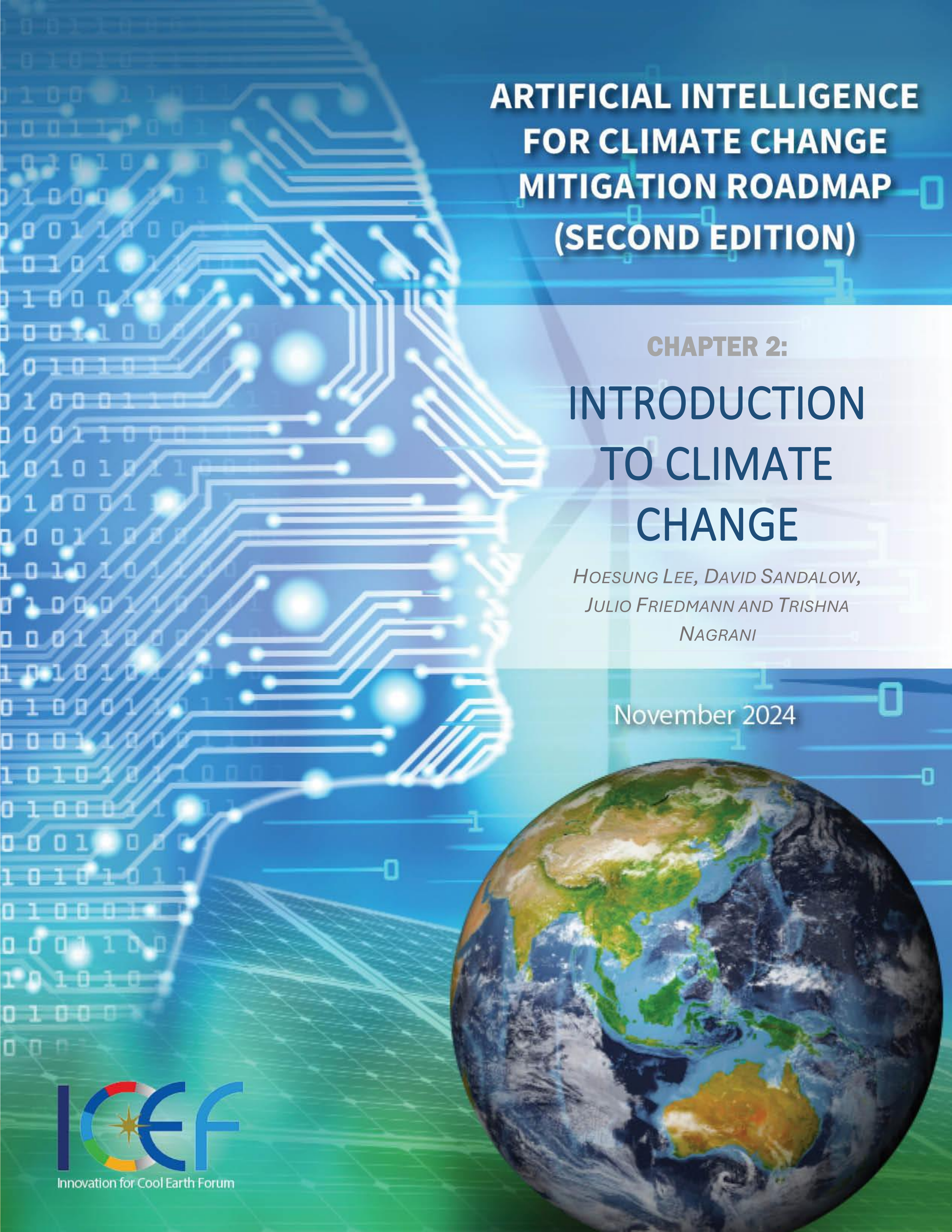

ARTIFICIAL INTELLIGENCE FOR CLIMATE CHANGE MITIGATION ROADMAP (SECOND EDITION)

CHAPTER 2:

INTRODUCTION TO CLIMATE CHANGE

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Innovation for Cool Earth Forum

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A. Climate Change Background

Concentrations of heat-trapping gases in the atmosphere are now higher than at any time in human history.[1] This is changing the Earth's climate.[2] (See Figures 2-1 and 2-2.)

The Earth's average global temperature has risen by more than 1 °C (almost 2 °F) since the second half of the 19th century.[a] (See Figure 2-3.) Based on global average temperatures:

- July 22, 2024 was the hottest day ever recorded[4]
- July 2023 was the warmest month ever recorded[3]
- 2023 was the warmest year on record, by a substantial margin (the average temperature was 1.45 ± 0.12 °C above pre-industrial levels)[3]
- The last decade is likely the warmest 10-year period on record[3]

The principal heat-trapping gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and fluorinated gases (such as HFCs and SF_6). These are commonly called greenhouse gases (GHGs). (See Figure 2.) CO_2 is responsible for roughly 76% of the warming impact of GHGs globally. Methane is responsible for roughly 18%, nitrous oxide for 4% and fluorinated gasses for 2%.[5]

Human activities are the principal cause of the buildup of GHGs in the atmosphere.[1] Those activities include burning fossil fuels (coal, oil and gas), land use and land-use change, and patterns of consumption and production.[1] Roughly 34% of global GHG emissions come from electricity and heat production; 24% from industry; 22% from agricultural, forestry and other land use; 15% from transport and 5% from buildings.[5]

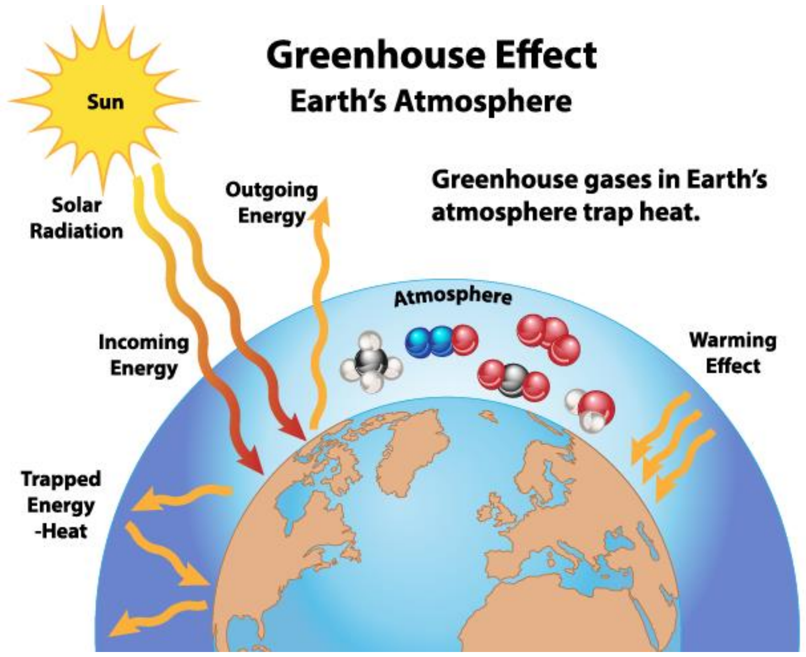

Figure 2-1. Greenhouse Effect.

[a] To be precise, the Earth's average global temperature from 2014-2023 was 1.2°C (1.9°F) above the 1850-1900 average.[3]

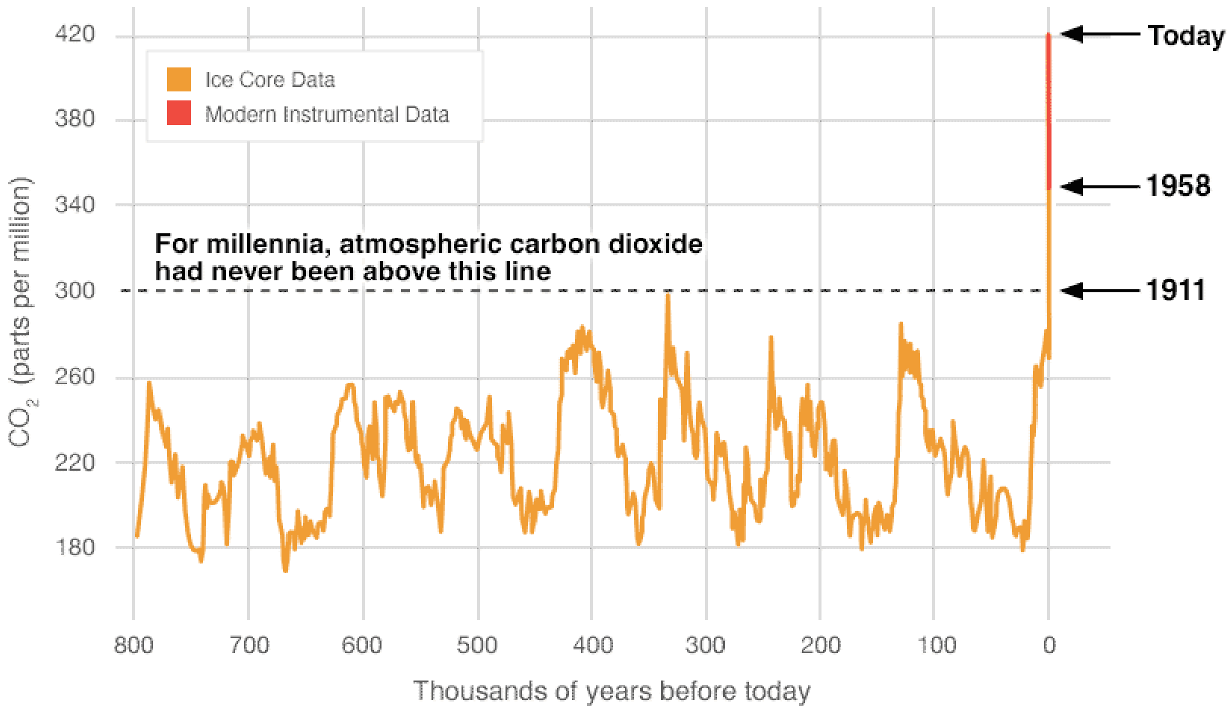

Figure 2-2. *NASA, Global Climate Change, Vital Signs of the Planet, Carbon Dioxide.*[6]

Since 1850, cumulative net CO_2 emissions have been 2400 ± 240 $GtCO_2$, 42% of which occurred during the last 30 years (see IPCC, 2023 *Summary for Policymakers* at p. 5[1]).

The impacts of a changing climate are being felt across the globe:

- Storms, heat waves and droughts have increased in frequency and intensity in recent decades. Scientists are increasingly able to attribute these increases directly to human activities—in particular the burning of fossil fuels.[7,8]
- Warming air temperatures and droughts, made more likely by climate change, have directly contributed to increased fire risk in many parts of the world. For example, changes in the climate over the past 30 years are associated with a doubling of extreme fire weather conditions in California.[9]
- Approximately 3.3–3.6 billion people are highly vulnerable to climate hazards, including acute food insecurity and reduced water security.[1]
- Between June and August 2022, Pakistan experienced unprecedented floods, which affected 33 million individuals. Over 1700 lives were lost and more than 2.2 million houses were destroyed or damaged.[10]

Billions of people face extraordinary risks unless the buildup of heat-trapping gases in the atmosphere slows and then reverses in the decades ahead.[11] Those risks include even more severe and frequent storms, floods, droughts and heat waves, as well as sea-level rise.[12] One study found

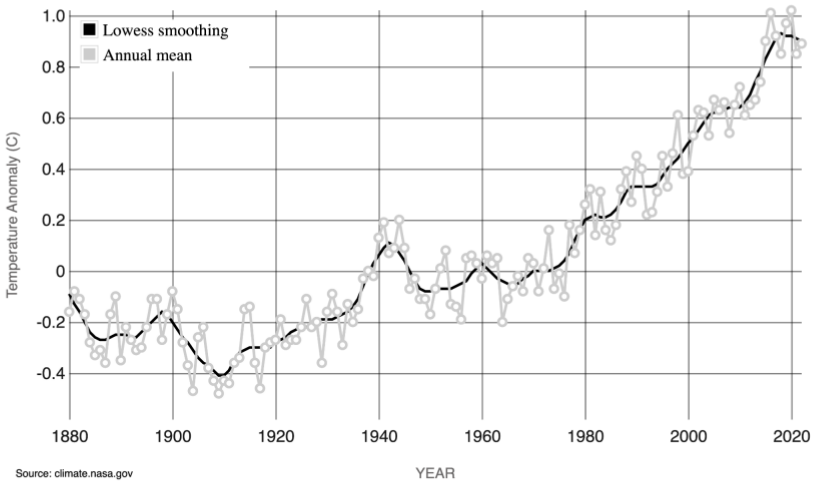

Figure 2-3. *Global average temperatures 1880-2022.*[13]

that, in roughly a dozen locations across the Mediterranean and Middle East, temperatures are likely to reach 50 °C every year in the latter part of this century. Such temperatures were extremely rare or impossible in these locations in the pre-industrial world.[14]

Climate change is expected to increase heat-related mortality rates and the incidence of lung and heart disease associated with poor air quality. Higher temperatures and more frequent flooding events caused by climate change contribute to the spread of infectious and vector-borne communicable diseases, such as dengue, malaria, hantavirus and cholera.[15]

In 2015, more than 190 nations adopted the Paris Agreement, which calls for “holding the increase in global average temperature to well below 2 °C (3.6 °F) above pre-industrial levels” and “pursuing efforts to limit the temperature increase to 1.5 °C (2.7 °F) above pre-industrial levels.”[16] However, policies currently in place around the world would result in a global average temperature increase of 2.2–3.5 °C (4–6.3 °F) (see IPCC, 2023 at p. 11[1]) above preindustrial levels by 2100,[1] and many policies to limit emissions are not being fully implemented.[17] The world is not on a path to meet globally agreed upon climate change goals.

In April 2022, the Intergovernmental Panel on Climate Change (IPCC) Working Group 1 (WGI) concluded that it is almost inevitable that the Earth’s average temperature will temporarily exceed the Paris Agreement’s 1.5 °C threshold in the short-term, although global average temperatures could return to below that level by the end of the century. The IPCC also found that a return to levels below the 1.5 °C threshold can only be achieved with rapid and deep reduction in GHG emissions and enhanced CO_2 removal (see IPCC, 2023 at p. 23[1]).

B. Contributions of Artificial Intelligence to Climate Science

Artificial intelligence (AI) is making important contributions to the scientific understanding of climate change. While AI applications are still in relatively early stages of development, the progress to date suggests real opportunity for better monitoring of anthropogenic climate impacts, better understanding of how the Earth’s climate is likely to evolve and better predictions of climate impacts.

i. Improving climate model performance

The best scientific understanding of climate dynamics and forecasts of climate impacts are based on computer simulations of complex climate models. To validate these simulations, results are compared across models ("model intercomparison") and to historical weather data ("hindcasting"). AI can help improve this comparison process, identifying biases in specific models and extracting the most useful physical results from increasingly massive amounts of climate model output data.[18]

AI can also complement conventional physics-based climate modeling in hybrid approaches, dramatically reducing the need for certain very intensive computations[19] or improving the resolution of model outputs.[20] In some cases, AI can analyze the voluminous output of high-resolution climate models and assess potential biases in their predictions. A Stanford study using AI to analyze maps of temperature anomalies, for example, suggested that climate models underestimate the average rate of warming and that temperature increases are likely to exceed 1.5 °C by 2030–2035.[21] Already, AI has improved both the pre-processing[22] and post-processing[23] of climate models and numerical weather prediction.

A potential drawback of incorporating AI into climate simulations is less reproducibility (meaning that calculations cannot necessarily be repeated and arrive at essentially identical results). The complexity and probabilistic nature of some AI and machine learning (ML) techniques make this more challenging.[24]

ii. Improving the understanding of climate processes and feedbacks

The ability of AI to ingest and interpret immense volumes of climate and weather data has helped illuminate natural processes and important hidden feedbacks within the climate system. For example, one study identified the role of US Midwestern precipitation in modulating North Atlantic salinity.[25] Another AI-driven analysis of river floods illustrated that data-driven, empirical modeling using AI could perform as well as science-based simulations in many situations.[26] AI can also reduce uncertainties in certain key climate drivers. For example, a recent study improved the understanding of the interactions between aerosols and clouds, which has long been challenging for climate models to accurately represent.[27]

Figure 2-4. *Svalbard, Norway. (photo: David Sandalow)*

iii. Providing more advanced warning for extreme weather

Already, AI is beginning to improve weather forecasts associated with extreme events, providing accurate, near-term advanced warning in critical contexts.[28] This work has made major strides in the past two years and could ultimately transform climate adaptation responses. Some of the most crucial areas in which this AI-enabled "nowcasting" (within 6 hours) capability is being applied include extreme precipitation[29] and extreme wind speeds,[30] with additional work on predicting extreme heat over timescales of days to weeks.[31]

iv. Attributing extreme events to human influence

Climate attribution is a rapidly changing field, and understanding how climate change leads to extreme events is important for governments, companies and public stakeholders. AI has already provided insights into human attribution around specific phenomena and mechanisms. These include river flooding in Europe,[32] tropical cyclone intensity,[33] periods of frost occurrence[34] and many more. New organizations and government programs like Europe's XAIDA[35] are dedicated to this important task.

v. Revealing additional climate drivers

The ability of AI to analyze visual and numerical data for patterns has greatly improved the understanding of certain man-made climate drivers. For example, AI-based analysis of satellite data from the US National Aeronautics and Space Administration (NASA) revealed much higher ship-track cloud formation than was previously known (10 times greater) and detected a long-term reduction over 20 years due to sulfur reductions in maritime fuels.[36]

C. Readings

There is a vast literature on climate change, including many books and articles introducing climate change to non-experts. The following sources may be helpful:

Books

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