

A Thesis
entitled
Development of Low-Cost Environmental Monitoring Sensor Prototypes for the GLOBE
Program
by
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Submitted to the Graduate Faculty as partial fulfillment of the requirements for the
Master of Science Degree in Chemical Engineering

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PREVIEW

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An Abstract of

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Environmental sensors provide vital data on a myriad of parameters including climate patterns, ecological processes, biodiversity levels, pollution concentrations, and soil conditions, among others. This data serves as a crucial foundation for policymaking, driving conservation efforts, managing natural resources, and expanding our collective knowledge of the natural world. Spaceborne sensors employed by NASA offer broad geographic coverage but can sometimes lack spatial precision in localized ground-level measurements. In contrast, ground-based sensors deliver precise, high-resolution localized data. However, to build a comprehensive picture, an extensive network of these sensors with wide geographic coverage is required. Here, the GLOBE program, a global citizen science initiative involving students, teachers, and citizens in collecting and reporting valid scientific measurements, emerges as a pivotal opportunity for widespread environmental data collection. Yet, the prohibitive costs of commercial ground sensors limit their broad deployment, especially in educational and community-driven monitoring contexts.

This work seeks to address this need by developing low-cost, customizable environmental sensors tailored for educational and citizen science initiatives like GLOBE,

which engage students and the public in hands-on environmental monitoring. Specifically, to develop inexpensive, easy-to-assemble Arduino-based sensors. In this study, air, surface, ground, urban heat island, and water quality sensors were developed using cost-effective, readily available components. These prototypes underwent rigorous calibration and validation testing to ensure their reliability and compliance with GLOBE's instrumentation specifications. The prototype is a configurable data logging system, that incorporates a real-time clock and an SD card module that enables customizable logging intervals and accurate timestamping of sensor data, and employs sleep modes to conserve power during deployment. This study includes comprehensive assembly instructions, program code, and materials lists to facilitate replication, modification, and future improvements. The successful testing and accessible nature of these sensor systems make them ideal for student learning and community-driven environmental monitoring in line with GLOBE's educational and scientific objectives.

This thesis is dedicated with love and gratitude to the memory of my beloved mother, whose endless love, resilience, and sacrifices made me the person I am today. She was my foundation and guiding light. Not a day goes by when I don't miss her presence. I would not have accomplished this feat without the values she instilled in me. I also dedicate this work to God Almighty, the author and finisher of my faith, for granting me the strength, wisdom, and perseverance to complete this journey successfully. It is by His grace that I have made it this far. I am eternally thankful for the opportunities I have been given and the purpose I have found.

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List of Abbreviations

CO ₂	Carbon dioxide
DIY	Do it yourself
DO.....	Dissolved Oxygen
EC	Electrical Conductivity
FS	Full Scale
FTDI.....	Future Technology Devices International Limited
GLOBE	Global Learning and Observations to Benefit the Environment
GPRTS.....	General Packet Radio Service
GPS	Global Positioning System
HDMI.....	High-Definition Multimedia Interface
ICSP	In-Circuit Serial Programming
IDE.....	Integrated Development Environment
I/O	Input/Output
IoT	Internet of Things
LoRa.....	Long Range Radio
LPDDR4	Low-Power Double Data Rate
MCU	Microcontroller Unit
MHz	Mega Hertz
NASA.....	National Aeronautics and Space Administration
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NPK.....	Nitrogen, Phosphorus and Potassium
NSF	National Science Foundation
NTP	Network Time Protocol
OTP	One Time Programmable
PCB	Printed Circuit Board
pH.....	Potential of Hydrogen
PM.....	Particulate Matter
PWM	Pulse Width Modulation
RTC.....	Real-Time-Clock
RX.....	Receiver
SCL	Serial Clock
SD	Secure Digital
SDA.....	Serial Data
SDRAM	Synchronous Dynamic Random Access Memory
SPI.....	Serial Peripheral Interface
STEM.....	Science, Technology, Engineering, and Mathematics

TX	Transmitter
UART.....	Universal Asynchronous Receiver/Transmitter
UHI	Urban Heat Island
USB.....	Universal Serial Bus
Wi-Fi/WiFi.....	Wireless Fidelity

PREVIEW

List of Symbols

°C	Degrees Celsius
mS/cm	millSiemens per centimeter
µS/cm	microSiemens per centimeter
mA.....	milliAmpere
mAh.....	milliAmpere hour
mg/L.....	milligram per liter
V.....	volt

Chapter 1

1 Introduction

1.1 Understanding the Impact of Climate Change and Industrialization

Throughout its history, Earth's climate has undergone numerous transformations, constantly shaping, and reshaping the planet's environment. However, the rapid rate of change observed since the industrial revolution in the 1800s marks an unprecedented shift in the environmental dynamics over the last 10,000 years as depicted in Figure 1-1 and Figure 1-2 [1]. Figure 1-1 illustrates the temporal trend of atmospheric carbon dioxide (CO_2) levels over the span of 800,000 years. Notably, it was only around 1950 that the CO_2 levels surpassed the historical peaks, which can be attributed to the significant release of CO_2 into the atmosphere through the burning of fossil fuels. This, in turn, has led to the rise in global surface temperatures, as illustrated in Figure 1-2, a phenomenon commonly referred to as global warming. The primary driver of this accelerated change has been the surge in industrial activities. These industrial operations, while instrumental in propelling human progress, have also exacted a considerable toll on the environment. The ramifications of this industrial growth are increasingly manifest in the extensive stress imposed on the entire ecosystem, including but not limited to the natural components such as water, air, soil, and biodiversity [2]. If the adverse impacts of industrialization are not

checked and mitigated, they could amplify into even more dire environmental problems. Climate change, air pollution, water pollution, and deforestation are some of the pressing issues that could intensify with continued unchecked industrialization [3]. These problems pose not just an existential threat to numerous species of flora and fauna, but also bear dire consequences for human health and well-being. Therefore, developing and implementing effective conservation strategies to address these issues is an urgent necessity.

1.2 Identifying and Quantifying Environmental Changes: The Role of GLOBE Protocols

At the heart of effective conservation lies the need to identify and quantify the changing parameters of the environment. Towards this end, NASA has devised a classification system, grouping these changing parameters into four major categories - the atmosphere, hydrosphere, biosphere, and pedosphere. These categories correspond to the Earth's air, water, living organisms, and soil, respectively [5]. Each of these categories encompasses various protocols, collectively known as GLOBE protocols as shown in Table 1-1. The GLOBE protocols refer to the set of methodologies and standards developed by the Global Learning and Observations to Benefit the Environment (GLOBE) Program. The GLOBE program is a program wherein students, teachers, and citizens are involved in observing the environment by taking valid scientific measurements and reporting them to a database [6]. These protocols provide comprehensive guidelines for collecting, analyzing, and sharing data about Earth's environment, thereby facilitating a systematic approach to understanding and addressing environmental changes [7, 8].

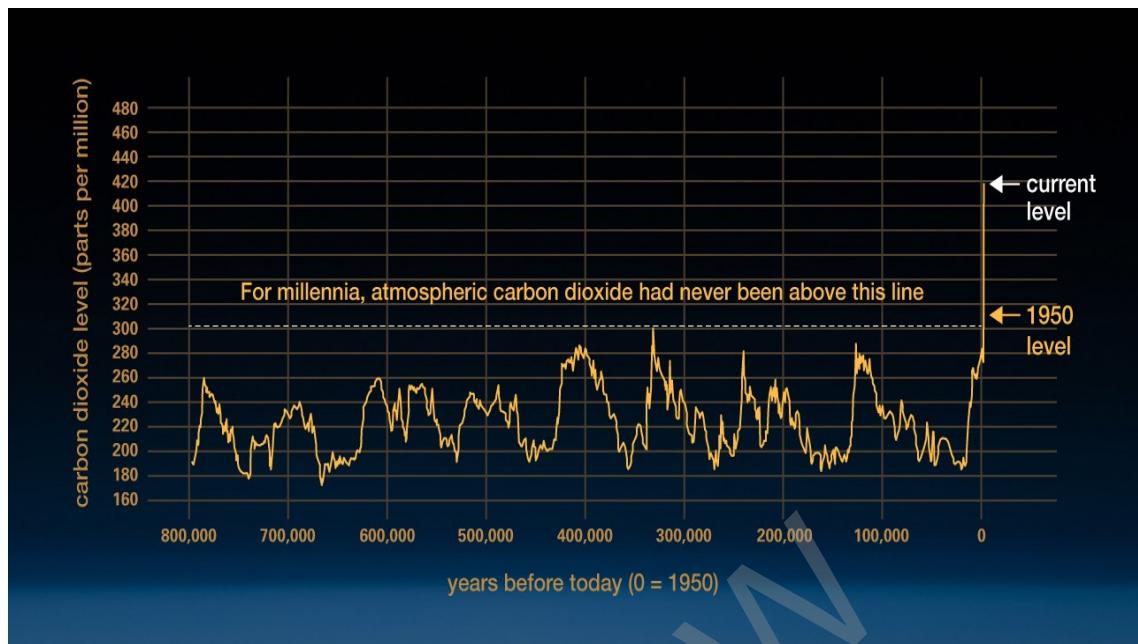


Figure 1-1: Atmospheric CO₂ changes over time [1]

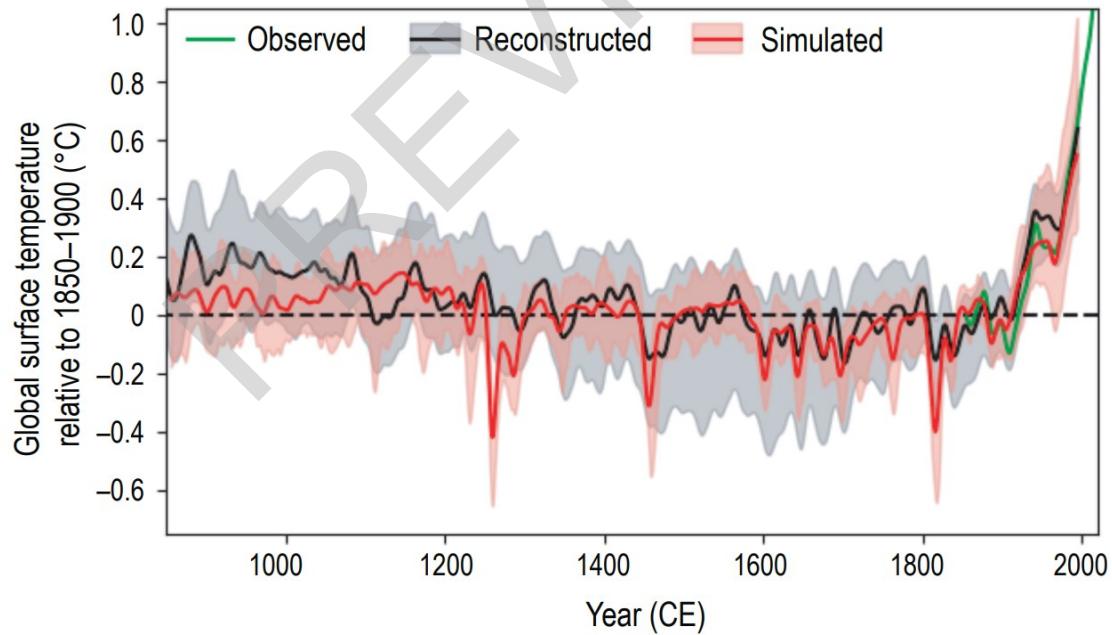


Figure 1-2: Global surface temperature in the past two thousand years [4]