

# Buoy Temperature Trends (1985-2024)

## Research Question

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How has sea surface temperature changed in Boston waters over the past 40 years, and does the warming trend vary by season?

```
library(data.table)
library(dplyr)
library(lubridate)
library(ggplot2)

# Load buoy data
load_buoy_data <- function(year) {
  url <- paste0("https://www.ndbc.noaa.gov/view_text_file.php?filename=44013h",
                year, ".txt.gz&dir=data/historical/stdmet/")
  header <- scan(url, what = 'character', nlines = 1, quiet = TRUE)
  buoy <- fread(url, header = FALSE, skip = 2, fill = TRUE)
  setnames(buoy, header)
  return(buoy)
}
all_data <- lapply(1985:2024, function(year) {
  tryCatch(load_buoy_data(year), error = function(e) NULL)
})
buoy_data <- rbindlist(all_data, fill = TRUE)

# Data cleaning
buoy_data <- buoy_data %>%
  mutate(
    YYYY = coalesce(as.character(YYYY), as.character(`#YY`), as.character(YY)),
    WTMP = na_if(as.numeric(WTMP), 999),
    datetime = ymd_h(paste(YYYY, MM, DD, hh), quiet = TRUE),
    Year = year(datetime),
    Month = month(datetime),
    Season = case_when(
      Month %in% c(12, 1, 2) ~ "Winter",
      Month %in% 3:5 ~ "Spring",
      Month %in% 6:8 ~ "Summer",
      Month %in% 9:11 ~ "Fall"
    )
  ) %>%
  filter(!is.na(WTMP) & !is.na(datetime))

# Filter complete years (≥50% data)
complete_years <- buoy_data %>%
  group_by(Year) %>%
  summarise(n = n()) %>%
  filter(n >= 4380) %>%
```

```
pull(Year)
buoy_data <- filter(buoy_data, Year %in% complete_years)
```

## Seasonal Temperature Trends

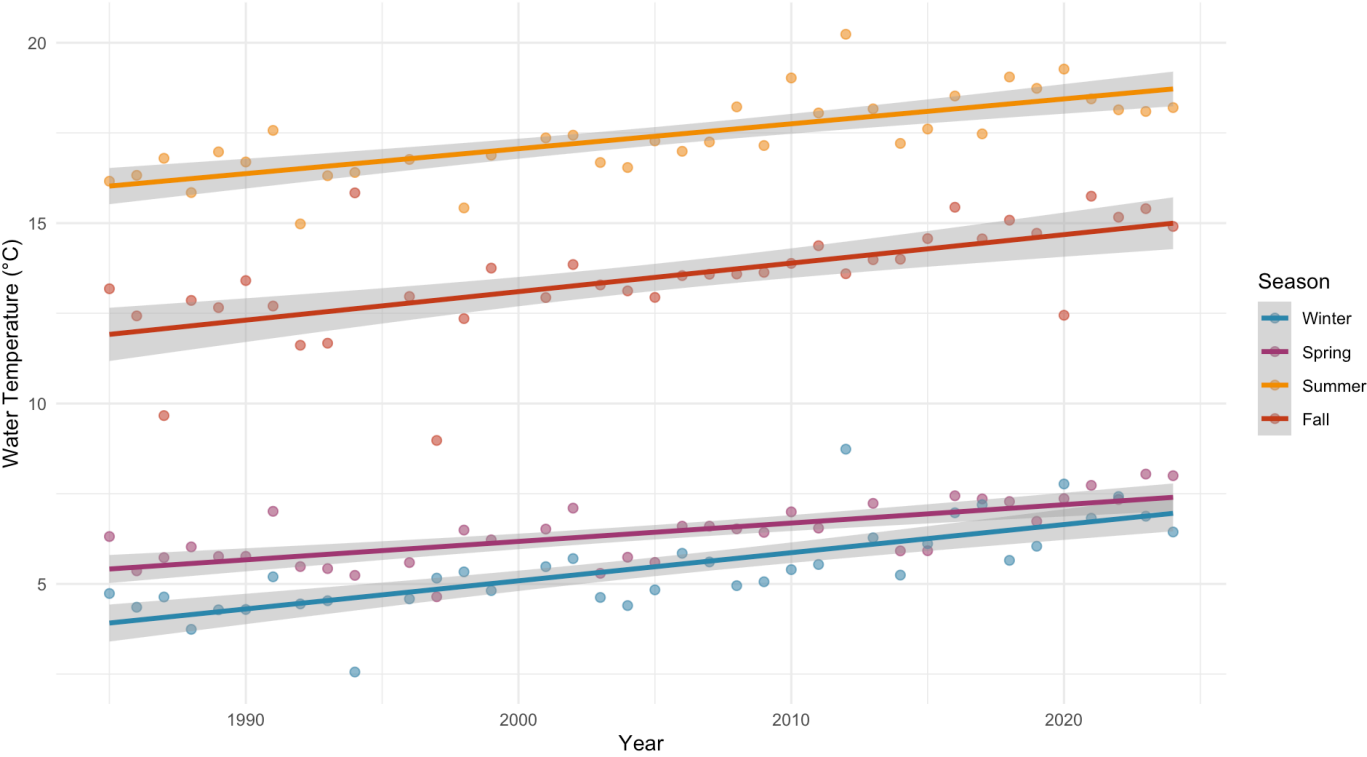
```
seasonal_avg <- buoy_data %>%
  group_by(Year, Season) %>%
  summarise(avg_temp = mean(WTMP, na.rm = TRUE), n = n(), .groups = 'drop') %>%
  filter(n >= 100)

seasonal_avg$Season <- factor(seasonal_avg$Season,
                              levels = c("Winter", "Spring", "Summer", "Fall"))

ggplot(seasonal_avg, aes(x = Year, y = avg_temp, color = Season)) +
  geom_point(alpha = 0.6, size = 2) +
  geom_smooth(method = "lm", se = TRUE, linewidth = 1.2) +
  scale_color_manual(values = c("Winter" = "#2E86AB", "Spring" = "#A23B72",
                                "Summer" = "#F18F01", "Fall" = "#C73E1D")) +
  labs(
    title = "Sea Surface Temperature Trends by Season (1985–2024)",
    subtitle = "NDBC Buoy 44013 – Boston Harbor",
    x = "Year",
    y = "Water Temperature (°C)"
  ) +
  theme_minimal() +
  theme(plot.title = element_text(face = "bold"))
```

Sea Surface Temperature Trends by Season (1985-2024)

NDBC Buoy 44013 - Boston Harbor



## Key Findings

```
# Warming rates by season
warming_rates <- seasonal_avg %>%
  group_by(Season) %>%
  summarise(
    temp_1990 = mean(avg_temp[Year <= 1990]),
    temp_2020 = mean(avg_temp[Year >= 2020]),
    change = temp_2020 - temp_1990,
    pct_change = (change / temp_1990) * 100)

overall <- buoy_data %>% # Overall warming
  group_by(Year) %>% summarise(annual_avg = mean(WTMP)) %>%
  summarise( early = mean(annual_avg[Year <= 1990]),
    recent = mean(annual_avg[Year >= 2020]), total_change = recent - early)
print(warming_rates)
```

```
# A tibble: 4 × 5
  Season temp_1990 temp_2020 change pct_change
<fct>    <dbl>    <dbl>   <dbl>    <dbl>
1 Winter      4.34      7.07    2.73     62.8
2 Spring      5.83      7.70    1.87     32.1
3 Summer     16.5     18.4    1.96     11.9
4 Fall       12.4     14.7    2.37     19.1
```

```
cat(sprintf("\nOverall change: %.2f°C (from %.2f°C to %.2f°C)\n",
    overall$total_change, overall$early, overall$recent))
```

Overall change: 2.05°C (from 9.85°C to 11.90°C)

- 1. Significant warming detected:** Boston waters warmed by **2.05°C** over 40 years.
- 2. Winter warming dominates:** Winter temperatures increased by **2.73°C (63%)**, far exceeding other seasons. This has major implications for marine ecosystems adapted to cold winters.
- 3. Seasonal differences:** Winter: +2.73°C (largest absolute and relative change). Fall: +2.37°C. Summer: +1.96°C (smallest relative change at 12%). Spring: +1.87°C
- 4. Ecosystem impacts:** The disproportionate winter warming disrupts seasonal temperature patterns that marine species depend on for migration, reproduction, and survival. This is consistent with broader Gulf of Maine warming trends, one of the fastest-warming ocean regions globally.