

# Enhancing Science Data Literacy Through Interactive Analysis of the Keeling Curve: A Case Study with Science-Gifted Students

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## Abstract

Climate change education requires data literacy to critically evaluate evidence. This study presents a Python-based module using authentic atmospheric carbon dioxide ( $\text{CO}_2$ ) data from the Keeling Curve to build science data literacy in secondary school students. Students analyze 67 years of Mauna Loa measurements, learn to access authoritative sources, apply computational visualization and analysis, and connect data to climate change conclusions. Assessments show significant gains in interpreting scientific data and understanding measurement uncertainty (Gould, Machado, Ong, Johnson, Molyneux, Nolen, Tangmunarunkit, Trusela, & Zanontian, 2016; Kjelvik & Schultheis, 2019).

## Introduction

**Background:** The Keeling Curve has documented atmospheric  $\text{CO}_2$  since 1958 and is a cornerstone dataset for climate change education (Keeling, Bacastow, Bainbridge, Ekdahl, Guenther, Waterman, & Chin, 1976; Keeling, 1960). Yet many students lack the data literacy needed to critically engage with such evidence.

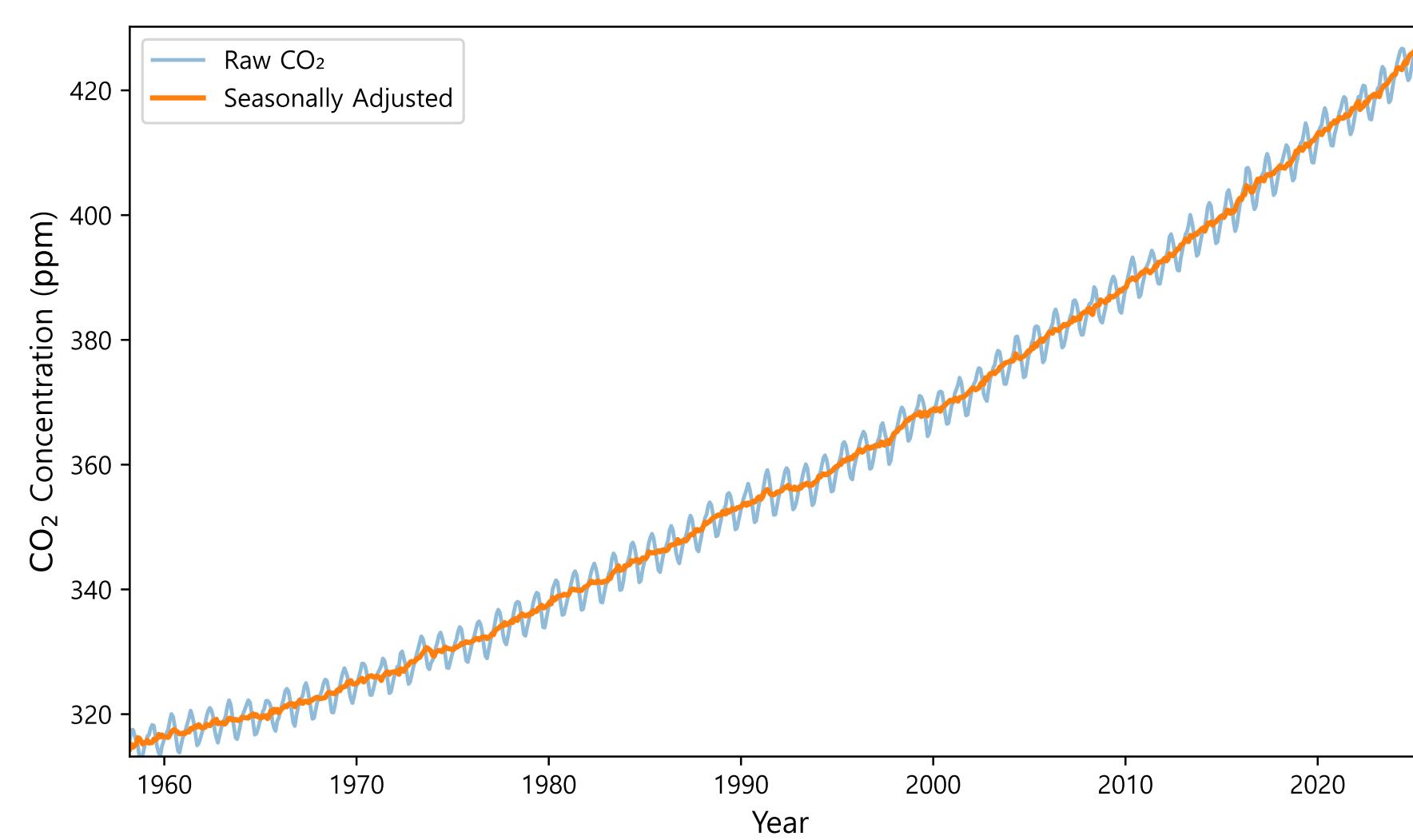


Fig. 1: Example of Keeling Curve visualization showing seasonal variation and long-term trend

**Why Data Literacy Matters:** Data literacy—the ability to read, work with, analyze, and argue with data (Wolff, Gooch, Cavero Montaner, Rashid, & Kortuem, 2016)—is essential for understanding climate science. Students must move beyond passive consumption and actively engage with primary data sources (National Research Council, 2012).

**Role of Computation:** Python and Jupyter notebooks make authentic datasets accessible and support both conceptual understanding and practical skills (Barba, Barker, Blank, Brown, Downey, George, Heagy, Mandli, Moore, Lippert, et al., 2019; Weintrop, Beheshti, Horn, Orton, Jona, Trouille, & Wilensky, 2016).

## Educational Framework

### 1. Learning Objectives

- Access and evaluate authoritative scientific data sources
- Apply Python tools for data visualization and analysis
- Interpret temporal patterns in atmospheric  $\text{CO}_2$  data
- Understand the relationship between data and climate science conclusions

**2. The 5E Instructional Model** This module follows the evidence-based 5E instructional framework (Bybee, Taylor, Gardner, Van Scotter, Powell, Westbrook, & Landes, 2006):

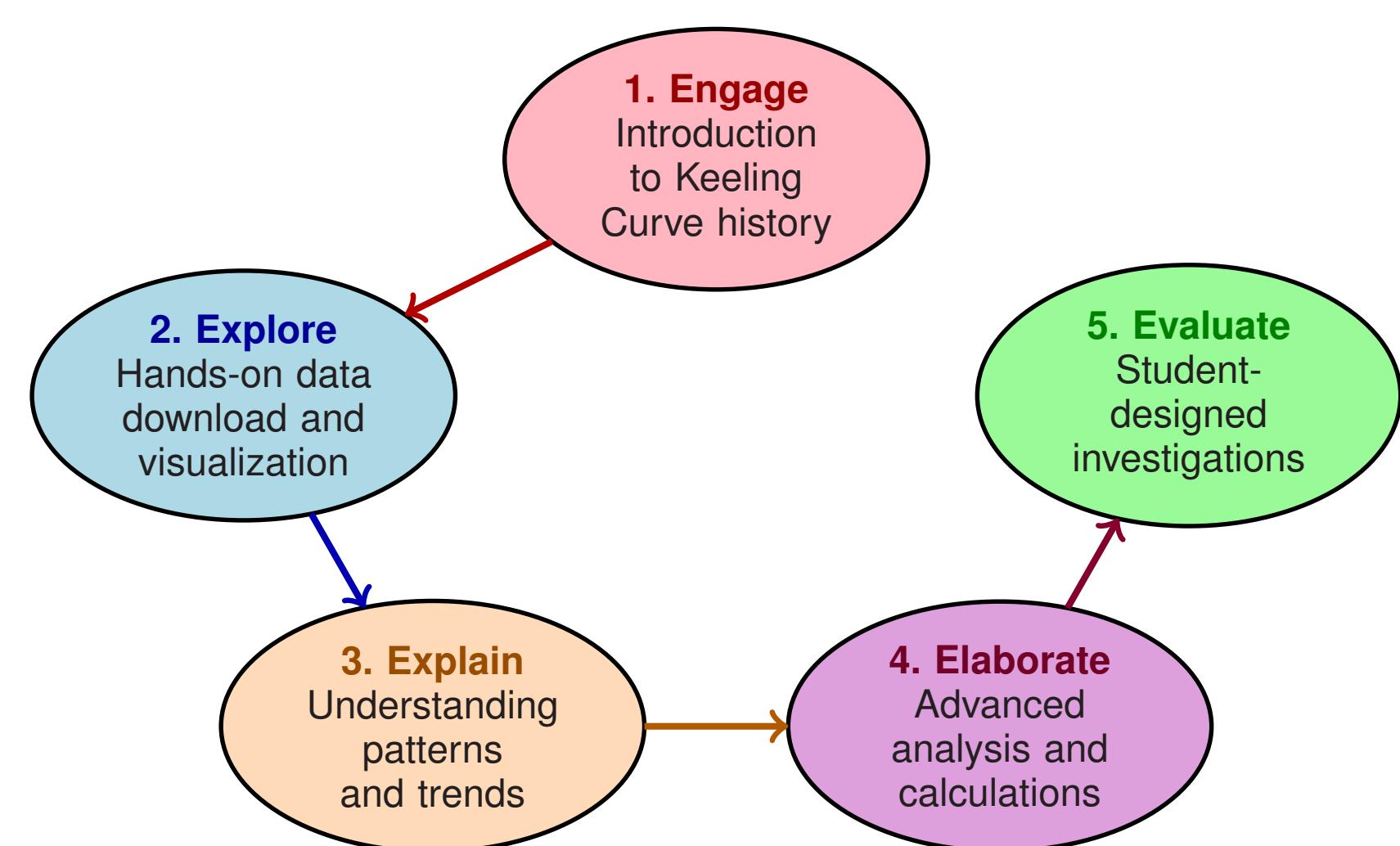


Fig. 2: The 5E instructional model used in this module

**3. Alignment with Standards** This approach aligns with Next Generation Science Standards (NGSS), emphasizing science practices, particularly analyzing and interpreting data (National Research Council, 2012; NGSS Lead States, 2013).

**4. The Keeling Curve Dataset** The Scripps  $\text{CO}_2$  Program provides the longest high-precision record of atmospheric carbon dioxide and underpins understanding of anthropogenic climate change. Its long time span and rigorous quality control make it well suited for educational applications.

- Source:** Scripps  $\text{CO}_2$  Program, Mauna Loa Observatory
- Duration:** 1958-present (67 years of continuous data)
- Significance:** Shows both seasonal variation and long-term trend (Keeling, Bacastow, Bainbridge, Ekdahl, Guenther, Waterman, & Chin, 1976; Thoning, Tans, & Komhyr, 1989)
- Current level:** 422.5 ppm (parts per million; 52% above pre-industrial)

## Methodology

### Technical Implementation

- Platform:** Jupyter Notebook with Python 3.8+
- Libraries:** pandas, matplotlib, numpy
- Cloud Option:** Google Colab for easy access
- Data Source:** Scripps  $\text{CO}_2$  Program

### Student Learning Activities

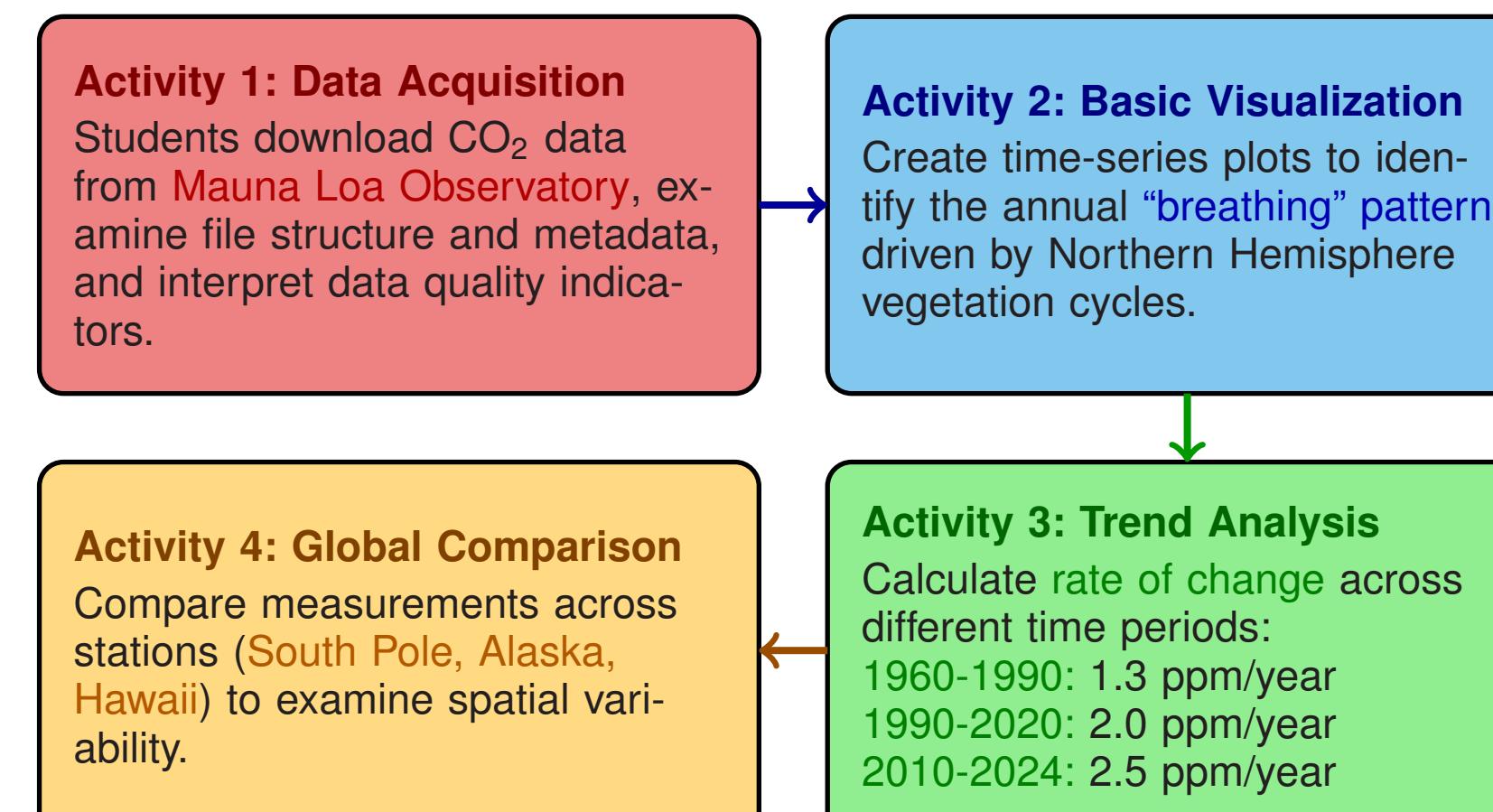


Fig. 3: Student learning activities aligned to the 5E cycle

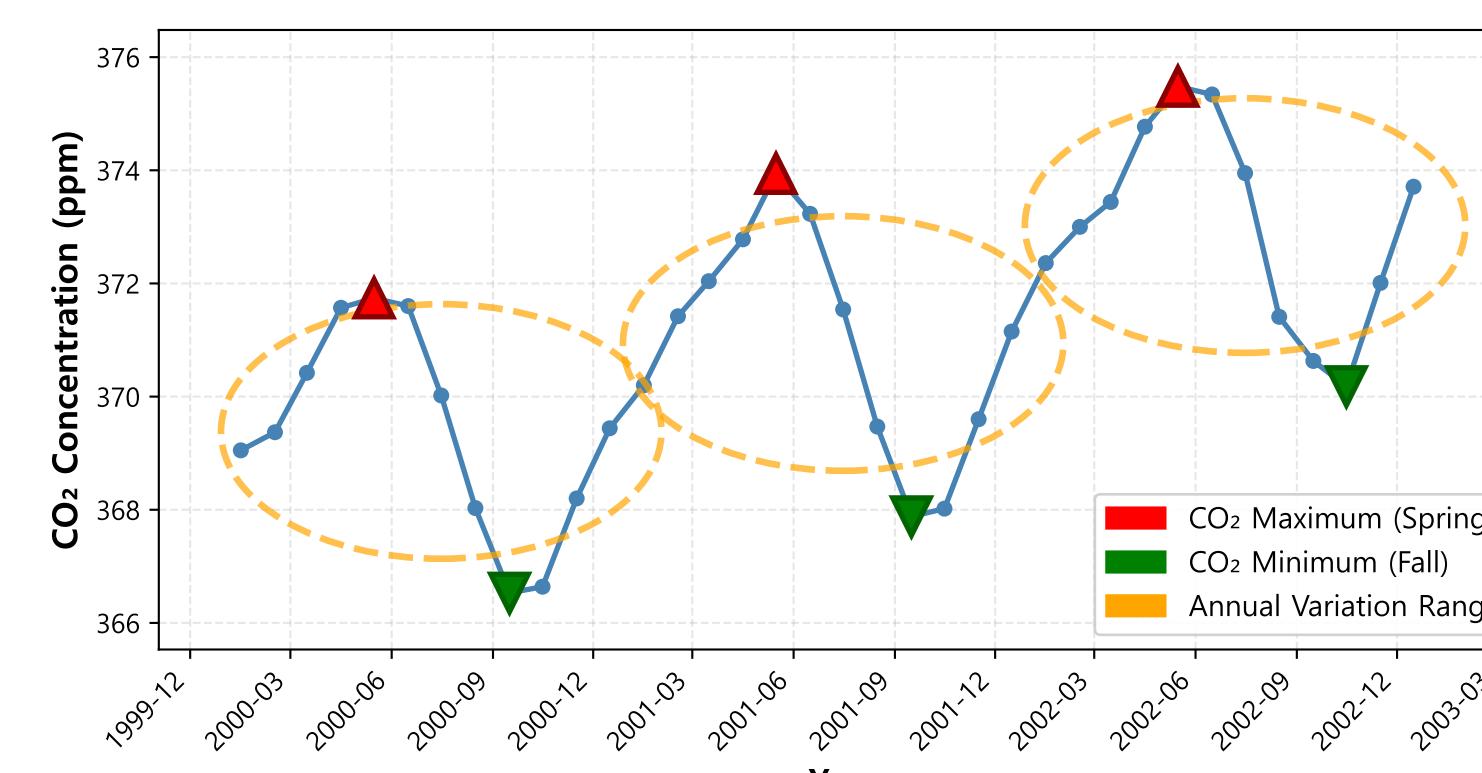


Fig. 4: Keeling Curve seasonal variation detail (2000-2002): understanding Earth's "breathing" pattern

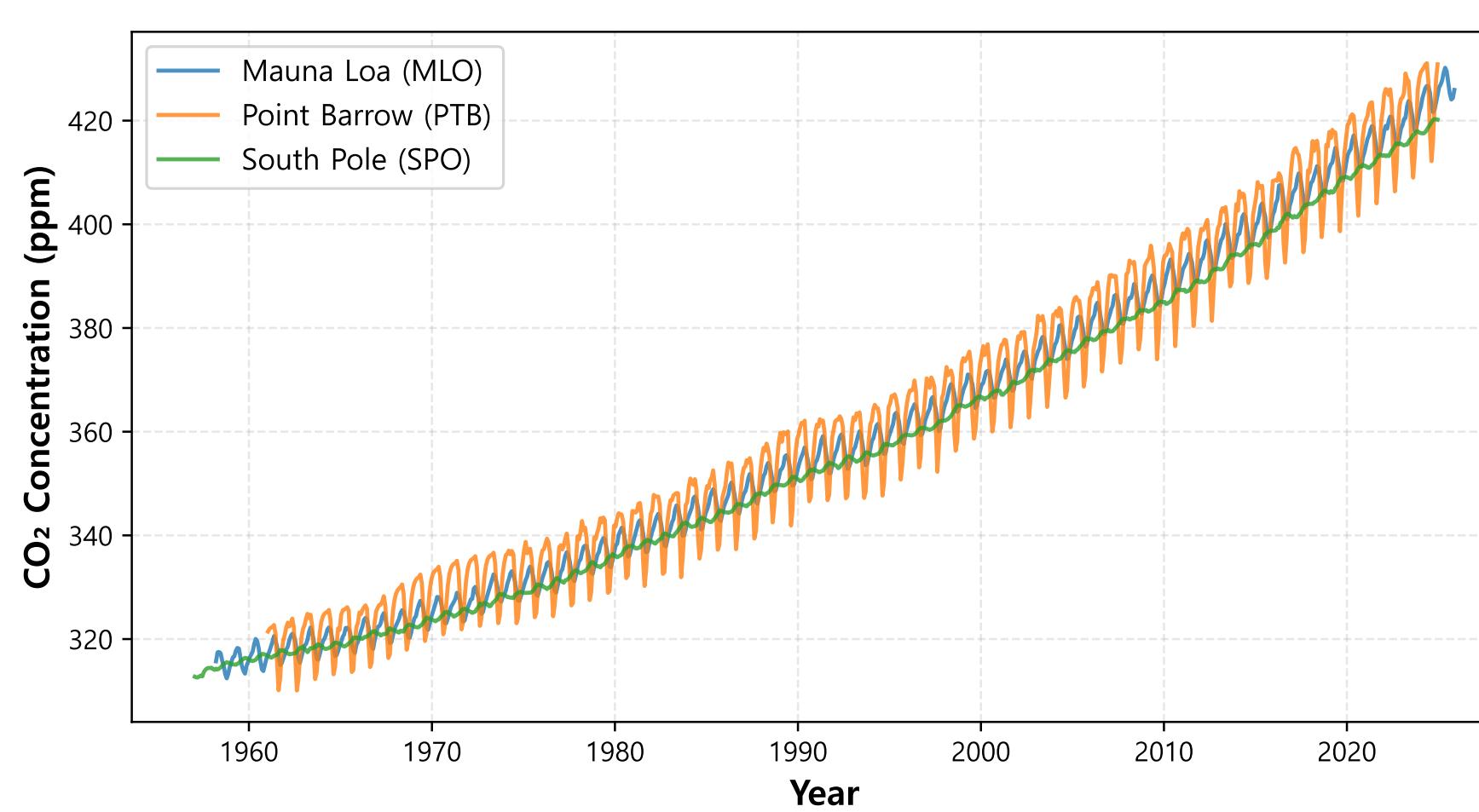


Fig. 5: Comparison of atmospheric  $\text{CO}_2$  across Mauna Loa, Point Barrow, and the South Pole

## Results

**Student Learning Outcomes** Assessments of 36 12th-grade students at a science-gifted high school showed significant gains across multiple dimensions (Pellegrino, 2013).

### Conceptual Understanding:

- Correctly explained seasonal  $\text{CO}_2$  oscillations
- Identified the long-term increasing trend
- Successfully calculated rate of change across decades
- Explained why Mauna Loa is appropriate for measurements

### Data Literacy Skills:

- Demonstrated ability to access authoritative data sources
- Correctly interpreted data quality indicators
- Distinguished raw vs seasonally-adjusted data
- Created appropriate visualizations

**Computational Competency:** Students executed Python code, modified it to answer new questions, wrote original code for calculations, and applied DataFrame operations.

**Engagement Metrics:** Engagement increased across indicators, including higher interest in climate science, preference for real data over textbook examples, and interest in using Python for future projects.

## Discussion & Conclusions

### Strengths of the Approach

- Authentic Science:** Using real data from authoritative sources (Scripps Institution) provides authentic scientific experience (Kjelvik & Schultheis, 2019)
- Scaffolded Learning:** Progressive complexity allows learners to engage at appropriate levels
- Interdisciplinary:** Integrates Earth science, mathematics, computer science, and communication
- Evidence-Based:** Students see climate change in data rather than rhetoric (IPCC, 2021)

### Challenges and Solutions

- Challenge:** Limited programming experience  
**Solution:** Provide pre-written code cells; use cloud platforms (Google Colab)
- Challenge:** Time constraints  
**Solution:** Modular design allows flexible implementation
- Challenge:** Mathematical prerequisites  
**Solution:** Visual explanations before formal treatment

### Key Findings

- Students engage successfully with authentic scientific datasets using computational tools (Weintrop, Beheshti, Horn, Orton, Jona, Trouille, & Wilensky, 2016)
- Direct interaction with data significantly enhances understanding of climate evidence
- Data literacy skills are transferable to other scientific contexts and align with NGSS standards for science practices (NGSS Lead States, 2013)

**Broader Significance** This approach shows that climate change education can move beyond passive information consumption to active scientific inquiry. By building data literacy with the Keeling Curve dataset, students gain conceptual understanding and practical skills essential for 21st-century citizenship (Monroe, Plate, Oxarart, Bowers, & Chaves, 2019).

### Future Directions

- Integration with temperature, ocean, and ice datasets
- Machine learning applications for predictive modeling
- Web-based interfaces for broader accessibility
- Cross-cultural adaptation and translation

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- Data Availability:** All Jupyter notebooks and educational materials are available at: [https://github.com/Kiehyun/ISCCCE2026/blob/main/appendix/The\\_Keeling\\_Curve\\_in\\_Action.ipynb](https://github.com/Kiehyun/ISCCCE2026/blob/main/appendix/The_Keeling_Curve_in_Action.ipynb)
- Atmospheric  $\text{CO}_2$  data courtesy of Scripps  $\text{CO}_2$  Program, Scripps Institution of Oceanography, UC San Diego (<https://scrippsc02.ucsd.edu/>).