

Refrigerants and Climate Change: Don't throw away your refrigerator

Description:

Refrigeration and cooling make food safer, people more comfortable, and protect us in heat waves. The chemicals used to power cooling can be extremely powerful greenhouse gases, adding to climate change. Students investigate the Montreal Protocol, CFC and HCFC replacement, summer heat patterns, and the physics of infrared energy. Then, they investigate two real-world questions in their local community.

Skills & Objectives

SWBAT

- Summarize the goals of the Montreal Protocol and its Amendments
- Concisely explain why CFCs have been replaced with other compounds
- Understand why refrigerants contribute to climate change
- Explain the relationship between warmer summers and increased use of refrigerants
- Investigate real-world questions in their local community

Skills

- Reading formal texts
- Science communication
- Graph reading
- Map reading
- Real-world investigation

Students Should Already Know That

The basics of the action of carbon dioxide and other gases as heat-trapping greenhouse gases.

Standards Alignment:

HS-ESS2-4 Use a model to describe how variations in the flow of energy into and out of Earth's systems result in changes in climate.

HS-ETS1-3 Evaluate a solution to a complex real-world problem.

HS-PS2-6 Communicate scientific and technical information about why the molecular-level structure is important in the functioning of designed materials.

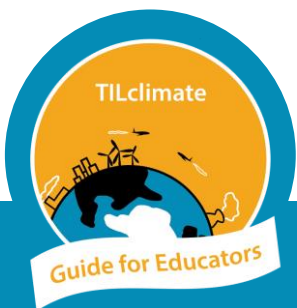
RST.9-12.2 Determine the central ideas or conclusions of a text

RST.11-12.9 Synthesize information from a range of sources into a coherent understanding of a process, phenomenon, or concept.

Disciplinary Core Ideas:

ESS3.C Human Impacts on Earth Systems

ESS3.D Global Climate Change



Refrigerants and Climate Change

How To Use These Activities:



Pages with the circular “TILclimate Guide for Educators” logo and dark band across the top are intended for educators. Simpler pages without the dark band across the top are meant for students.

Each of the included activities is designed to be used as a standalone, in sequence, or integrated within other curriculum needs. A detailed table of contents, on the next page, explains what students will do in each activity.

A Note About Printing

All student pages are designed to be printable in grayscale, except for the graph and map on page 5. A few copies of this page could be printed color for students to share, or the image projected in the classroom. Larger versions of this graph and map are provided on pages 6 and 7.

For the Montreal Protocol activity, students could read the article online or the teacher may print copies ahead of time.

The worksheets do not leave space for students to answer questions. Students may answer these questions in whatever form is the norm for your classroom – a notebook, online form, or something else. This allows you, the teacher, to define what you consider a complete answer.

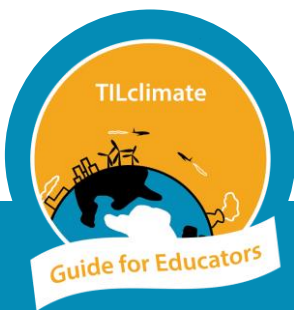
A Note About Timing

The first four activities all take about the same amount of time – less than a class period, allowing for an introduction and discussion. These four activities could be done as stations across multiple class sessions, or as a jigsaw with small groups each only doing one activity and sharing their learning with the rest of the class.

Share with us! We would love to hear any podcasts or see any other projects you or your students create! Email us at tilclimate@mit.edu, tweet us @tilclimate, or tag us on Facebook @climateMIT.

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Refrigerants and Climate Change

Detailed Table of Contents

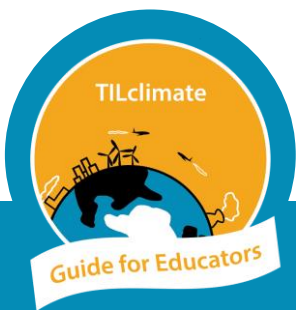
Page	Title	Description	Time (min)
	Podcast Episode	Students listen to TILclimate: Don't throw away your refrigerator, either as pre-class work at home or in the classroom. https://climate.mit.edu/podcasts/e3-dont-throw-away-your-refrigerator	10-15
1	The Montreal Protocol	Students read about the Montreal Protocol and its Amendments, with guiding questions.	30+
2-3	Telling a Story with Data	Students analyze AGAGE/NASA data on the presence of refrigerant chemicals in the atmosphere and try their hand at telling a concise story.	30+
4-7	Summer Heat	Students analyze temperature anomaly data for summer heat and consider the impact of these changes on air conditioning use around the world.	30+
8	Infrared Windows (internet required)	Students use a visualization to examine the power of synthetic refrigerants to trap more heat in Earth's atmosphere.	30+
9	Where Do Your Refrigerants Go? (internet required)	Students investigate what happens to refrigerators and air conditioners when they are disposed of in their community.	Variable
10	Investigate Your Supermarket (internet required)	Students visit their local supermarket and investigate and report which refrigerants are being used.	Variable

A Note About Real-World Investigations

The final two activities in this Guide require that students venture into the community to ask questions and investigate. For the disposal question, they may need to call or email city officials and businesses. For the supermarket investigation, they will need to take a geotagged photo of the refrigeration case and email it to an organization.

Depending on school rules, parental comfort, and student access to the necessary technology, these activities may not be appropriate for all situations.

Consider carefully whether your students have the technology, support, and know-how to ask these kinds of questions safely.



Refrigerants and Climate Change

Refrigeration and Refrigerants

This Educator Guide includes a reading, multiple data explorations, and two real-world investigations. Educators may pick and choose among the pieces of the Guide, as suits their class needs.

Parts of this Guide may align with the following topics:

- Physical science: Atmospheric chemistry, infrared energy, and chemical breakdown.
- Life/environmental science: Effects of ozone deterioration and climate change.
- History/social science: The Montreal Protocol and its Amendments.
- ELA/nonfiction: Reading and understanding legal and scientific texts.
- ELA/fiction: Futuristic fiction dealing with climate change.

MIT Resources

We recommend the following as resources for your own better understanding of climate change or as depth for student investigations. Specific sections are listed below:

- Climate Science, Risk & Solutions, an interactive introduction to the basics of climate change. <https://climateprimer.mit.edu/>
 - Chapter 02
 - Chapter 10
- MIT Climate Portal Explainers are one-page articles describing a variety of climate topics. New Explainers are posted monthly. <https://climate.mit.edu/explainers>
 - Heating and Cooling
 - Extreme Heat
 - Urban Heat Islands
 - Greenhouse Gases
 - Radiative Forcing
- MIT professors can answer your and your students' questions about climate change! Submit your questions or see other answers at <https://climate.mit.edu/ask-mit-climate>



Refrigerants and Climate Change

Wrap-Up Discussion Questions

- What are some successes of the Montreal Protocol and its amendments?
- What predictions do you make about the use of refrigeration and air conditioning around the world over the next few decades?
- Why are synthetic refrigerants such strong greenhouse gases?
- What surprised you when you investigated how refrigerants are disposed of?
- What surprised you when you visited your supermarket?

Climate Solutions

Climate solutions can be thought of as falling into four categories outlined below. Across all categories, solutions at the community, state or federal level are generally more impactful than individual actions. For example, policies that increase the nuclear, solar and wind mix in the electric grid are generally more effective at reducing climate pollution than asking homeowners to install solar panels. For more on talking about climate change in the classroom, see “How to Use This Guide”.

•Energy Shift

How do decision-makers make the switch from carbon-producing energy to carbon-neutral and carbon-negative energy?

•Energy Efficiency

What products and technologies exist to increase energy efficiency, especially in heating and cooling buildings?

•Adaptation

How can cities and towns adapt to the impacts of climate change?

•Talk About It

Talking about climate change with friends and family can feel overwhelming. What is one thing you have learned that you could share to start a conversation?

What solutions are the most exciting in your classes? We would love to hear from you or your students! Images, video, or audio of student projects or questions are always welcome. Email us at tilclimate@mit.edu, Tweet us @tilclimate, or tag us on Facebook @climateMIT.



Refrigerants: The Montreal Protocol

“The Montreal Protocol was a landmark piece of environmental policy. It was enacted in 1987 and within about 10, 15 years it stimulated the phase out of the chlorofluorocarbons and their replacement by less dangerous chemicals to the ozone layer called hydro chlorofluorocarbons and hydrofluorocarbons—the latter ones containing no chlorine at all.”

*Professor Ron Prinn, MIT Department of Earth, Atmospheric and Planetary Sciences
TILclimate podcast: Don't throw away your refrigerator*

The Montreal Protocol

In 1987, all 197 member countries in the UN ratified the Montreal Protocol, which phased out chlorofluorocarbons. This action, along with follow-up additions to the Protocol, has had wide-ranging effects on Earth's atmosphere, climate, human health, and ecological health.

Read the United Nations Environment Programme's summary of the Montreal Protocol at <https://www.unep.org/ozonaction/who-we-are/about-montreal-protocol>

For each segment, answer the following questions:

The Montreal Protocol

- What does the original 1987 Montreal Protocol regulate?
- How does the Protocol handle developed vs developing countries' responsibilities?
- How does the Protocol get updated over time?

The Multilateral Fund

- What kinds of projects are supported by the Fund?

The Montreal Amendment

- Why was the Protocol amended?
- Which chemicals are targeted by this amendment?

The Kigali Amendment

- Why was the Protocol amended again?
- Which chemicals are targeted by this amendment?

Success Achieved

- What are some successes of the Montreal Protocol and its amendments?

Refrigerants: Telling a Story with Data

“In the 1970s, there was a discovery that the chlorofluorocarbons, when they are leaked to the atmosphere, catalytically destroy ozone.”

*Professor Ron Prinn, MIT Department of Earth, Atmospheric and Planetary Sciences
TILclimate podcast: Don't throw away your refrigerator*

Telling a Story with Graphs

When faced with data, graphs, math, and chemistry, it can be tempting to think, “I don’t know enough about this to understand it.” When we tell a story with data and graphs, we can make it accessible and understandable – even when we don’t know absolutely every detail.

In the podcast episode, we learned that chlorofluorocarbons (CFCs) were phased out after the 1987 Montreal Protocol. In their place, refrigerants called hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) are used today.

On the next page, you will find a series of graphs from the Advanced Global Atmospheric Gases Experiment (AGAGE) at MIT. They show the concentration (amount) of various CFCs, HFCs, and HCFCs in Earth’s atmosphere over time.

Tell the Story

1. Look closely at the graphs on the following page. Pay special attention to the dates at the bottoms of the graphs.
2. What do you notice about the amounts of these compounds in the atmosphere?
3. In a pair or small group, discuss what you notice across the graphs.
4. If you put the data together (overlapping the graphs), how could you explain what happened? Try to use simple language, as if you were explaining it to a 4th or 5th grade student.

Watch Out!

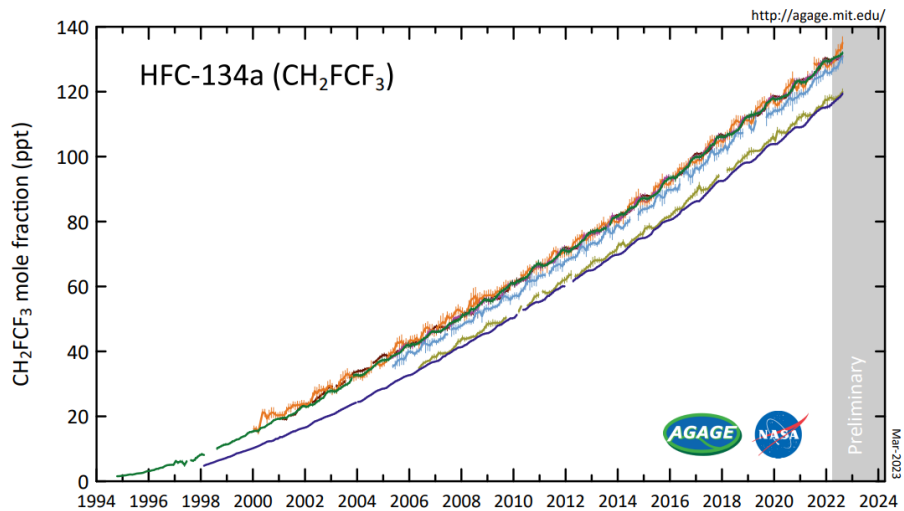
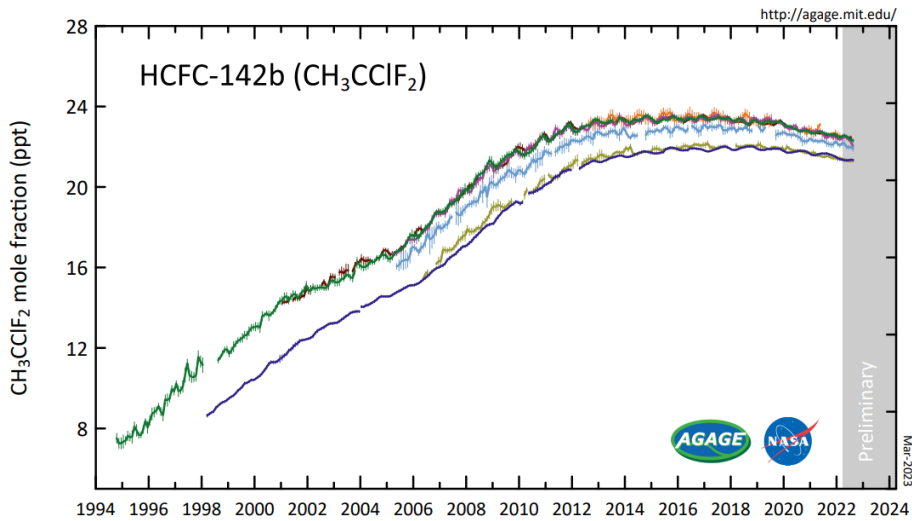
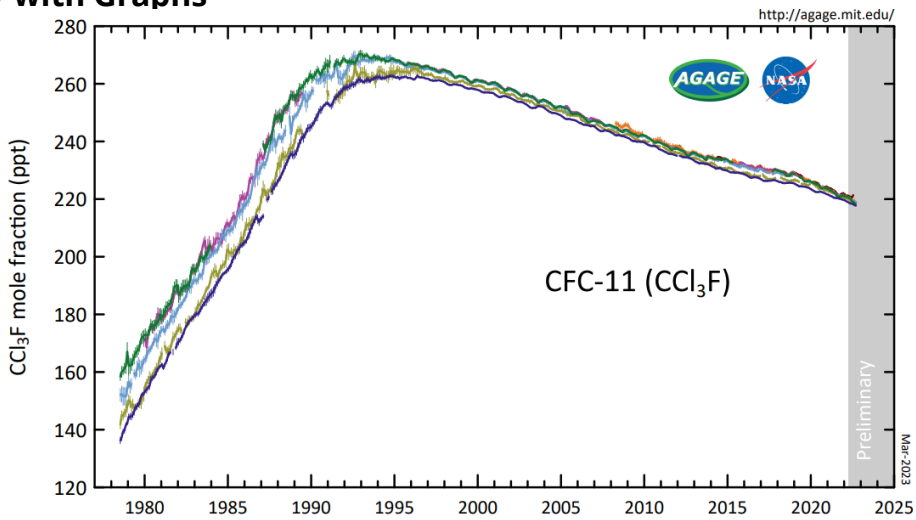
The Montreal Protocol was designed to counter the effect of CFCs on the **ozone layer** of Earth’s atmosphere. Later amendments to the Protocol have focused on CFCs, HCFCs, and HFCs for their ability to trap heat and add to **climate change**.

It is easy to mix these two stories up! Make sure that your explanation for these graphs focuses on the original story about the “hole” in the ozone layer.

If you’d like a challenge, see if you can add in the fact that these chemicals also trap heat in the atmosphere, without confusing your audience.

Refrigerants: Telling a Story with Data

Telling a Story with Graphs



The ALE/GAGE/AGAGE Data Base <http://agage.mit.edu/data>

Refrigerants: Summer Heat

“The refrigerants are in every refrigerator and freezer in your home. The refrigerants are also in the air conditioners in your home, either the window air conditioner or the big compressor that sits outside.”

*Professor Ron Prinn, MIT Department of Earth, Atmospheric and Planetary Sciences
TILclimate podcast: Don't throw away your refrigerator*

We Do Need Refrigerants

Refrigeration keeps food safer and allows us to transport foods around the world.

Air conditioning saves lives during heat waves.

Medical treatments are made possible by keeping medications cold.

Refrigeration, and the refrigerants that make it possible, has made life better for billions of people around the world.

But They Do Have Impacts

When refrigerant chemicals leak (from faulty equipment or disposal), they enter Earth's atmosphere. These chemicals, along with carbon dioxide, methane, and others, act like a blanket around Earth, trapping heat. This trapped heat is warming Earth, making average temperatures warmer in almost all parts of the planet.

While we may still experience cooler months or cold snaps in the winter, average temperatures across the globe are going up. On the next page, you will see a graph and a map showing *temperature anomalies* for the summer months.

Observe

What statements can you make from the graph and map?

What story do these data tell?

Analyze

Based on what you observe, what predictions do you make about the use of refrigeration and air conditioning around the world over the next few decades?

Extend

To explore maps based on a different base period, or to see anomalies during other times of year, visit <https://data.giss.nasa.gov/gistemp/maps/>

What is a Temperature Anomaly?

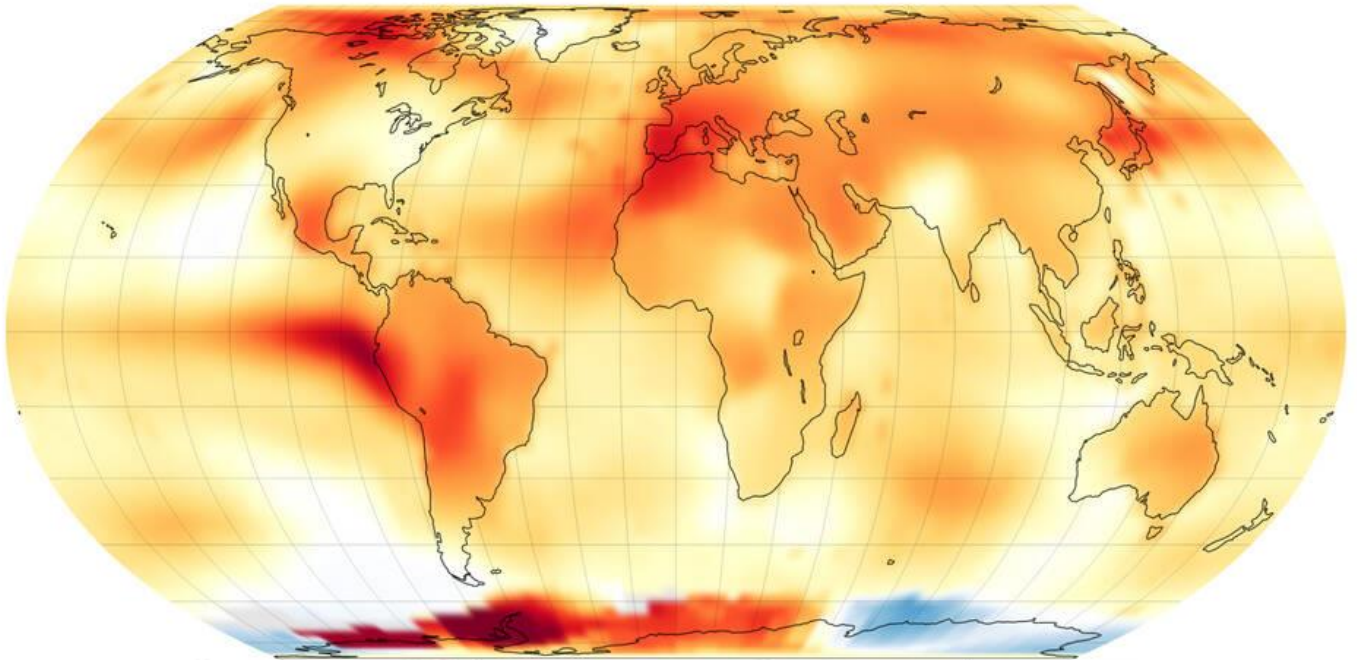
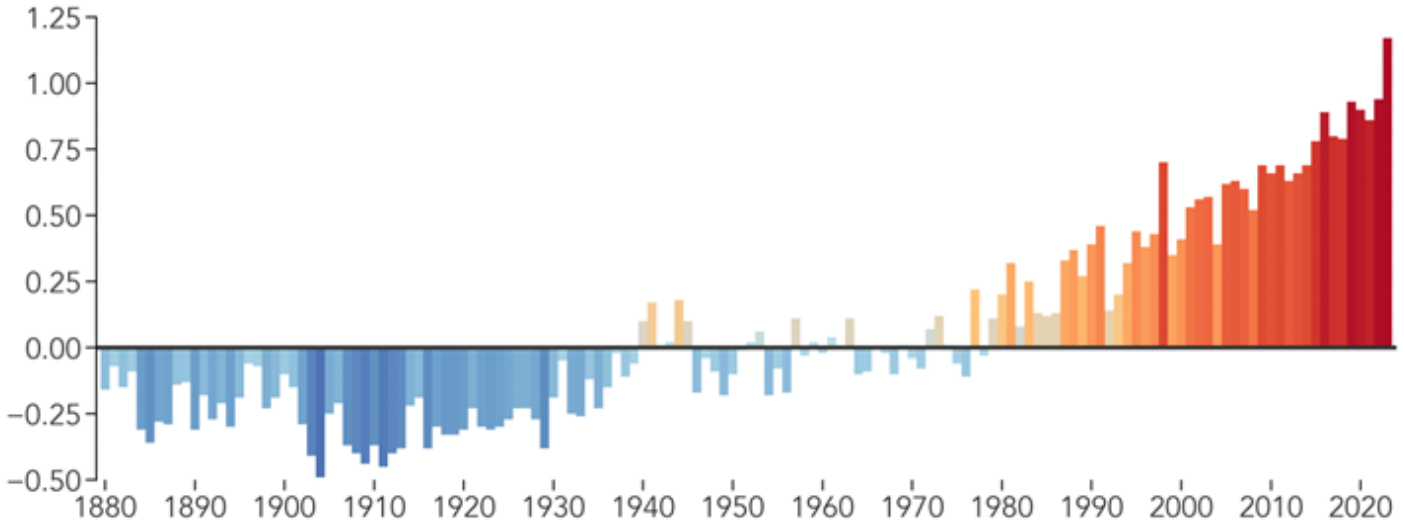
An *anomaly* is something that is out of the ordinary. To calculate a temperature anomaly, scientists use a three-decade (30 year) average and compare to that average, called the *base period*. In this case, an average from 1951-1980.

Average temperatures from June, July, and August (summer in the Northern Hemisphere) were compared against the average from these same months over those three decades.

Refrigerants: Summer Heat

Summer Temperature Anomalies

June, July, and August Global Temperature Anomaly (°C compared to the 1951-1980 average)



June, July, and August Global Temperature Anomaly (°C compared to 1951-1980 average)

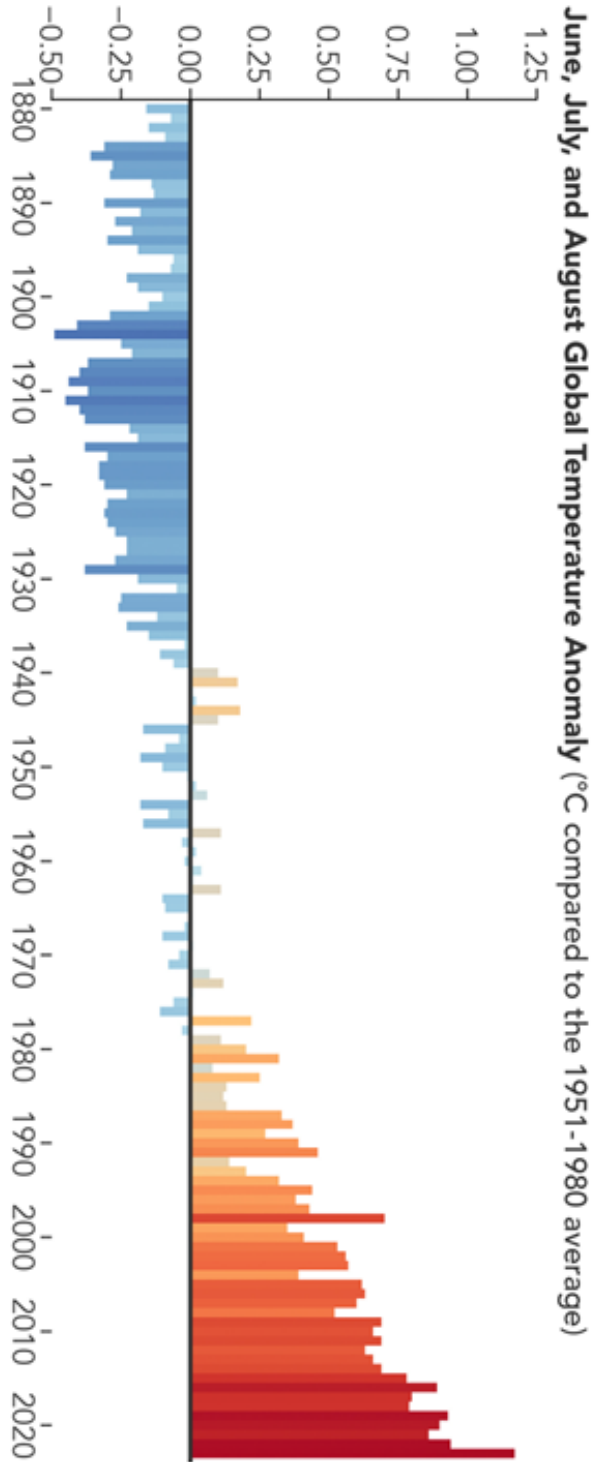


2023 Global average 1.17°C (2.11°F) above 1951-1980 average

NASA Earth Observatory/Lauren Dauphin
<https://www.nasa.gov/press-release/nasa-announces-summer-2023-hottest-on-record>

Refrigerants: Summer Heat

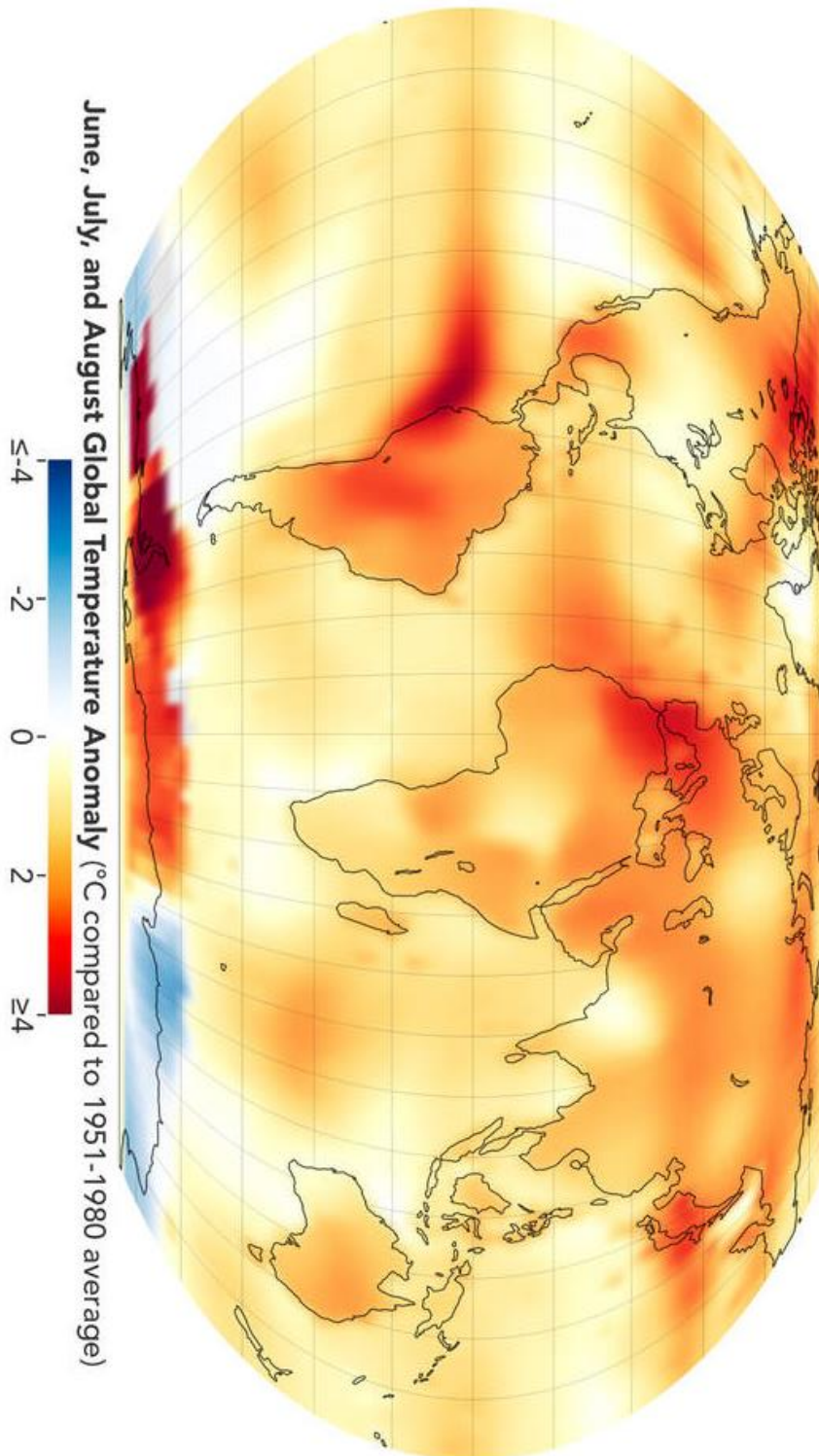
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Refrigerants: Infrared Windows

“They are potent because many of them last for thousands of years in the atmosphere, but they are more potent even because they absorb in regions of the infrared spectrum of the planet that carbon dioxide and water vapor do not absorb.”

*Professor Ron Prinn, MIT Department of Earth, Atmospheric and Planetary Sciences
TILclimate podcast: Don't throw away your refrigerator*

Infrared in the Atmosphere

As Earth's surface is warmed by the sun's rays, that warmth radiates back out toward space in the form of infrared (IR) energy. Atmospheric molecules, such as ozone (O₃), carbon dioxide (CO₂), water vapor (H₂O), methane (CH₄), and nitrous oxide (N₂O) can capture some of this IR energy. They release some of it out to space and radiate some of it back toward Earth's surface.

Molecules absorb and release different wavelengths of energy within the infrared range of the electromagnetic spectrum. Between the wavelengths absorbed, infrared energy passes through to space and does not get trapped by the atmosphere. These gaps are called *atmospheric windows* or *infrared windows*.

Refrigerant chemicals in the atmosphere, such as HFCs and CFCs, absorb wavelengths within these windows, increasing the amount of infrared energy that is reflected back to Earth instead of escaping to space.

Explore Infrared Windows

1. Visit <https://applets.kcvs.ca/IRWindows/IRWindows.html>
2. Along the bottom of the screen, select the following non-synthetic molecules: **H₂O**, **O₃**, **CO₂**, **CH₄**, and **N₂O**.

The y axis is labeled “Relative Intensity.” Molecules are categorized as having a *weak*, *medium*, or *strong* intensity at different wavelengths. On this graph, a *strong* intensity is close to zero, while a *weak* intensity is close to 1.

3. Look for “windows” where none of the selected molecules has a *medium* or *strong* effect.
4. Add in the following synthetic molecules: **C₃F₈**, **HFC**, and **CF₂Cl₂**.
5. Do these molecules “fill in” any “windows”?
6. Under **Display Options**, add **Black Body Curve**. This black line will highlight the range of IR wavelengths that are most reflected by Earth toward the atmosphere.
7. Which molecules (synthetic and non-synthetic) have *strong* effects within this curve?
8. What else can you learn from this graph?

Refrigerants: Where Do Your Refrigerants Go?

“Usually when they're dropped into the dump, they will end up leaking. And there are still a lot of chlorofluorocarbons stored in waste dumps around the world in old refrigerator units, and ultimately they've begun leaking out of the waste dumps as well.”

*Professor Ron Prinn, MIT Department of Earth, Atmospheric and Planetary Sciences
TILclimate podcast: Don't throw away your refrigerator*

Where Do Your Refrigerants Go?

When refrigerators or air conditioners stop working, owners generally want to get them out of their homes as quickly and easily as possible. Not only are these appliances heavy and awkward, but they also contain refrigerants that could leak.

Once the owner gets the appliance out of their home, what happens to it? Let's investigate.

Choose one place in your daily life that has a fridge or A/C. This could be your home, or, if appliances are owned by a landlord, you could choose your school or someplace else.

Location:

Which appliance will you focus on?

1. If you needed to throw out a refrigerator or air conditioner, who would you contact? This may be your city's Department of Public Works, a private company that handles garbage and recycling, or an individual who picks up scrap metal.
2. Ask whoever you contact how the refrigerants will be recovered, recycled, or reclaimed.
3. If they do not know, who else can you ask?
4. Once you get the name of a company or service, visit their website.
5. From the website, try to learn the following:
 - a. Are refrigerants recovered, recycled, or reclaimed? (For more on these definitions, visit <https://refrigerantservicesllc.com/how-refrigerants-are-recycled/>)
 - b. Are they an EPA-certified refrigerant reclaimer or do they send refrigerants to a certified reclaimer? (Double-check at <https://www.epa.gov/section608/epa-certified-refrigerant-reclaimers>)
 - c. If they are not prepared to safely dispose of refrigerants, EPA has information on how they can meet the legal requirements. <https://www.epa.gov/section608>
 - d. What else did you find that was interesting or surprising?
6. Compare with a partner. What did they learn about their place? What surprises you?

Refrigerants: Investigate Your Supermarket

“The best is to replace them with new, less dangerous chemical compounds. The ones that have the least impact on global warming among these synthetic fluorinated gasses are the shorter-lived ones. The shorter their lifetime, then the less damaging they'll be.”

*Professor Ron Prinn, MIT Department of Earth, Atmospheric and Planetary Sciences
TILclimate podcast: Don't throw away your refrigerator*

Supermarket Refrigeration

From the open produce and meats cases, to aisles of freezers, to the air conditioning that keeps the store cool in the summer, refrigeration is key to the functioning of supermarkets. Under ideal conditions, these systems should not leak very much refrigerant, but leaks happen due to maintenance, storage, and removal of units. By switching to less-damaging refrigerants, supermarkets can keep our food safe while adding much less to climate change.

Community-driven data collection can help organizations push more effectively for big businesses to change how they work. By investigating and reporting the refrigerants used at your local market, you are adding to a data pool that can be used to push for a quicker transition to less-damaging chemicals.

Investigate Your Market

1. Visit <https://www.climatefriendlysupermarkets.org/add-your-store> to learn how to read the labels on refrigerator cases at the supermarket.
2. Check the map at <https://www.climatefriendlysupermarkets.org/map> to see whether your local supermarket has already been reported. Try to choose a supermarket to visit that is not already on the map.
3. Visit your chosen supermarket and follow the instructions to take a geotagged photo of the refrigerator labels and email it in.

Consider

What did you learn from this investigation?

Were you surprised by what you found?

What other questions do you have about refrigerants at stores and businesses?