facts regardless of one's beliefs regarding climate change. For instance, in example 12, the logical reasoning that temperatures must fall for ice to form is unassailable. One may speculate that as empirical data confirming climate change grows clearer, the strength and clarity offered by such a modal would be employed more frequently, yet this modal offering force and certainty has decreased nearly 95% in frequency. Its decline reflects the policy-neutral mission of the IPCC as well, as the absence of the modal in later reports indicates an increasingly objective, distant tone as authors choose not to forward interpersonal directives or calls to action.

- (10) Furthermore, we *must* recognise that our imperfect understanding of climate processes (and corresponding ability to model them) could make us vulnerable to surprises... (IPCC, 1990)
- (11) The fraction of carbon emitted by fossil fuel burning, cement production and land use changes that does not accumulate in the atmosphere *must* be taken up by land Ecosystems and by the oceans. (IPCC, 2007)
- (12) If all the ice is lost, temperatures *must* decline to below a critical threshold for regrowth of the ice sheet... (IPCC, 2013)

- (13) However, more accurate estimates of SLE *must* account for additional processes affecting mean sea level rise, such as shoreline migration. (IPCC, 2021)

Would and *could* are the final two modals displaying strong negative use trends; *would* is a modal primarily producing meanings of prediction while *could* construes possibility. In the COCA-A *would* is used approximately 1500 pm while it occurs greater than 800 pm in the Climatology Corpus. In the IPCC, *would* begins at greater than 1,000 pm but ultimately falls to fewer than 300 pm — an approximately 75% decline in use to a rate well below its pm rates in the reference corpora. The modal *could* records a pm approaching 1,000 in 1990 before decreasing nearly 80% to 217 pm in 2021. In comparison, *could* occurs 935 times pm in the COCA-A but slightly greater than 500 pm in the Climatology Corpus. Again, this is a precipitous drop to levels well below comparable reference corpora.

The analysis focused upon those modals displaying consistently decreasing pm rates and thereby produced the strongest coefficient measures. However, while the balance of modals remaining may not yield strong coefficient figures due to peaks and troughs in their frequencies over the 6 time periods, the use of each remaining modal (*might*, *shall*, *can*, *will*) is declining. For instance, the modal *might* decreases in use by 78%, *can* falls by 46%, and *will* declines 57% from the first report to the sixth. Their weak Kendall's Tau rates are a result of rises in use in one of the respective reports; for example, *will* has a considerable increase in use from the fourth to the fifth report.

4.2. Stance Adverbs in IPCC Texts

The thresholds of +/-0.80 yielded a list of 21 adverbs whose use across the six texts had consistently decreased or increased over the time period. However, of the 21 items that met the threshold, not one adverb displayed positive growth (i.e., exceeded +0.80) as all items on the list are experiencing consistent declines in use. Of these 21 stance adverbs, 20 were epistemic and one was attitudinal.

	1990	1995	2001	2007	2013	2021	Tau	P-value
empirically	16.39	12.86	11.12	10.18	2.46	0.98	- 1.000	0.003
fully	152.98	122.13	100.04	81.42	55.75	54.15	- 1.000	0.003
probably	240.39	170.34	76.22	59.79	38.53	10.34	- 1.000	0.003
appreciably	21.85	6.43	6.35	2.54	2.46	0.98	- 1.000	0.003
considerably	103.80	89.99	77.81	75.06	40.17	24.62	-	0.003

							1.000	
relatively	442.54	414.60	290.60	281.15	183.65	115.69	-	0.003
substantially	163.90	147.84	134.98	129.76	104.94	103.38	-	0.003
unfortunately	49.17	28.93	33.35	8.91	0.82	0.00	-	0.017
certainly	43.71	19.28	25.41	11.45	3.28	0.49	-	0.017
highly	202.15	186.41	149.27	109.40	83.62	91.08	-	0.017
obviously	21.85	28.93	11.12	2.54	1.64	0.98	-	0.017
critically	27.32	38.57	25.41	13.99	9.84	3.94	-	0.017
seriously	21.85	16.07	4.76	3.82	1.64	2.46	-	0.017
actually	49.17	25.71	34.94	21.63	12.30	8.37	-	0.017
successfully	27.32	32.14	17.47	13.99	9.02	7.88	-	0.017
effectively	43.71	32.14	34.94	19.08	14.76	8.86	-	0.017
perhaps	54.63	115.70	53.99	30.53	9.84	2.46	-	0.017
poorly	87.41	83.56	69.87	80.15	50.01	27.57	-	0.017
positively	38.24	6.43	7.94	6.36	4.92	1.97	-	0.017
evidently	10.93	9.64	3.18	5.09	0.00	0.00	-	0.022
basically	10.93	12.86	3.18	1.27	0.00	0.00	-	0.022

Table 3: Stance adverbs in IPCC texts

As stated, no stance adverbs displayed positive growth across the timespan. The decline in use of these stance devices indicates that authors aim to lessen authorial presence in

the texts by withdrawing such interactive stance features as they seek to create reports that are objective and distant in style and tone. Several of the items on the decline such as *appreciably*, *considerably*, *substantially*, *certainly* and *obviously* are emphatic in their judgement of propositions, and thus, each could be viewed as rhetorically risky lexical choices in a contentious discourse space in which skeptics seek all available openings, however small they may be, to cast doubt on climate science. Such absolute adverbs as *certainly* and *obviously* inject authors into the texts and open them to potential challenges. Additionally, adverbs such as *successfully* and *poorly* strongly evaluate the effectiveness, or lack thereof, of various models, simulations, and procedures while inserting authors more clearly into the text. These two items have echoes of attitudinal meanings as they reflect author evaluations of various entities. The injection of emphatic authorial judgment these various stance features produce could then lead to the NIPCC claim that the IPCC has become 'alarmist' (Taylor, Burnett & Watts, 2021) in their framings of climate change and its science.

The declining use of these devices may also indicate attempts by the IPCC to standardize their language use, as authors will most likely vary in the probabilities and likelihoods assigned to adverbs such as *considerably* and *substantially*. In other words, what one author perceives as substantial, considerable, or certain may not be judged similarly by fellow authors and various readers. In fact, in 2010, the IPCC published '*Guidance note for lead authors of the IPCC Fifth Assessment report on consistent treatment of uncertainties*' (Mastrandrea *et al.*, 2010) to ensure that all contributors to the reports ascribed similar levels of certainty and likelihood to their claims by instituting a rubric to guide language choices. If authors are divergent in their application of such framings, it creates inconsistencies in how climate data is represented across the body of the text. As the subsequent mediatization of the reports and their findings is a critical part of climate change communication, it seems prudent to limit possible variation in interpretation to diverse public audiences. The declining deployment of such stance adverbs would restrict the potential variation in how findings are reported and enable the many authors of the reports to more consistently evaluate data.

While the aforementioned adverbs (e.g., *appreciably*, *considerably*, *substantially*, *certainly*, *obviously*) are joined by additional emphatic items (e.g., *fully*, *highly*, *effectively*), only three adverbs on the list are prototypical hedges functioning to lessen the strength extended to a claim: *probably*, *relatively*, and *perhaps*. The first of these weakening epistemic adverbs, *probably*, opens in 1990 and 1995 at frequencies much greater than its use in the reference corpora — approximately 125 pm in the COCA-A and 100 pm in the Climatology Corpus. However, by 2021, its use has dropped from nearly 250 pm to 10 pm, representing a dramatic 96% decrease in use across the timespan. As reflected in examples 14-17, this adverb functions to construe likelihood and degrees of certainty while hedging the level of commitment extended by the writer to the proposition under evaluation. The change in

its use reflects the rather nascent status of climate science at the time of the first report as many statements were rather cautiously forwarded in acknowledgement of the many unknowns present in climate science. It appears that many of those propositions, claims, and questions originally annotated with the adverb *probably* in the first two iterations of the report are now being presented more declaratively as climate change science has solidified. In other words, by 2021, such frequent hedging of probability — though it is still present at times — was not required as the full picture regarding the anthropogenic origins of climate change became clearer.

(14) Slow variations in the earth's orbit affect the seasonal and latitudinal distribution of solar radiation. These were *probably* responsible for initiating the ice ages. (IPCC, 1990)

(15) Mid-latitude storms are driven by the equator-to-pole temperature contrast. As this contrast will *probably* be weakened in a warmer world, it might be argued that... (IPCC, 1990).

(16) This is *probably* related to shortcomings in the simulation of persistent weather events in the Mid-Latitudes (IPCC, 2021)

(17) ... characteristics of Mcss are viewed in new perspectives in recent years, *probably* because of both the development of dense Mesoscale observing networks and advances in high-resolution Mesoscale Modelling. (IPCC, 2021)

Of the two remaining hedging epistemics, *relatively* closes in 2021 with the highest pm frequency of 115 pm. In the first four reports, the pm rate for *relatively* (442, 414, 290, 281 pm) far exceeds its pm use rate in COCA-A (146 pm) but is more aligned in the final two reports (183 and 115 pm). These use rates also fall well below its 256 pm frequency in the Climatology Corpus. With a 75% decline in use, this epistemic adverb has declined precipitously across the timespan. Finally, the epistemic *perhaps* typically functions to modify commitment and reflect likelihood/probability. In the IPCC reports, it most frequently provides space for speculation. In this manner, it allows authorial interaction and engagement as it acknowledges unknowns in climate change science. In example 18, it enables speculation concerning the past size of the Greenland ice sheet while in example 19 — the final instance of *perhaps* in the 2021 report — it enables speculation regarding the likelihood of potential future outcomes. Considering the speculative function the adverb makes possible, it is unsurprising that it appears at such a low pm rate in the final three reports. In contrast, it appears at 66 pm in the Climatology Corpus and almost 225 pm in the COCA-A. Thus, authors in related discourse spaces use this epistemic adverb at greater rates than it appears in the IPCC reports.

(18) Sea-Level was somewhat higher than now, the Greenland ice sheet was *perhaps* smaller, and orbital parameters favoured greatly enhanced... (IPCC, 1990)

- (19) and show how droughts may change in the future, *perhaps* with even greater precipitation deficits or longer duration. (IPCC, 2021)

Though epistemic stance devices are the primary focus of the analysis, a brief discussion of the sole adverb coded as attitudinal is warranted. Attitudinal stance markers form a second semantic class of stance features relating to a writer or speaker's 'personal feelings or opinions about a proposition' (Charles 2007: 206); for example, items such as *fortunately*, *amazingly*, and *sadly* construe a speaker/writer's personal feelings and/or opinions regarding a proposition. The attitudinal adverb present in table 3 is the item *unfortunately*. The use of *unfortunately* peaked at approximately 50 pm in 1990, descended to fewer than 10 instances pm in 2007, and was absent from the 2021 IPCC report. In contrast, in the COCA-A, the pm frequency of *unfortunately* is approximately 45 instances pm while it appears 27 times pm in the Climatology Corpus. Thus, this adverb in the IPCC begins at a comparable rate to COCA-A but later falls well below its COCA-A and Climatology Corpus use rates. While the decline in *unfortunately* does not indicate absence of attitudinal markers broadly across the IPCC texts, it is revealing of a shift to a more author-absent style in IPCC reports across the timespan.

In its early instances in the IPCC, *unfortunately* most commonly occurred in contexts where certain climate-relevant knowledge was yet unknown, existing models were incomplete, or data at that time were inadequate. In the final instance of *unfortunately* from 2013 displayed in example 22, a related concern for lack of data is noted. This adverb is a rather overt marker of personal opinion and feeling regarding a proposition. As the IPCC has been criticized by climate change skeptics and their work politicized and attacked, the absence of such an explicit personal marker could possibly forestall certain critiques as the reports gravitate to a more apolitical, author-absent style.

- (20) *Unfortunately*, even though this is crucial for climate change prediction, only a few models linking all the main components of the climate system in a comprehensive way have been developed. (IPCC, 1990)
- (21) *Unfortunately*, present quantitative knowledge of the Luge-Scale Watci budget is still very poor. For example, it has not yet been possible to measure or deduce from existing measurements either global precipitation or global evaporation. (IPCC, 1990)
- (22) *Unfortunately*, there are extremely limited data on the changes of Albedo over time, and we must rely instead on analyses from ice cores, direct recent observations, and Modelling. (IPCC, 2013)

5. Limitations

This study, as is often the case in corpus-assisted discourse analyses, focused upon items whose use most clearly diverged across time. Yet, numerous stance adverbs did not experience change as their frequencies of use remained rather stable or experienced irregu-

lar fluctuations. One could argue that the methods applied were too narrowly concerned with divergence rather than similarity, as it is possible that consistent use of certain stance devices is also revealing of language use in the reports. Though this point is acknowledged, the approach pursued in the present study enabled a focus on stance features whose changing patterns of use provide insight into these reports and the contexts in which they are produced. Future research could, however, place greater emphasis in analyzing those items whose frequency of use remained constant across the period or those which experienced fluctuation in use.

Finally, it would be exceedingly difficult to code the function of each instance of each modal verb and stance adverb discussed in the analysis. Thus, our study focuses upon trends and common uses. This is a subjective process and one could challenge our selection of concordance lines as biased to support claims forwarded. Throughout the analysis, we attempted to include examples from across the texts which exemplified typical uses for each item.

6. Conclusion

Multiple noteworthy trends were present in the use of stance devices over the 30-year period in which the IPCC has published climate change assessment reports. First, the use of modal verbs consistently declined across the six publications of the time period to frequencies below their use in comparable reference corpora. This decrease in use of modal verbs may be attributed to the reality that climate change science has grown increasingly incontrovertible and agreed upon since the IPCC first issued an assessment report in 1990. The consistent decline of these features indicates a shift to a more declarative presentation in which the commentary on propositions that modals make possible is less needed. Their decline may also be attributed to efforts to standardize language use — for instance, the 2010 guidance report (Mastrandrea *et al.*) — in the reports in order to create greater consistency in how climate science is presented. These reports are the products of scores of authors. It seems inevitable that authors will diverge on the degree of certainty and likelihood each ascribes various modals—again, a proposition one author frames with *would*, *may*, or *might* may earn divergent modal framings from another.

In consideration of the social and political contexts in which these documents are produced, it would not be surprising if modal use had remained somewhat stable across the time period. Indeed, Hyland & Jiang (2016) report that use of stance devices has remained quite stable in published Biology research — hedges slightly increased, boosters declined, and attitude markers remained stable. Yes, climate science consensus has solidified, but climatologists consistently develop, evaluate, and refine methods, models, analytic techniques, etc. In such a context, it seems reasonable that as the study of climate change remains quite complex that modals would remain relatively constant in use. Additionally, climate change continues to generate controversy in certain national contexts,

and these IPCC reports are highly visible documents studied by both proponents and skeptics alike. As skeptics seek opportunities to sow doubt, one may anticipate writers using modal verbs in order to craft cautious, measured statements with limited rhetorical risk. Despite the contentious climate in which these reports are generated and consumed, language use of the reports has grown more declarative as modals decline in frequency.

In the case of stance adverbs, it was observed that the strongest diachronic trends were also decreases in use. Of the 21 adverbs meeting the ± 0.80 Kendall's Tau threshold, none were on the rise. The majority of these items were emphatics which heighten commitment and strengthen degrees of likelihood/certainty concerning a proposition. As noted in the discussion section, such epistemic adverbs as *appreciably*, *certainly*, *considerably*, *substantially*, *fully* and others are steadily declining in their deployment in the texts while only three epistemic adverbs lessening the degree of commitment were present. These trends seem to demonstrate a movement toward a more author-absent and cautious presentational style. Even though understanding of climate science has strengthened, boosters are less frequent in the texts. The absence of these features backgrounds author-presence to possibly forestall challenges that the IPCC is politicized or biased. Language use in the reports has gravitated toward an impersonal center as the modulation offered by modals on one end and the power offered by emphatic epistemics on the other have receded toward a style and tone in which authorial presence is increasingly absent from the reports.

It is reasonable to conclude that the importance of these reports and the intense scrutiny they attract influences the discursive choices of the authors. As skeptics generally seek to convince publics that climate science remains unsettled, they mine such reports as these from the IPCC in attempts to highlight any perceived weakness or irregularity. One of the most commonly asserted critiques of the IPCC from such skeptics is that they overstate climate science and are 'alarmist' in their tone and style (Taylor, Burnett & Watts, 2021). In this environment, the IPCC, thus, must maintain precision and consistency. As previously noted, in 2010, the IPCC released a guidance report (Mastrandrea *et al.*) to ensure that all contributors ascribed similar levels of certainty and likelihood to their claims by instituting a rubric to guide language choices. There was an initial expectation that influences of the official guidance document may be evident in the data for the items under analysis in the present study. This did not appear to be the case. While the guidance note may have strengthened trends, the trends were largely present before the assessment report which followed the 2010 guidance document. This guidance document has not been above critique, as calls for further clarification have been made (Janzwood, 2021).

The present study did not explore whether the trends observed with stance features in the IPCC reports are unique to these particular texts or whether similar trends may be observed in science writing generally and climatology specifically. Future research could explore if these trends in stance use are present in science writing and climatology, as it

would be worthwhile to determine the degree to which these stance trends are responses to the unique rhetorical and contextual circumstances of the IPCC reports or are reflective of use across science writing and climatology broadly. Additionally, research could explore variation in stance use between the IPCC and the oppositional NIPCC.

In closing, we recall Kuhn's comments from the opening pages of *The Structure of Scientific Revolutions* (1962) in which he asserted that scientific developments do not occur in a vacuum and the piecemeal process of accumulation of knowledge is not without obstacles. We similarly contend that these linguistic developments in the IPCC reports do not occur in a vacuum and that as knowledge is generated and ratified by the scientific community, the language used to report and disseminate information likewise evolves. Yet, again, this process is not absent of conflict and contention, as in this case, climate change skeptics are well-funded and dogged. Thus, the language use present in these documents reflects the dynamic relationship between the coalescing of knowledge and consensus on one side and the skepticism and doubt of the other.

Competing interests

The authors have no competing interests to declare.

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