How do we know that the recent rise in CO_2 is driving global warming, rather than being just a remnant of a natural process like the end of the last ice age?

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1. Timing and Rate of CO_2 Increase

- **Ice core data** show CO_2 levels over hundreds of thousands of years. After the last ice age (~12,000 years ago), CO_2 did increase naturally, but **very slowly** - on the order of 10 to 20 ppm per thousand years.
- In contrast, since the Industrial Revolution (~1750), CO_2 has risen from ~280 ppm to over 420 ppm **in just 270 years** . That's orders of magnitude faster than natural post-ice-age increases.
- This rapid rise is much faster than any natural process could produce and correlates closely with fossil fuel burning.

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2. Carbon Isotope Evidence

- Carbon in CO_2 comes in different isotopes: C^{12}, C^{13}, C^{14}.
    - C^{12} has 6 protons and 6 neutrons for a mass number of 12
    - C^{13} has 6 protons and 7 neutrons for a mass number of 13
    - C^{14} has 6 protons and 8 neutrons for a mass number of 14
- Fossil fuels are very old, so their carbon is depleted in C^{13} and has no C^{14}, which are radioactive. Radioactive carbon decays over thousands of years.
- Observations show that the extra CO_2 in the atmosphere is **isotopically identical to fossil fuels** , meaning it's not leftover natural CO_2 from the ice age.

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3. Energy Balance and Physics

- The physics of greenhouse gases is well understood. CO_2 traps heat by absorbing infrared radiation emitted from the Earth's surface.
- Laboratory experiments and satellite measurements confirm that the amount of warming expected from the observed CO_2 increase matches what we are seeing globally.
- If CO_2 weren't increasing, global temperatures would not rise as fast as they have.

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4. Global Temperature Records

- The warming pattern matches CO_2-driven models:
    - Faster warming at night than day (consistent with greenhouse effect).
    - More warming in the Arctic than the tropics.
- These patterns cannot be explained by leftover ice-age effects.

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5. Other Natural Causes Are Ruled Out

- Volcanic activity, solar changes, and orbital cycles are well-studied.
    - Volcanic CO_2 emissions originate from magma, crustal materials, and recycled subducted materials, with their isotopic signatures tending to have a higher ratio of carbon-13 to carbon-12 than present in the atmosphere.
    - If solar activity were driving modern warming, both the surface and upper atmosphere would heat simultaneously, but observations show surface warming and stratospheric cooling, which matches the effect of greenhouse gases, not the sun.
    - Precise measurements show no recent increase in solar radiation reaching Earth that would result from orbital cycles; in fact, incoming solar energy has slightly decreased over the last 40 years.
- None of these can account for the rapid warming of the last 150 years. The only major factor that matches both the **timing and magnitude** of warming is the increase in CO_2 and other greenhouse gases.

☑ **Bottom line:**
The CO_2 we see today is mostly from fossil fuels, not the ice age. The increase is rapid, isotopically identifiable, and fully consistent with the observed global warming and physical climate models. The “remnant CO_2 from the ice age” idea is inconsistent with both the speed and the chemical signature of the CO_2 rise.

The raw **ice core data** are publicly available from several scientific archives. Here are some of the main sources where you can download them:

◇ **1. NOAA Paleoclimatology Data Center (USA)**

- Maintained by the National Centers for Environmental Information (NCEI).
- Has data from major ice core projects (Vostok, Dome C, Law Dome, etc.).
- Website: NOAA Paleoclimatology Ice Core Data

◇ **2. NOAA Mauna Loa Observatory (modern CO_2 records)**

- Continuous atmospheric CO_2 measurements since 1958.
- Often used together with ice cores to extend the record.
- Website: NOAA Global Monitoring Laboratory

◇ **3. World Data Center for Paleoclimatology (WDC Paleo)**

- A repository of paleoclimate data including Antarctic and Greenland ice cores.
- Provides CO_2, CH_4, N_2O, and isotopic data.
- Website: WDC Paleo Archive

◇ **4. European Project for Ice Coring in Antarctica (EPICA)**

- Produced the famous Dome C 800,000-year record.
- Data are freely available through the European ice core databases.
- Info: EPICA Project Page

◇ **5. National Snow & Ice Data Center (NSIDC)**

- Hosts ice core and related paleoclimate datasets.
- Website: NSIDC Data