OD34A-2755: Finding NOMAD: An Examination of the Impacts of Changing Wave Systems on Long-term Wave Measurements

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1. Motivation

National Data Buoy Center (NDBC) presently operates almost 300 marine observing stations, of which, more than 100 measure waves and some wave measurement records cover more than 30 years (Figure 1). Studies (Gemmrich *et al.*, 2011, Thomas *et al.*, 2011; and Livermont *et al.*, 2015) have shown that changes of significant wave heights (H_s) can be attributed to changes in wave systems (Figure 2). These changes can lead to inaccurate inferences about trends and variance (Figures 3 & 4).

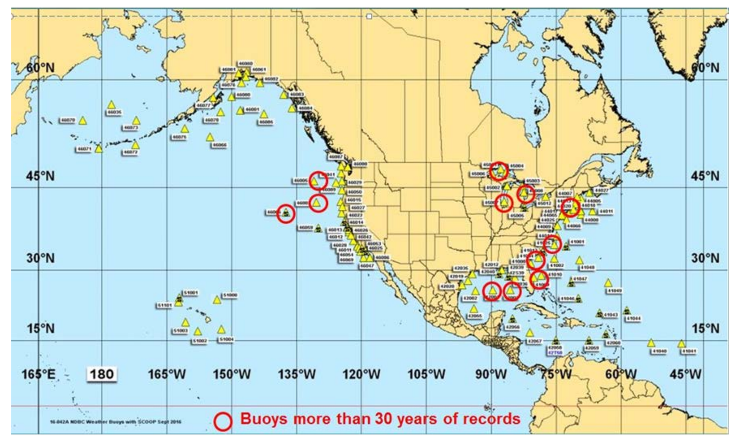

Figure 1: Locations of NDBC Wave Measuring Buoys as of 2017

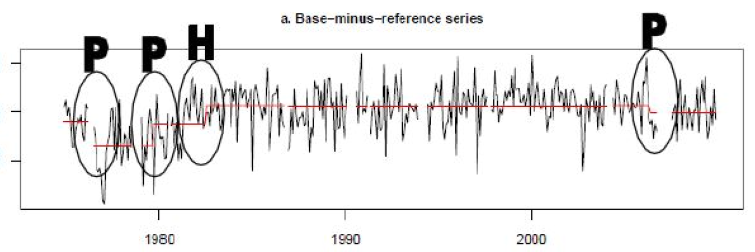

Figure 2: Long-term Wave Height Records from NDBC buoy 46005. P = step change due to change in wave processing. H= step change due to change in buoy hull. Source: Thomas *et al.*, 2011.

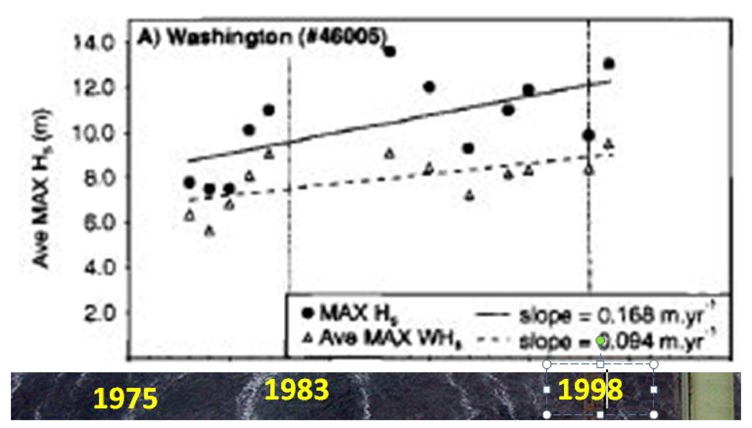

Figure 3: Trend analysis of wave measurements without considering changes. Allen and Komar, 2000.

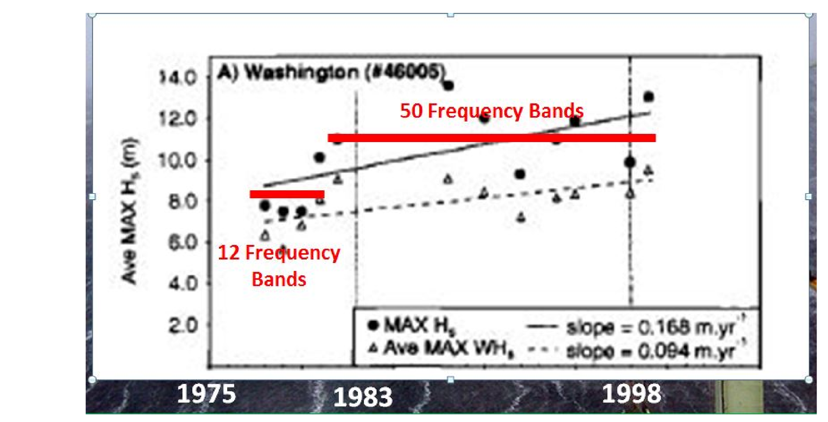

Figure 4: Trend reanalyzed considering changes to wave measurements. In the 70s NDBC only measured 12 frequency bands switching to 50 in the 80s.

2. Project FLOSSIE

To understand the effects of changing wave systems on wave measurements, the US Army Corps of Engineers Coastal and Hydraulics Laboratory funded project FLOSSIE (**F**ield **L**aboratory for **O**cean **S**ea **S**tate **I**nvestigation and **E**xperimentation, Jensen *et al*, 2015), to have NDBC equip and deploy a NOMAD (**N**avy **O**ceanographic and **M**eteorological **A**utomatic **D**evice, van Straten, 1966) hull (Figure 5) with an older wave measuring system, **W**ave **A**nalyzer (WA). Nearby is a smaller 3-m hull with a newer wave measuring system, the DDWM (**D**igital **D**irectional **W**ave **M**odule). NDBC once employed 61 NOMAD hulls (6 m long, boat-shaped hull), but they have been phasing out for smaller hulls (3 m or less, discus hulls). NOMADS were first deployed in 1975 and the WA wave system in the mid-80s. 3-m hulls have been used since the 1990s and DDWM has been used for about the last 10 years.
The FLOSSIE buoy was deployed in July 2015 off the coast of Monterey Bay, CA (Figure 6) near the operational NDBC buoy, 46042. The analysis will use two years of data from July 2015 through July 2017 .

Figure 5: Photo of 6-meter NOMAD Buoy on a cradle.

Figure 6: Project FLOSSIE Test Area. The NOMAD buoy is 6N-FLO and 3-m DDWM is 3D-46042.

3. Analysis and the Experiment

We analyze two years of data from both the WA on the NOMAD buoy (WA:NOMAD) and DDWW on a 3-m diameter buoy (DDWM:3M). We then simulate a change in both wave systems and hull by appending the second year of DDWM on the 3-m buoy to the first year of WA on the NOMAD. The stitched together time series is labeled WA:NOMAD – DDWM:3M in the graphics and then perform linear least squares fit of the trends. For significant wave height (H_s), the DDWM:3M has a slightly positive slope one-tenth that of the WA:NOMAD ;however, even this slight difference, leads to a negative slope for the Combined data set (Figure 7). We perform an experiment by extending the linear least squares fit out three years that leads to a marked difference in projections with both original data sets leading to increases in H_s, while the projection using the Combined dataset indicates decreasing wave heights (Figure 8).

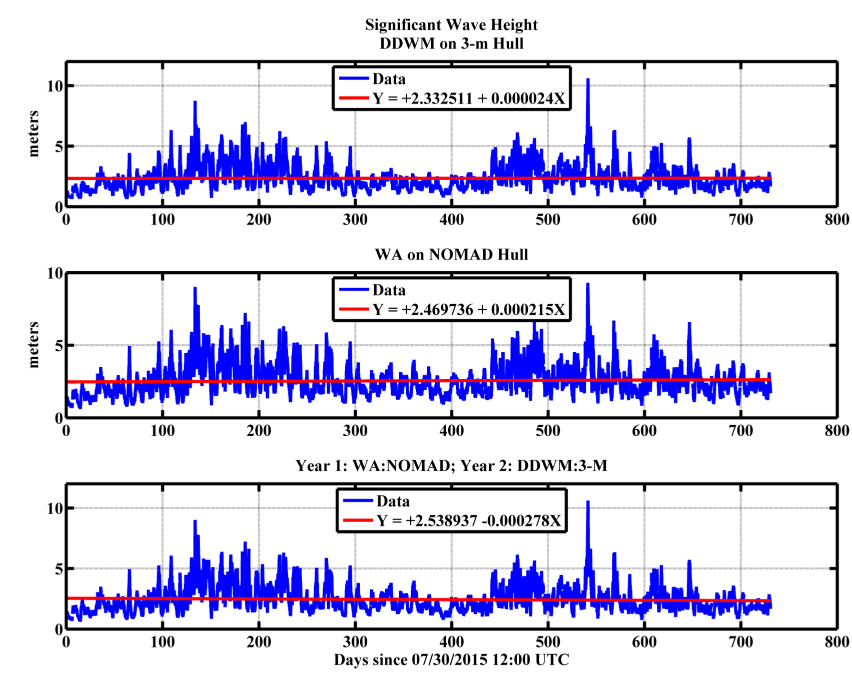

Figure 7: Significant wave height measurements

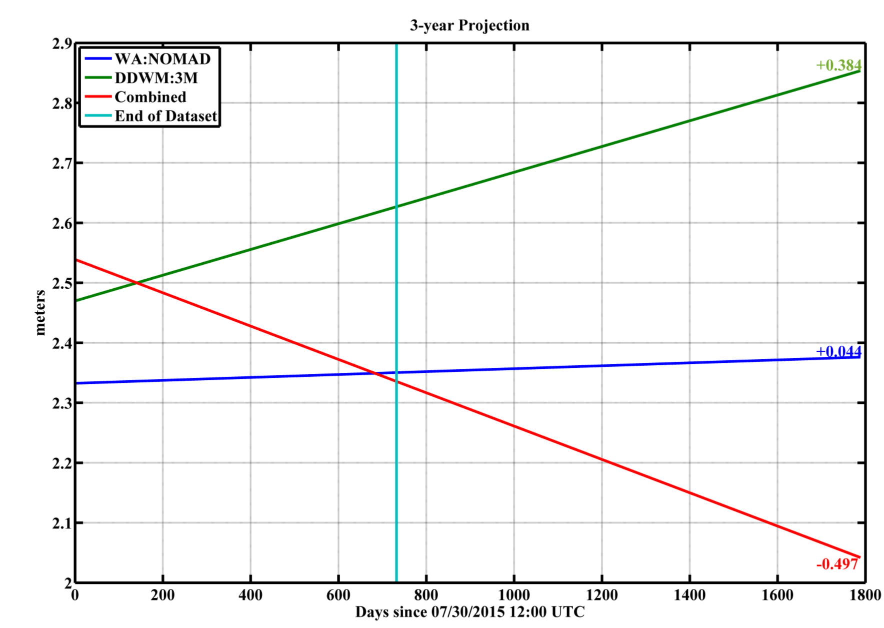

Figure 8: 3-year projections for significant wave

We then examine the effects on two parameters often projected into the future: for ship design, Average Wave Steepness (Figure 9) (Binter-Gregersen and Soares, 2007); and for renewable energy, Wave Power (Figure 11). Both parameters include the wave periods (not shown) in addition to the wave height (See section ***6. Calculations***). Again, by forming a combined dataset, the 3-year projections would show markedly different projections then either of the original datasets (Figures 10 and 12).

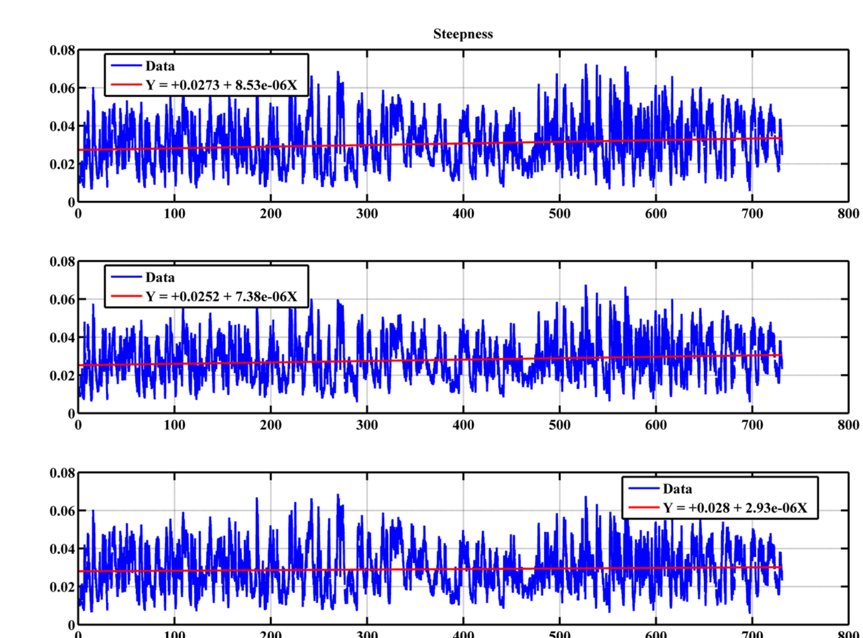

Figure 9: Wave Steepness. Graph similar to Figure 7.

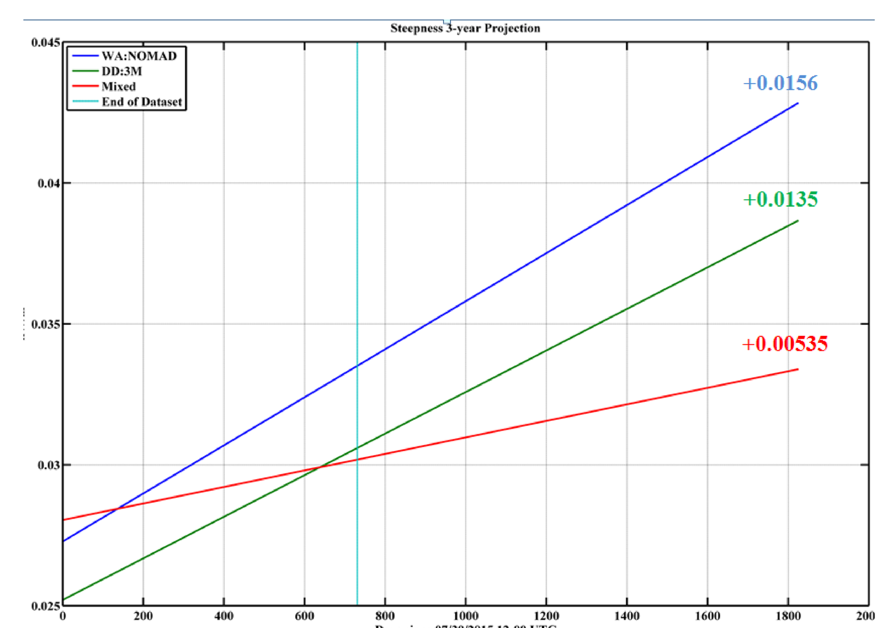

Figure 10: 3-year projection for Wave Steepness. Graph similar to Figure 8.

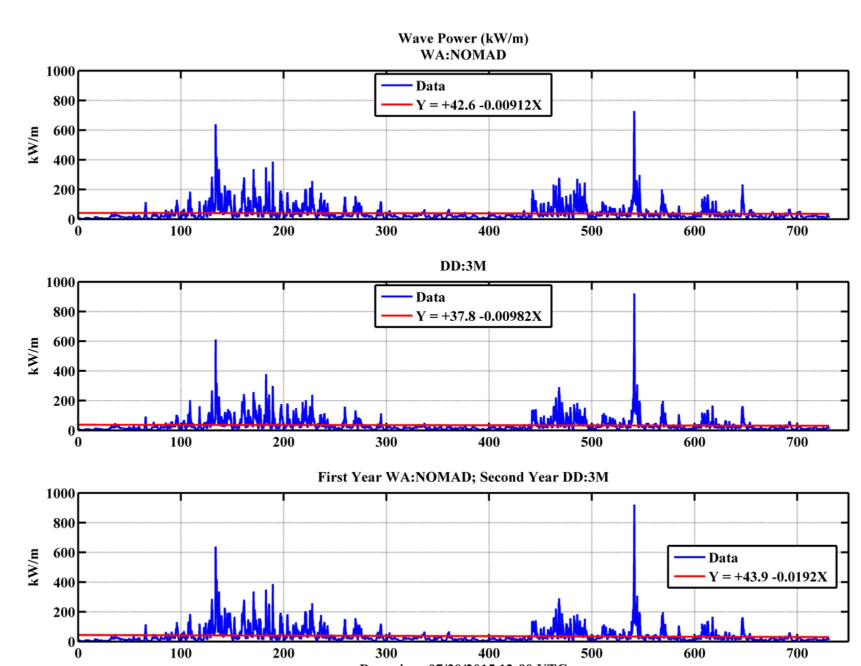

Figure 11: Wave Power. Graph similar to Figure 7.

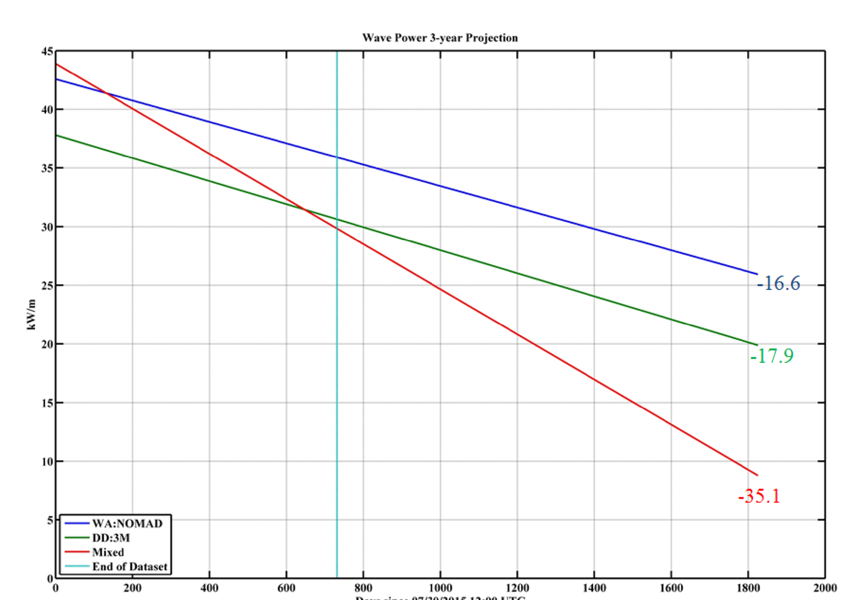

Figure 12: 3-year projection for Wave Power. Graph similar to Figure 8.

4. Conclusions

- From two years of wave measurements made simultaneously from two different buoy hulls and two different wave measuring systems, the trends are analyzed and 3-year projections are made of Significant Wave Height, Wave Steepness, and Wave Power.
- A combined dataset using the older buoy/wave system for the first year and the newer buoy/wave system for the second year is formed. Trend analysis and 3-year projections of the combined dataset show significant changes from either of the original time series datasets.
- While this experiment is rather simplistic and deliberately abrupt, the study and the experimental projections confirm previous studies that changes in hull or wave measuring system can introduce non-geophysical changes into the long-term records.

5. Future Work

The FLOSSIE Project will examine corrective factors that may be used to mitigate changes between systems and thus construct homogenous datasets that can provide consistent and reliable understanding of past and future changes.

6. Calculations

NDBC uses the displacement density spectra, *S(f)*, units m^2/s, a function of frequency (*f*), to compute other wave parameters (see NDBC, 1996).
Spectral Moments (m_n) are calculated from: $\sum_{f1}^{f2}((S(f)) * (f^n) * (\Delta f))$
Significant Wave Height (H_s, meters) is calculated from the zeroth moment: $4*\sqrt{m_0}$

Wave Steepness is calculated from H_s and the Average Wave Period (T_z): $\frac{8*\pi*H_s}{g*T_z^2}$, where: $T_z = \sqrt{\frac{m_0}{m_2}}$, and g = 9.81 m/s^2

Wave Power (kW/m) is calculated (Kamranzad *et al.*, 2016) using H_s and the Wave Energy Period (T_e): $0.49* (H_s\,\hat{}2) * T_e$
where T_e is computed from (Pecher and Kofoed, 2017) : $\frac{m_{-1}}{m_0}$

7. References

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van Straten, F.W., 1996: *Weather Or Not*, Dodd-Mead, 237 pp. [FLOSSIE is named to honor CDR Florence (nickname Flossie) W. van Straten, a pioneering US Navy meteorologist, who devised the name NOMAD for these hulls, see http://science.dodlive.mil/2010/03/30/a-pioneer-in-naval-meteorology-cdr-florence-van-straten/]

Acknowledgement: The authors wish to thank Mr. Stuart Hayes for assistance with producing the poster.