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CLIMATE CHANGE

Global Average Temperature rise

ENVS 202/SDP 201 Spring Semester 2025

Instructor: xxx

Hours: xxx

Class Location xxx

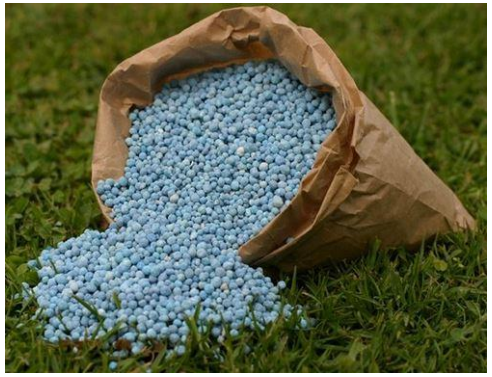
Office hour: xxx

Office: C-103

Email: xxx

- Intro to Null hypothesis, confidence intervals, confidence levels, inferential stats, etc

Fossil Fuels are omnipresent



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REVIEW

CLIMATE PROJECTION

Assessing ExxonMobil's global warming projections

G. Supran[1]*†, S. Rahmstorf[2,3], N. Oreskes[1,4]

Climate projections by the fossil fuel industry have never been assessed. On the basis of company records, we quantitatively evaluated all available global warming projections documented by—and in many cases modeled by—Exxon and ExxonMobil Corp scientists between 1977 and 2003. We find that most of their projections accurately forecast warming that is consistent with subsequent observations. Their projections were also consistent with, and at least as skillful as, those of independent academic and government models. Exxon and ExxonMobil Corp also correctly rejected the prospect of a coming ice age, accurately predicted when human-caused global warming would first be detected, and reasonably estimated the "carbon budget" for holding warming below 2°C. On each of these points, however, the company's public statements about climate science contradicted its own scientific data.

Comparisons

We compare observations to model projections in two quantitative ways:

(1) change in temperature versus time; and

(2) change in temperature versus change in radiative forcing (the "implied transient climate response," or iTCR)

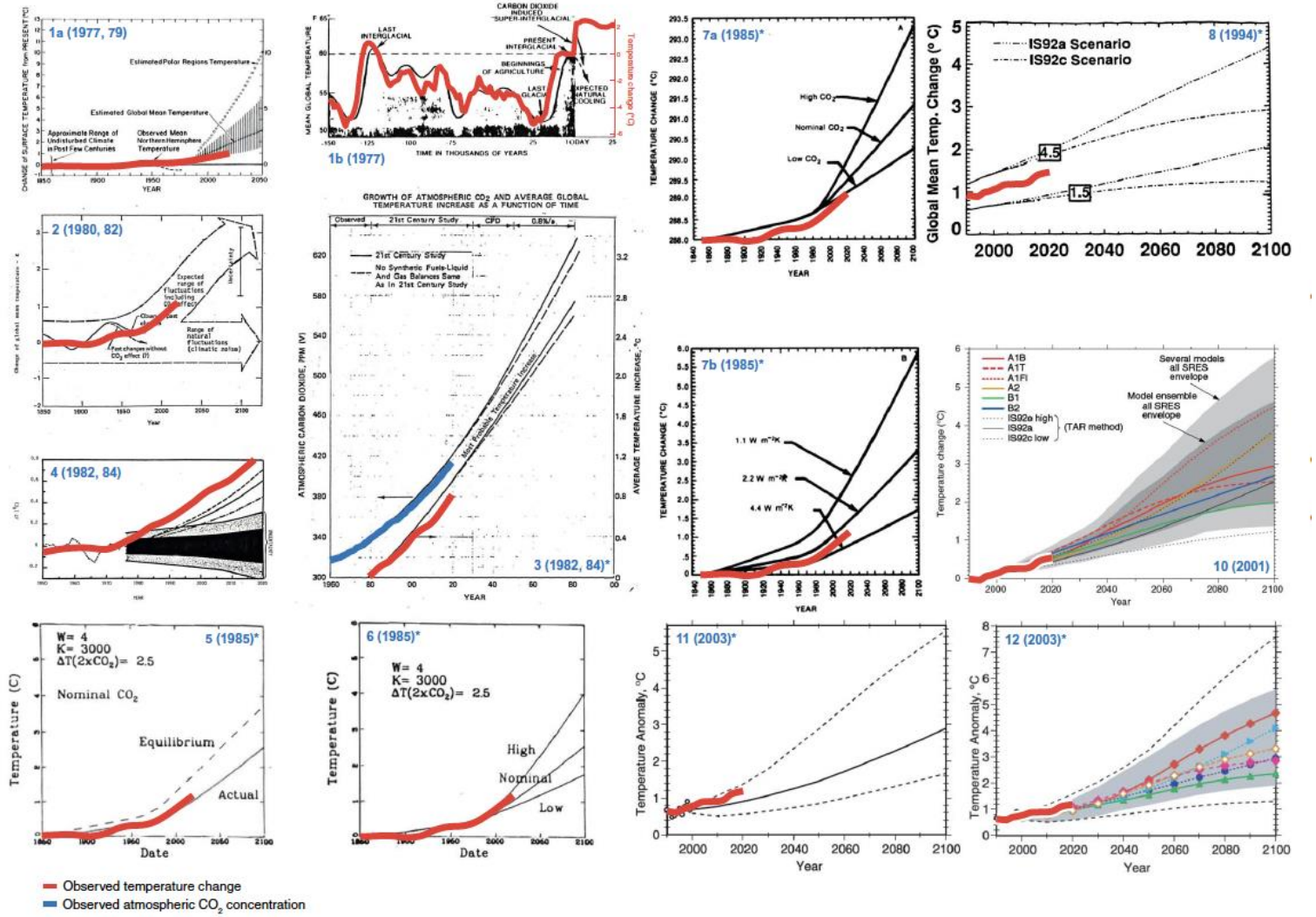
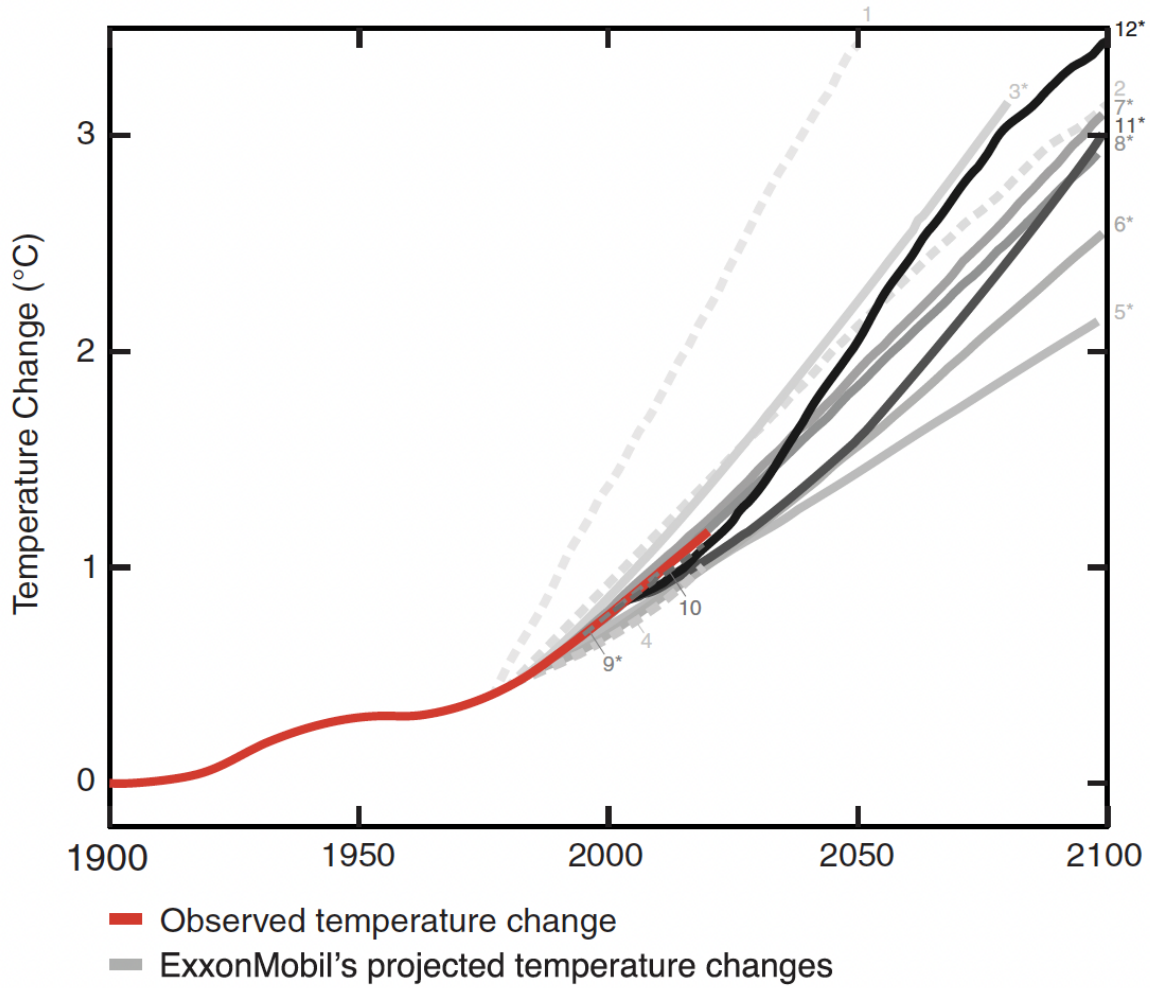


Fig. 1. Historically observed temperature change versus time (red) compared against global warming projections reported by ExxonMobil scientists in internal documents and peer-reviewed publications. Panel numbers indicate projections reported in internal documents: (1a, b) Black (1977, vugraphs 10 and 11, respectively) (*54*) and Mastracchio (1979) (*88*), (2) Shaw (1980) (*89*) and Glaser (1982, fig. 9) (*36*), (3) Glaser (1982, fig. 3) (*36*) and Shaw (1984) (*37*), (4) Weinberg *et al*. (1982) (*42*) and Callegari (1984) (*41*), (5, 6) Flannery (1985, pages 23 and 24, respectively) (*39*); and in peer-reviewed publications: (7a, b) Hoffert and Flannery (1985, figs. 5.16A and B, respectively) (*38*), (8) Jain *et al*. (1994) (*40*), (10) Albritton *et al*. (2001) (*90*), (11, 12) Kheshgi and Jain (2003, figs. 7c and 8c, respectively) (*91*). Asterisks indicate global warming projections modeled by ExxonMobil scientists themselves. Panels have been numbered to match the labels in Fig. 2; this means that (9) Kheshgi *et al*. (1997) (*92*), which reports projections in tabulated rather than graphical form, is represented in Fig. 2 but is not included here. Temperature observations reflect the smoothed annual average of five historical time series. The only exception to this is the historical temperature record in (1b), which reflects a smoothed Earth system model simulation of the last 150,000 years driven by orbital forcing only, with an appended moderate anthropogenic emissions scenario. Panel 3 additionally compares projected atmospheric carbon dioxide concentrations against annual mean observations (blue). For data sources and plotting details, see SM sections S1 and S2.

- *Figure 1 reproduces all 12 identified unique graphs, which contain 15 of the 16 identified temperature projections (the 16th was reported as a table).*
- *In Fig. 1, we overlay the original graphs with observed atmospheric CO2 concentrations and temperature changes, shown in blue and red, respectively.*
- *In general, observations closely track projections.*

Fig. 2. Summary of all global warming projections (nominal scenarios) reported by ExxonMobil scientists in internal documents and peer-reviewed publications (gray lines), superimposed on historically observed temperature change (red). Solid gray lines (and asterisked numerical labels) indicate global warming projections modeled by ExxonMobil scientists themselves; dashed gray lines indicate projections internally reproduced by ExxonMobil scientists from third-party sources. Shades of gray and numerical labels scale with model start dates, from earliest (1977: lightest, "1") to latest (2003: darkest, "12"). Numerical labels correspond to panels in Fig. 1, which displays all original graphical projections reported by ExxonMobil scientists. Observations reflect the smoothed annual average of five historical time series. For data sources and plotting details, see SM sections S1 and S2.



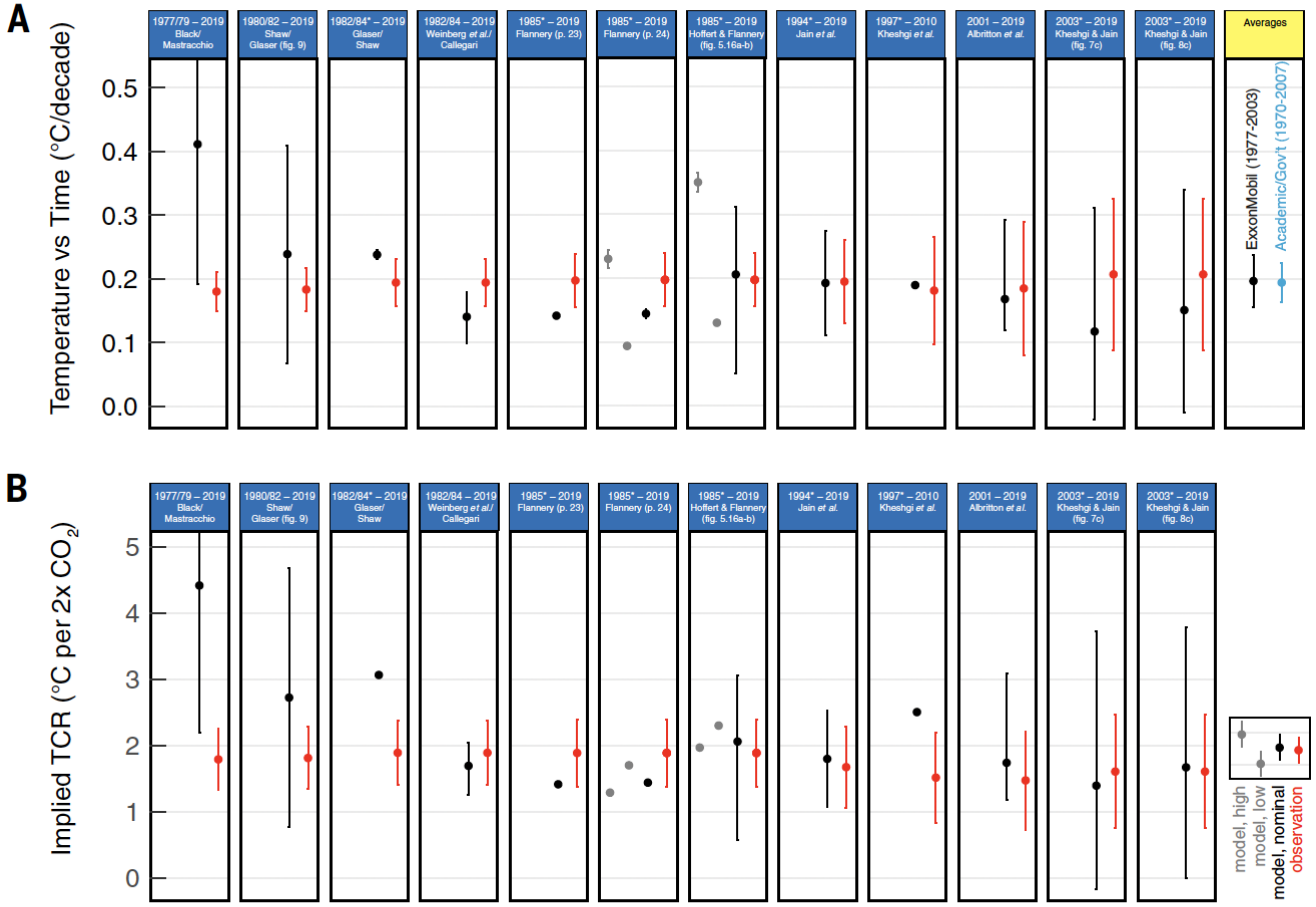


Fig. 3. Comparison of (red) historical temperature observations and (gray or black) global warming projections reported by ExxonMobil scientists in internal documents and peer-reviewed publications, as illustrated in Figs. 1 and 2. Observed and projected trends are compared in terms of (**A**) temperature change versus time and (**B**) temperature change versus change in radiative forcing ("implied TCR"). iTCR is defined as the change in temperature versus change in radiative forcing (see materials and methods and SM section S1.2.3 for details). The left-to-right order of panels corresponds to the numbering of projections ("1" to "12") in Figs. 1 and 2. Trends are computed over model projection periods indicated in the blue boxes above each panel. Asterisks indicate global warming projections modeled by ExxonMobil scientists themselves. The yellow-labeled box in (A) displays averages and bootstrapped standard errors of (black) the 16 projections reported by ExxonMobil scientists spanning 1977 to 2003 and (cyan) 18 academic and government climate model projections spanning 1970 to 2007 reported by Hausfather *et al*. (2020) (*16*).

- *With respect to temperature change versus time, we find the average of the median skill scores of all 16 reported projections to be 67 ± 7%. Across projections modeled by ExxonMobil scientists themselves, it is 72 ± 6%.*

- *For comparison, NASA scientist James Hansen's global warming predictions presented to the US Congress in 1988 have been found to have skill scores ranging from 38 to 66% across the three different forcing scenarios that he reported*

Table 1. Skill scores of global warming projections reported by ExxonMobil scientists in internal documents and peer-reviewed publications. Scores are shown for ($\Delta T/\Delta t$) temperature change versus time; and ($\Delta T/\Delta F$) temperature change versus change in radiative forcing ("implied TCR"). Average skill scores are summarized for (i) all projections and (ii) projections modeled by ExxonMobil scientists themselves (indicated by asterisks). A skill score of 100% indicates perfect agreement with observations; a score less than zero indicates worse performance than a zero temperature change null hypothesis. For each projection, median scores and 5th and 95th percentile confidence intervals are shown, all as percentages. For each average skill score, the mean and the 1σ standard error of the mean are shown. Confidence intervals for projections over short periods—such as Kheshgi *et al*. (1997), Albritton *et al*. (2001), and Kheshgi and Jain (2003)—are large, primarily owing to the substantial impact of interannual and subdecadal variability on short-term temperature trends.

Projection	Reference	Time frame	Skill $\Delta T/\Delta t$ (%)	Skill $\Delta T/\Delta F$ (%)
1977 Black (vugraph 10); 1979 Mastracchio | nominal	(*54*, *88*)	1977–2019	22 (−55 to −4)	−49 (−102 to 0)
1980 Shaw; 1982 Glaser (fig. 9) | nominal	(*36*, *89*)	1980–2019	73 (53 to 84)	49 (16 to 78)
1982* Glaser (fig. 3/table 4); 1984 Shaw | nominal	(*36*, *37*)	1982–2019	82 (61 to 92)	37 (1 to 68)
1982 Weinberg *et al*.; 1984 Callegari | nominal	(*41*, *42*)	1982–2019	70 (64 to 82)	90 (73 to 99)
1985* Flannery (page 23) | nominal	(*39*)	1985–2019	70 (63 to 83)	76 (61 to 92)
1985* Flannery (page 24) | high	(*39*)	1985–2019	87 (66 to 97)	69 (55 to 84)
1985* Flannery (page 24) | low	(*39*)	1985–2019	46 (42 to 55)	90 (73 to 99)
1985* Flannery (page 24) | nominal	(*39*)	1985–2019	71 (64 to 84)	77 (62 to 94)
1985* Hoffert and Flannery (fig. 5.16) | high	(*38*)	1985–2019	28 (−5 to 44)	92 (71 to 99)
1985* Hoffert and Flannery (fig. 5.16) | low	(*38*)	1985–2019	64 (58 to 76)	77 (49 to 97)
1985* Hoffert and Flannery (fig. 5.16) | nominal	(*38*)	1985–2019	99 (80 to 99)	89 (65 to 99)
1994* Jain *et al*. | nominal	(*40*)	1994–2019	97 (71 to 99)	89 (54 to 99)
1997* Kheshgi *et al*. | nominal	(*92*)	1997–2010	93 (49 to 98)	34 (−43 to 80)
2001 Albritton *et al*. | nominal	(*90*)	2001–2019	84 (60 to 98)	81 (18 to 98)
2003* Kheshgi and Jain (fig. 7c) | nominal	(*91*)	2003–2019	56 (41 to 85)	85 (55 to 98)
2003* Kheshgi and Jain (fig. 8c) | nominal	(*91*)	2003–2019	72 (51 to 95)	88 (37 to 99)
Average of all projections			67 (60 to 74)	67 (58 to 76)
Average of ExxonMobil models			72 (66 to 78)	75 (70 to 81)

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Best of luck!