# TRENDS AND CHANGES IN THE NDBC WAVE RECORDS OF THE U.S. EAST COAST

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# Overview

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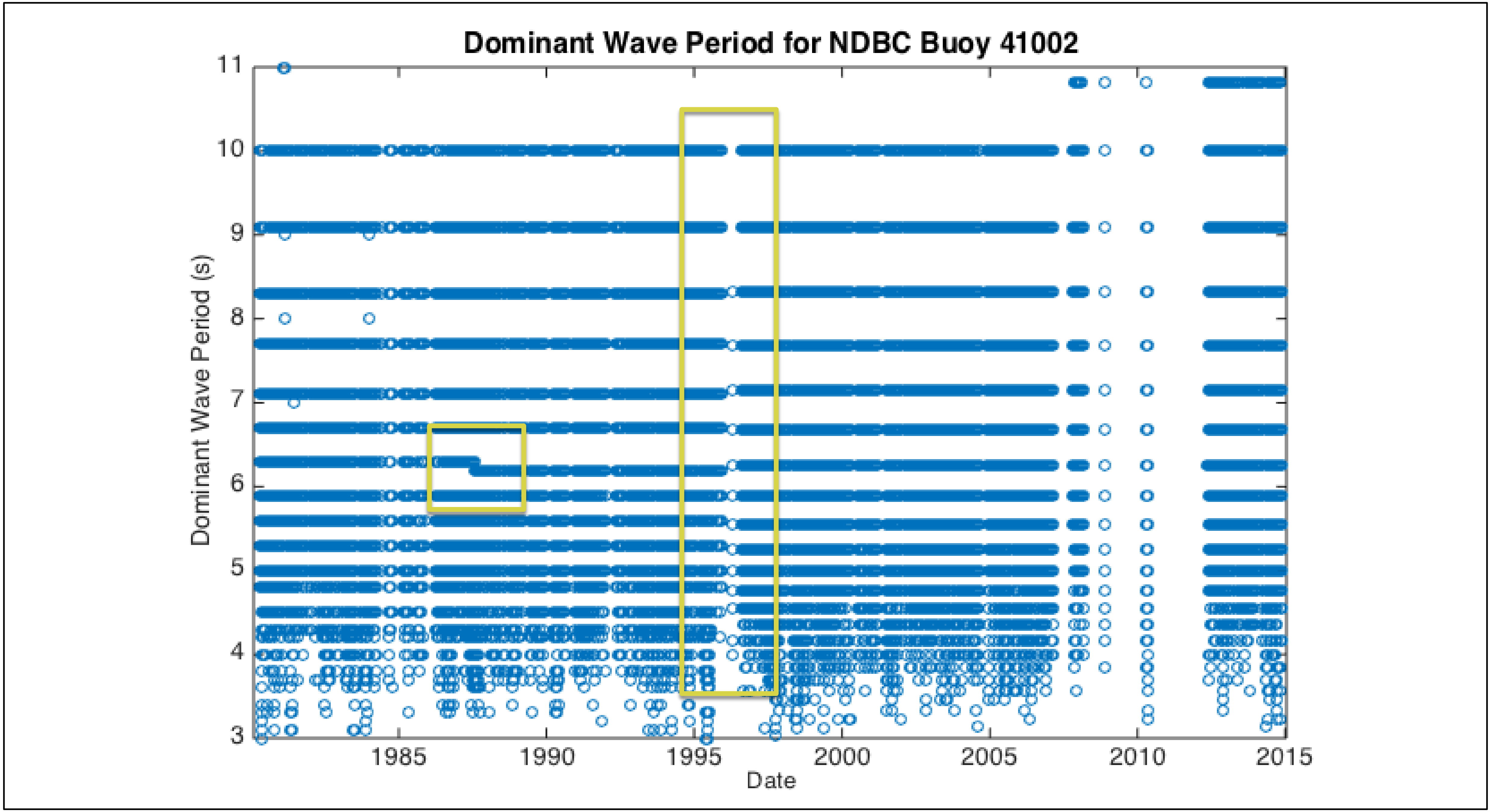
- Data Description
- Visual Inspection of Wave Records
- Methods: ANCOVA & Multiple Comparison Tests
- Results
  - Hull Type & Payload Type Analysis
  - Long-Term Trend Analysis
- Conclusions

# MOTIVATION



Dominant Wave Period for NDBC Buoy 41002
Dominant Wave Period (s)
Date
3
4
5
6
7
8
9
10
11
1985
1990
1995
2000
2005
2010
2015

# Available Metadata for Buoy 41002

| Buoy Number | Initial Deployment Date | Latitude (°N) | Longitude (°W) |
|---|---|---|---|
| 41002 | Dec-1973 | 32.3 | 75.3 |
| 41002 | Sep-1996 | 32.3 | 75.2 |
| 41002 | Feb-2002 | 32.3 | 75.4 |
| 41002 | Jul-2003 | 31.9 | 74.8 |

http://www.ndbc.noaa.gov/data_availability/data_avail.php

# data for Buoy 41002



| | | |
|---|---|---|
| 41002 | | |
| 41002 | | |
| 41002 | | |
| 41002 | Apr-1990 | 6N |
| 41002 | Jul-2003 | 3D |

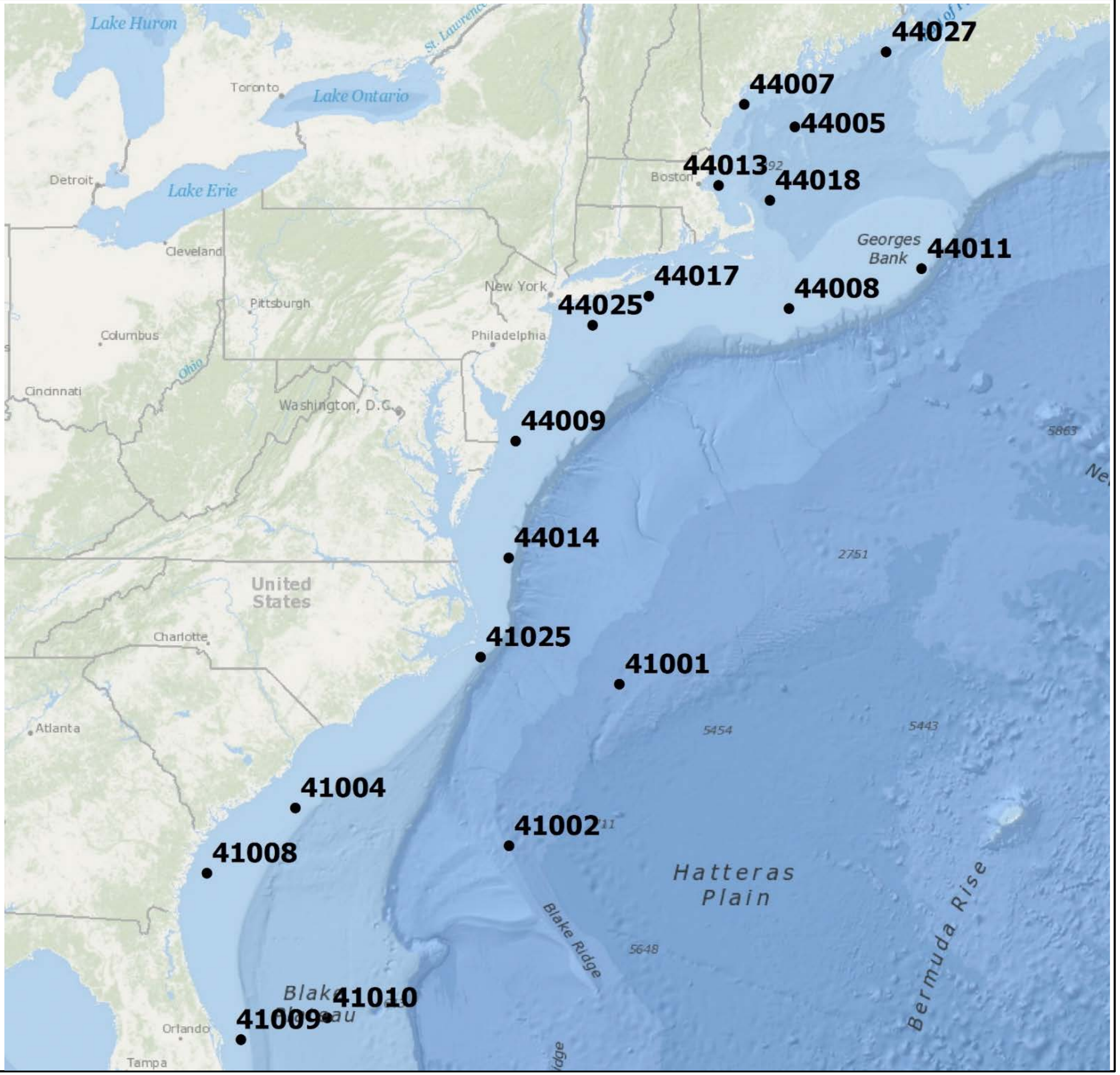
http://www.ndbc.noaa.gov/data_availability/data_avail.php

# DATA DESCRIPTION

# Selected Buoys

Three basic criteria

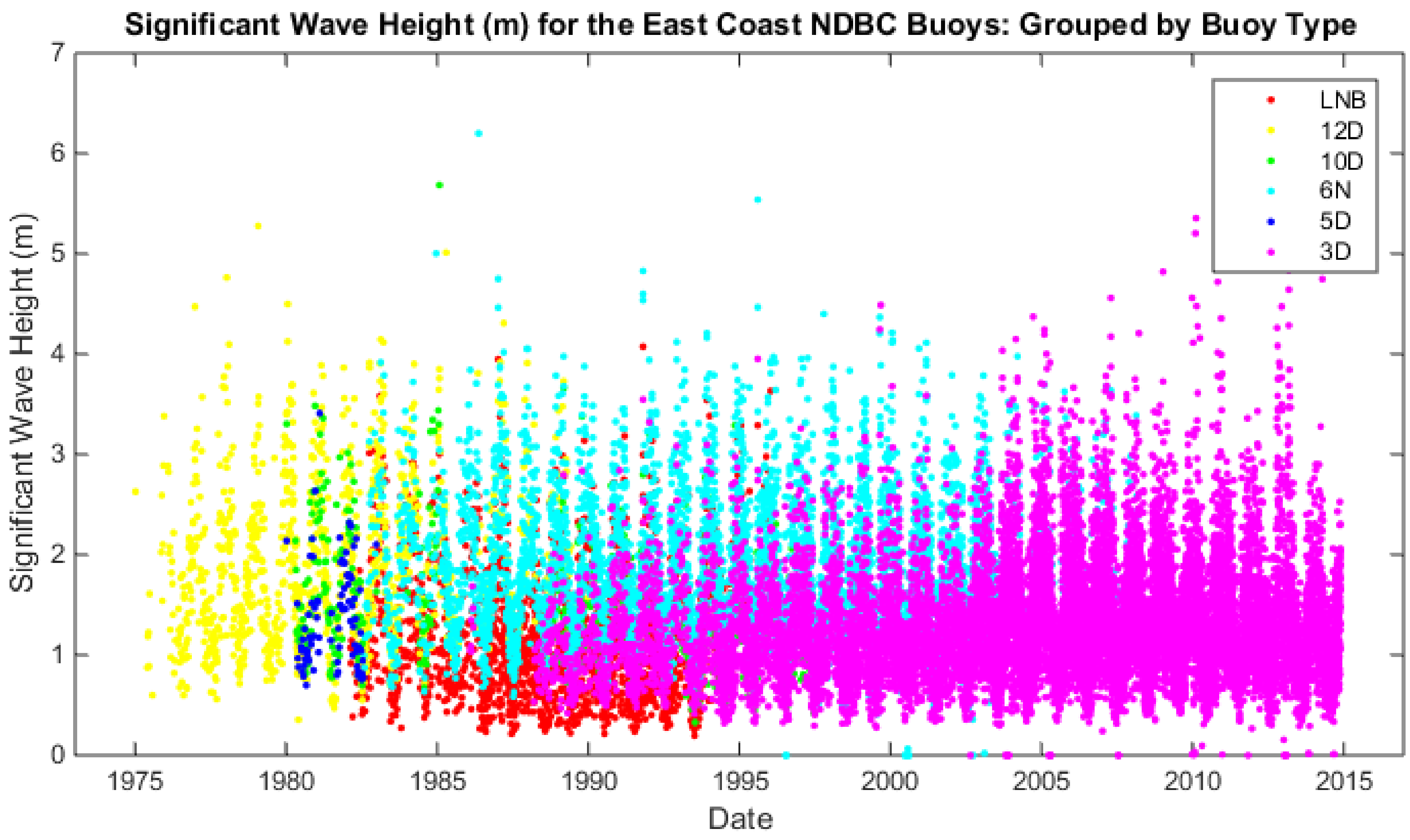
- U.S. East Coast
- Currently considered operational
- At least 10 years of data

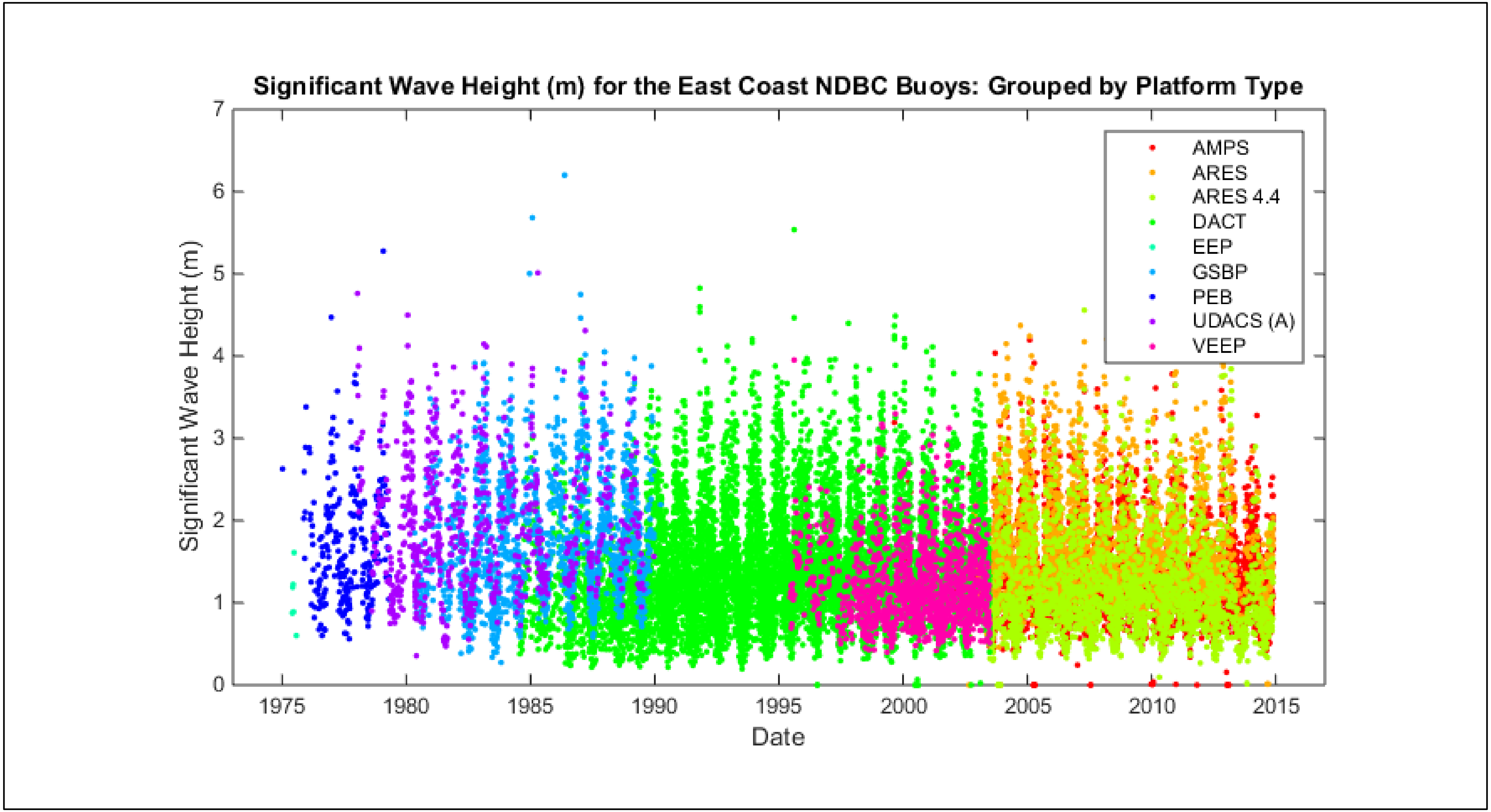


# NDBC Buoy Characteristics

| Buoy Number | Latitude (N) | Longitude (W) | Depth (m) | Initial Deployment |
|---|---|---|---|---|
| 41001 | 34°33'40” | 72°37'50” | 4462.3 | 6/76 |
| 41002 | 31°51'42” | 74°50'6” | 4297 | 12/73 |
| 41004 | 32°30'2” | 79°5'58” | 38.4 | 6/78 |
| 41008 | 31°24'0” | 80°52'5” | 19.5 | 3/88 |
| 41009 | 28°31'18” | 80°11'18” | 40.5 | 8/88 |
| 41010 | 28°54'10” | 78°27'50” | 1873 | 11/88 |
| 41012 | 30°2'32” | 80°32'1” | 38.1 | 6/02 |
| 41013 | 33°26'11” | 77°44'35” | 23.5 | 11/03 |
| 41025 | 35°0'22” | 75°24'7” | 68.6 | 3/03 |
| 44004 | 38°29'2” | 70°25'57” | 3182.1 | 9/77 |

# VISUAL INSPECTION


Significant Wave Height (m) for the East Coast NDBC Buoys: Grouped by Buoy Type
Significant Wave Height (m)
Date
LNB
12D
10D
6N
5D
3D
0
1
2
3
4
5
6
7
1975
1980
1985
1990
1995
2000
2005
2010
2015



Significant Wave Height (m) for the East Coast NDBC Buoys: Grouped by Platform Type
Significant Wave Height (m)
Date
0
1
2
3
4
5
6
7
1975
1980
1985
1990
1995
2000
2005
2010
2015
AMPS
ARES
ARES 4.4
DACT
EEP
GSBP
PEB
UDACS (A)
VEEP

# Co-Occurrences for Hull and Payload Type

| | 10D | 12D | 3D | 5D | 6N | LNB |
|---|---|---|---|---|---|---|
| **AMPS** | | | 10 | | | |
| **ARES** | | | 9 | | 1 | |
| **ARES 4.4** | | | 4 | | | |
| **DACT** | 2 | | 12 | | 9 | 4 |
| **EEP** | | 1 | | | | |
| **GSBP** | 2 | 1 | | 1 | 7 | 2 |
| **MVXI** | | | | | 2 | |
| **MVXII** | | 1 | | | | |
| **PEB** | | 4 | | | | |
| **UDACS (A)** | | 4 | | | | |
| **VEEP** | | | 6 | | 2 | |

# METHODS

# Analysis of Covariance

- Combines analysis of variance and regression
- Determines if different levels of a categorical independent variable influence the population means of the dependent variable
- Controls for the effects of other continuous variables (in this work, time), which are known as covariates

# Multiple Comparison Test

- ANCOVA tests the hypothesis that the means of several groups are all equal
- It provides no information about which groups are significantly different from each other.
- The test employed here is the Tukey-Kramer
  - Considered one of the most conservative multiple comparison tests
  - Tests the two-tailed null hypothesis between all possible combinations of the relevant grouped variable.

# RESULTS

# ANCOVA Results

| Source | d.f. | Sum Sq | Mean Sq | F | P-value |
|---|---|---|---|---|---|
| **Hull Type** | 5 | 341.8 | 68.3609 | 174.29 | 1.19E-182 |
| **Date** | 1 | 10.67 | 10.6723 | 27.21 | 1.84E-07 |
| **Hull Type * Date** | 5 | 84.88 | 16.9755 | 43.28 | 1.44E-44 |
| **Error** | 23035 | 9035.1 | 0.3922 | | |

| Source | d.f. | Sum Sq | Mean Sq | F | P-value |
|---|---|---|---|---|---|
| **Payload Type** | 8 | -0.78 | -0.0972 | -0.24 | 1 |
| **Date** | 1 | 47.58 | 47.5829 | 115.3 | 0 |
| **Payload Type * Date** | 8 | 108.44 | 13.5548 | 32.85 | 0 |
| **Error** | 23029 | 9503.4 | 0.4127 | | |

# Hull Type Analysis

## Multiple Comparison Results

| | 3D | 5D | 6N | 10D | 12D |
|---|---|---|---|---|---|
| **LNB** | 0.47 | 0.97 | 0.31 | 0.00 | 0.00 |
| **12D** | 0.00 | 1.00 | 0.00 | 0.00 | |
| **10D** | 0.00 | 0.81 | 0.00 | | |
| **6N** | 0.00 | 0.95 | | | |
| **5D** | 0.98 | | | | |

# Payload Type Analysis

## Multiple Comparison Results

| | VEEP | UDACS(A) | PEB | GSBP | EEP | DACT | ARES 4.4 | ARES |
|---|---|---|---|---|---|---|---|---|
| **AMPS** | 0.96 | 0.87 | 0.99 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 |
| **ARES** | 0.98 | 0.83 | 0.99 | 0.00 | 1.00 | 0.00 | 1.00 | |
| **ARES 4.4** | 1.00 | 0.77 | 0.99 | 0.00 | 1.00 | 0.00 | | |
| **DACT** | 0.00 | 0.10 | 1.00 | 0.09 | 1.00 | | | |
| **EEP** | 1.00 | 1.00 | 1.00 | 1.00 | | | | |
| **GSBP** | 0.00 | 0.00 | 1.00 | | | | | |
| **PEB** | 0.96 | 1.00 | | | | | | |
| **UDACS(A)** | 0.59 | | | | | | | |

# Co-Occurrences for Hull and Payload Type

| | 10D | 12D | 3D | 5D | 6N | LNB |
|---|---|---|---|---|---|---|
| AMPS | | | 10 | | | |
| ARES | | | 9 | | 1 | |
| ARES 4.4 | | | 4 | | | |
| DACT | 2 | | 12 | | 9 | 4 |
| EEP | | 1 | | | | |
| GSBP | 2 | 1 | | 1 | 7 | 2 |
| MVXI | | | | | 2 | |
| MVXII | | 1 | | | | |
| PEB | | 4 | | | | |
| UDACS (A) | | 4 | | | | |
| VEEP | | | 6 | | 2 | |

# Trend Analysis

- The wave records were grouped by buoy number, hull and platform type and then normalized

$$z = \frac{(X - \mu)}{\sigma}$$

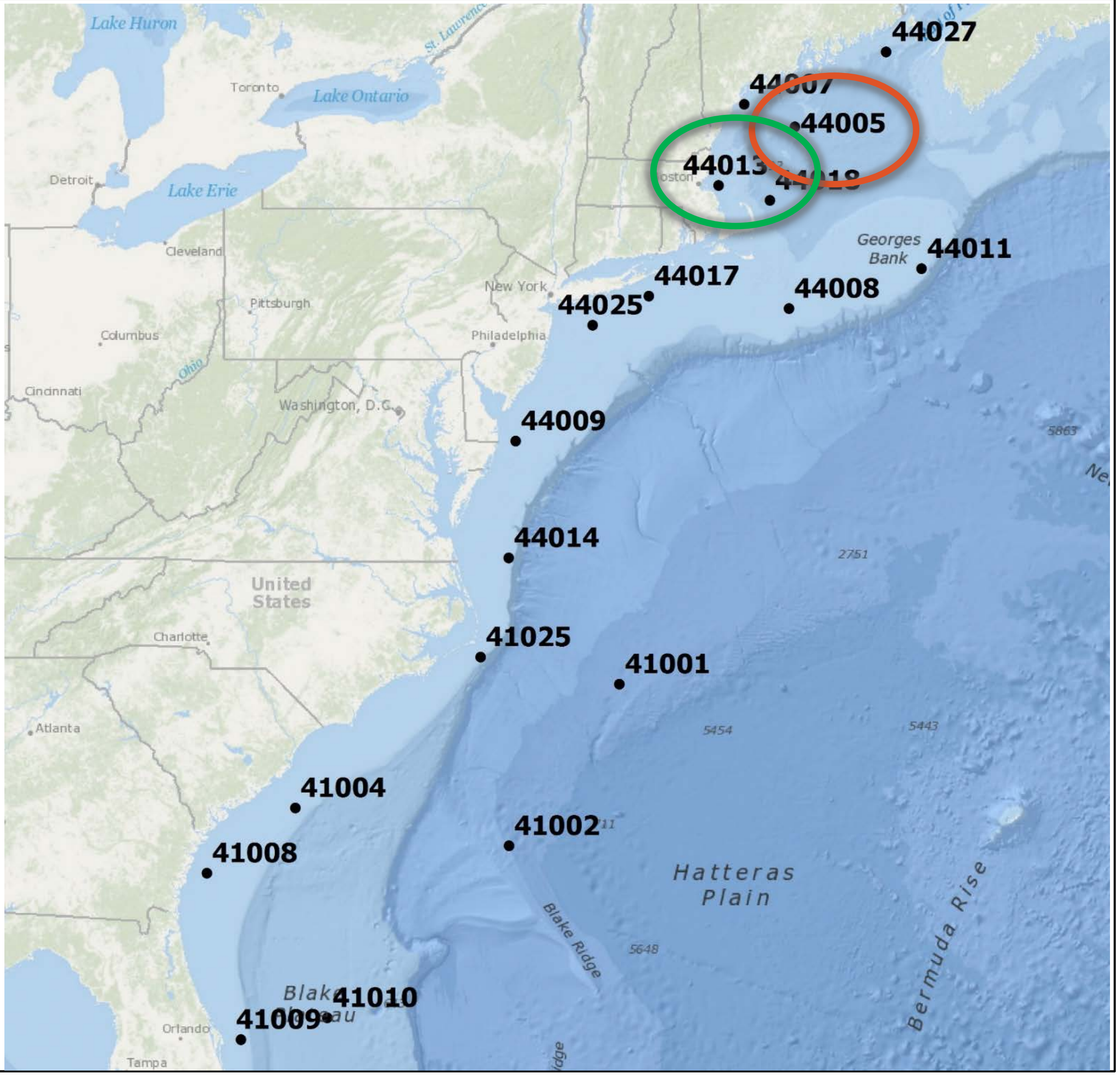
- Linear models were fit to the wave record for each buoy
  - Original dataset
  - Hardware corrected
  - Platform corrected
  - Corrected for both

| Buoy Number | Original Dataset | |
|---|---|---|
| | ***Slope (n-mm/yr)*** | ***p-Val*** |
| Buoy 41001 | 3.027 | 0.000 |
| Buoy 41002 | 0.593 | 0.000 |
| Buoy 41004 | -4.941 | 0.000 |
| Buoy 41008 | -3.914 | 0.000 |
| Buoy 41009 | 4.123 | 0.001 |
| Buoy 41010 | 1.590 | 0.000 |
| Buoy 41012 | 3.009 | 0.000 |
| Buoy 41013 | 3.007 | 0.000 |
| Buoy 41025 | 3.009 | 0.000 |
| Buoy 44004 | -2.625 | 0.000 |

| Buoy Number | Original Dataset | |
|---|---|---|
| | ***Slope (n-mm/yr)*** | ***p-Val*** |
| Buoy 44005 | -8.582 | 0.000 |
| Buoy 44007 | 0.282 | 0.000 |
| Buoy 44008 | 8.219 | 0.000 |
| Buoy 44009 | 8.994 | 0.000 |
| Buoy 44011 | 2.824 | 0.553 |
| Buoy 44013 | 14.581 | 0.000 |
| Buoy 44014 | 2.640 | 0.327 |
| Buoy 44017 | 3.008 | 0.000 |
| Buoy 44018 | 3.011 | 0.000 |
| Buoy 44025 | 7.526 | 0.000 |
| Buoy 44027 | 3.008 | 0.000 |

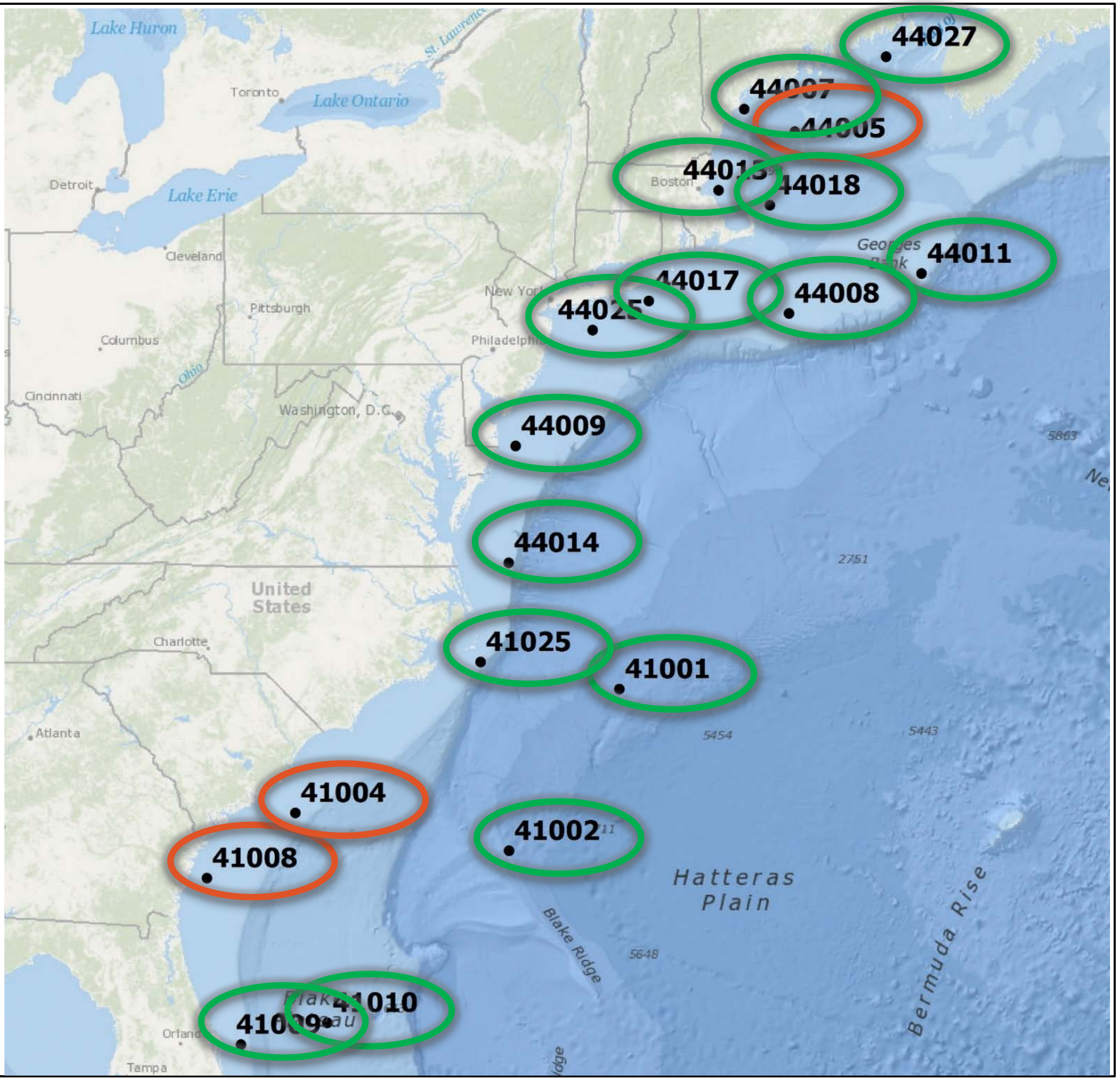
# Selected Buoys

| | |
|---|---|
| Maximum | 14.581 |
| Minimum | -8.582 |
| Average | 1.991 |
| Median | 3.007 |
| Std. Dev. | 5.320399 |



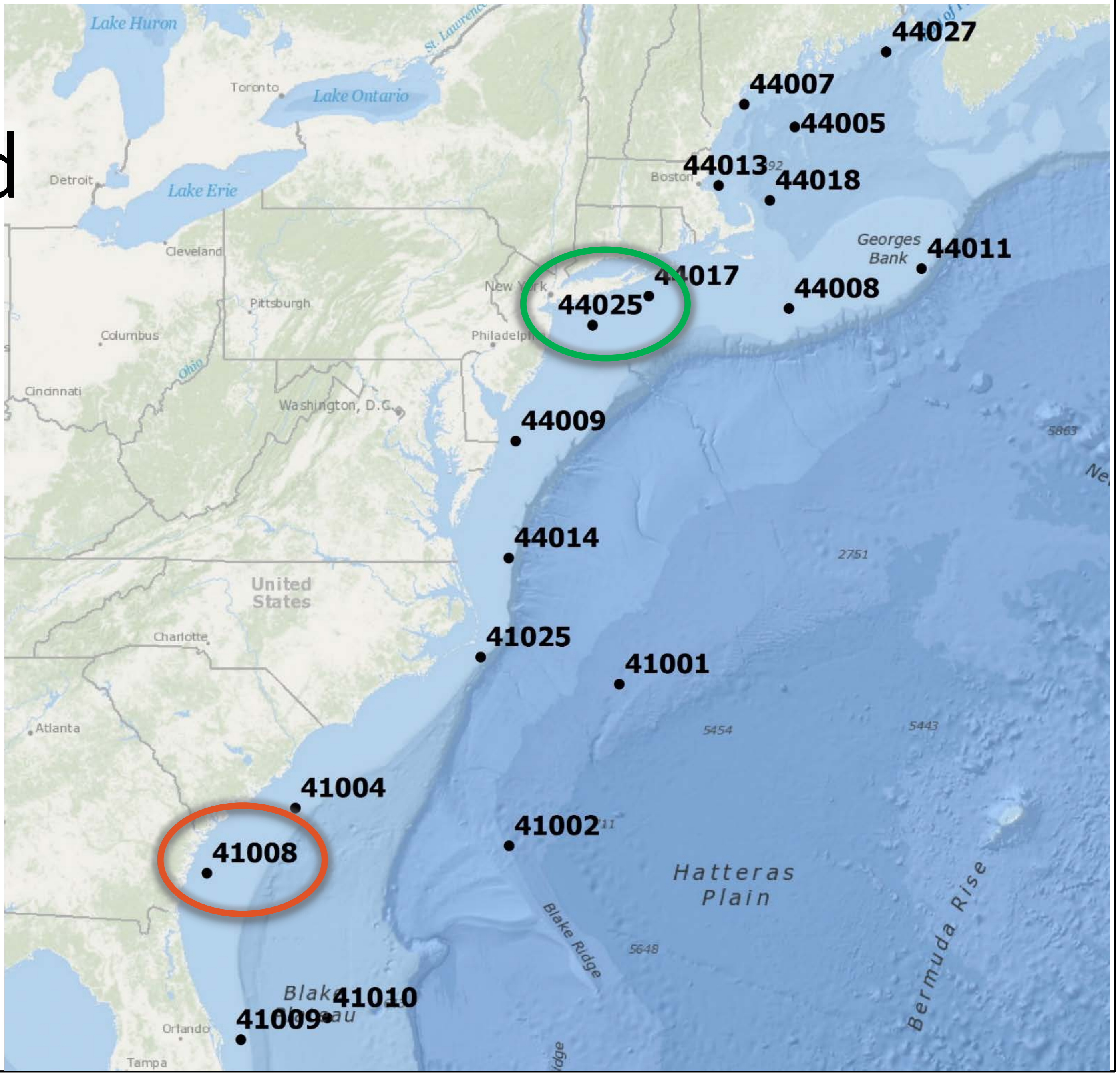
# Selected Buoys

| | |
|---|---|
| Maximum | 14.581 |
| Minimum | -8.582 |
| Average | 1.991 |
| Median | 3.007 |
| Std. Dev. | 5.320399 |



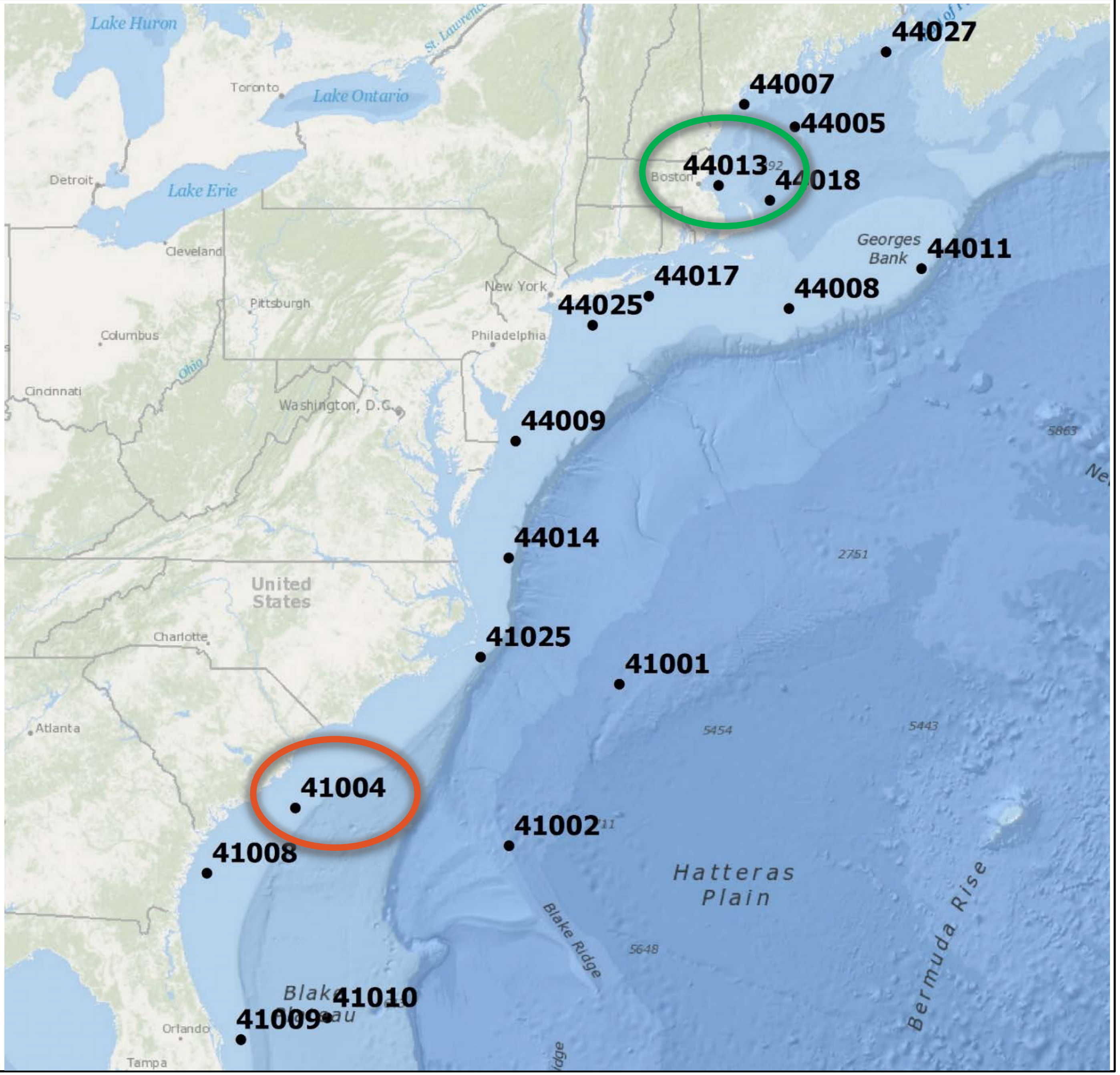
# Hardware Corrected

| | Corrected | Original |
|---|---|---|
| Maximum | 7.526 | 14.581 |
| Minimum | -3.914 | -8.582 |
| Average | 0.160 | 1.991 |
| Median | 0.375 | 3.007 |
| Std. Dev. | 2.483043 | 5.320399 |



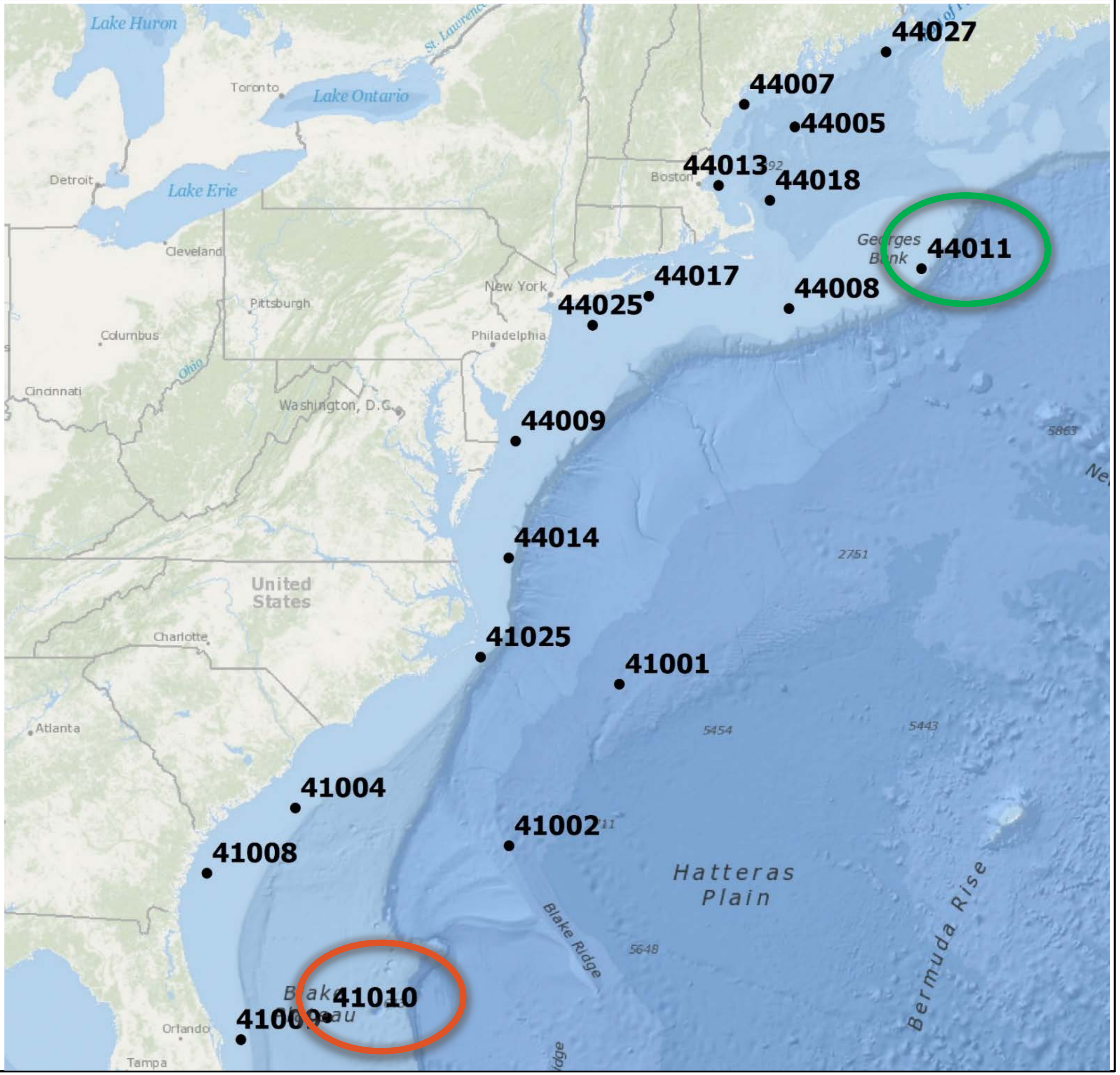
# Platform Corrected

| | Corrected | Original |
|---|---|---|
| Maximum | 5.404 | 14.581 |
| Minimum | -1.709 | -8.582 |
| Average | 0.146 | 1.991 |
| Median | -0.003 | 3.007 |
| Std. Dev. | 1.633422 | 5.320399 |



# Both Corrected

| | Corrected | Original |
|---|---|---|
| Maximum | 1.582 | 14.581 |
| Minimum | -1.932 | -8.582 |
| Average | -0.342 | 1.991 |
| Median | -0.003 | 3.007 |
| Std. Dev. | 0.98921 | 5.320399 |

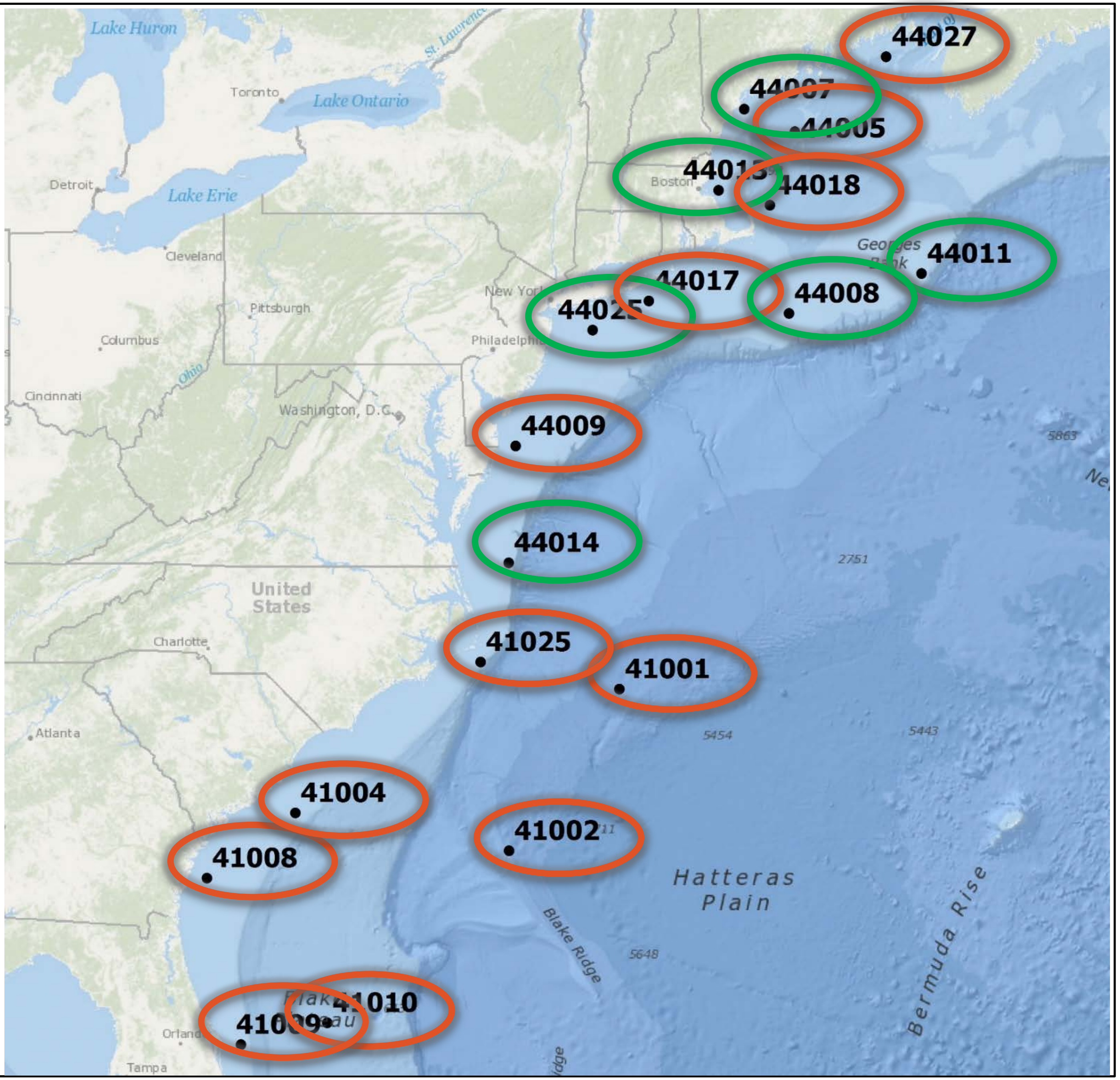


| Buoy Number | Corrected | |
|---|---|---|
| | *Slope (n-mm/yr)* | *p-Val* |
| Buoy 41001 | -0.003 | 0.988 |
| Buoy 41002 | -0.264 | 0.368 |
| Buoy 41004 | -1.709 | 0.000 |
| Buoy 41008 | -1.691 | 0.000 |
| Buoy 41009 | -1.909 | 0.000 |
| Buoy 41010 | -1.932 | 0.000 |
| Buoy 41012 | -0.003 | 0.996 |
| Buoy 41013 | -0.003 | 0.985 |
| Buoy 41025 | -0.003 | 0.995 |
| Buoy 44004 | -1.129 | 0.001 |

| Buoy Number | Corrected | |
|---|---|---|
| | *Slope (n-mm/yr)* | *p-Val* |
| Buoy 44005 | -1.311 | 0.000 |
| Buoy 44007 | 0.518 | 0.070 |
| Buoy 44008 | 1.171 | 0.000 |
| Buoy 44009 | -0.921 | 0.004 |
| Buoy 44011 | 1.582 | 0.000 |
| Buoy 44013 | 0.115 | 0.714 |
| Buoy 44014 | 0.231 | 0.554 |
| Buoy 44017 | -0.003 | 0.994 |
| Buoy 44018 | -0.003 | 0.989 |
| Buoy 44025 | 1.052 | 0.008 |
| Buoy 44027 | -0.003 | 0.995 |

# Both Corrected

| | Corrected | Original |
|---|---:|---:|
| Maximum | 1.582 | 14.581 |
| Minimum | -1.932 | -8.582 |
| Average | -0.342 | 1.991 |
| Median | -0.003 | 3.007 |
| Std. Dev. | 0.98921 | 5.320399 |



# Conclusions

- It was shown that both hull and platform type resulted in significant changes to the time series, with the hull type as the more significant contributor.
- The time series were corrected to remove the influence of the modifications and then analyzed to determine if there were any long-term trends in the wave conditions along the U.S. East Coast.
- While the long-term coefficient estimates for the trend were significant for sixteen of the twenty-one buoys, there was not a spatial pattern in the long-term trends.
- It is crucial for long-term records to document the observational changes which introduce artificial trends into the data, and adjust the buoy time series prior to trend analysis.
- Further work will investigate other methods to remove the influence of both hull and platform type from the wave record.