Wave Observing Changes and Trends in NE Pacific Monthly Mean Hs

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Waves on Oregon coast (Peeples, 2010, Image: E. Harris)

INTRODUCTION

- There is considerable interest in wave climate and trends [e.g.3, 4, 9]
- Homogeneous wave time series are important for analysis of wave climate trend and variability, and for coastal planning
- Changes in wave observing programs at US National Data Buoy Center (NDBC) and Environment Canada (EC)'s Meteorological Services Canada (MSC) have resulted in artificial step changes (shifts in the mean) in the long-term record of significant wave height, Hs
- Gemmrich *et al.* (2011) [1]:
  - assess the changes in the observed time series due to observing changes at 7 offshore moored buoy stations in the NE North Pacific
  - use the results to adjust the hourly data using the step size relative to the mean - a percentage-based adjustment factor
  - calculate trends in daily means and in estimates of extremes.
- This poster:
  - provides more detail on the assessment of the observing changes presented in Gemmrich *et al.* (2011)
  - shows the impact of adjustments on trends in monthly mean Hs

DATA and METADATA

- source for NDBC buoy data: NDBC and NODC (National Oceanographhic Data Center) archives
- source for MSC buoy data: ISDM (Fisheries and Oceans Canada's Integrated Science Data Management Division), with additional QC
- Information about the observations: the NODC archived data, the NDBC web page, internal NDBC technical reports and records, and for the MSC buoys, status reports and email from buoy technicians.
  - payload (onboard processor) type for each NDBC buoy was readily available, but the wave processor type (in the first decade or so) was not
  - in some cases wave processor type was deduced from information such as spectral band details

METHOD

- calculated monthly mean Hs; used months with ≥ 60% data coverage
- used statistical software RHTestsV3 [5-8] to detect shifts, make adjustments, and calculate trends
- used reference series of Hs from GROW2000 Wind and Wave Reanalysis, 1970-2009 (Oceanweather 2007) [2] (Use of good reference series increases sensitivity, less chance shifts are related to interannual climate variations)
- detected Type 1 (most significant) shifts in mean in the difference (buoy – ref.) and in de-seasonalized (monthly anomaly) series
- matched steps with metadata when possible, to refine date of shift
- adjusted means using step changes before recalculation of trend

Locations, WMO ID, and station names of buoys operated by EC (indicated by C) and NDBC; Examples of hull types
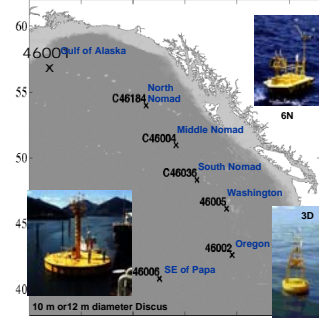
Hull and Wave Sensor Types

Hull Sizes/Types	
10D	10-m Discus (10-m diameter hull)
12D	12-m Discus (12-m diameter hull)
6N or NOMAD	Navy Oceanographic Meteorological Automatic Device (6-m boat-shaped hull)
3D	3-m Discus (3-m diameter hull)
Wave Sensor Types (Acc = accelerometer)	
SD	Strapped-down acc. (Columbia or Schaevitz)
DW	vertically-stabilized (gimballed) acc. (Datawell)

### Payload Types (* = discontinued)
[wave processors used with this payload]

NDBC	
EEP*	Engineering Experimental Phase (1st wave measuring weather buoy, deployed at 3 stations, 1 in NE Pacific) [EEP]
PEB*	Prototype Environmental Buoy [WSA]
PEB UDACS*	PEB (General Dynamics) UHF Data Acquisition and Control System [WSA]
UDACS (A)*	UDACS (modification A) [WDA]
MXVII (MOD)*	Magnavox Phase II (modified) [WDA]
GSBP*	(Magnavox) Generalized Service Buoy Payload [WDA]
DACT	Data Acquisition and Control Telemetry [WA]
VEEP	Value Engineered Environmental Payload [WA, WPM]
ARES 4.4	Acquisition and Reporting Environmental System [WA, WPM]
AMPS	Advanced Modular Payload System [WA, WPM]
EC	
Zeno*	(AXYS Environmental Ltd) Zeno [Zeno]
WM	(AXYS Environmental Ltd) Watchman [WM]

Wave Processor Types (* = discontinued)

NDBC	
EEP*	Internal to EEP payload (used Blackman-Tukey)
WSA*	Wave Spectrum Analyzer (internal to PEB - analog input only, 12-channel (band) starting at 0.05 Hz)
WDA*	Wave Data Analyzer (Blackman-Tukey)
WA	Wave Analyzer (uses Fast Fourier Transform (FFT))
WPM	Wave Processing Module (uses FFT; doubling of frequency bands for freq < 0.1 Hz, compared to WDA or WA)
EC	
Zeno*	Internal to Zeno payload, used FFT
WM	Watchman, uses FFT, same freq. bands as Zeno (module within WM payload)

RESULTS: OBSERVING CHANGES & SHIFTS IN MONTHLY MEAN SIG. WAVE HT, Hs
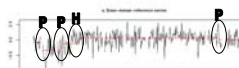
S = segment, R = possible/probable reason (observing chg) for step (at start of segment): P = wave processor; H = hull type/size; F = faulty sensor; nF = no longer faulty; U = unexplained; A = acc.


46001 Gulf of Alaska (NDBC)

S	Data Start	Data End	Hull	Payload	Wave Proc	Acc	ΔHs (m)	R
1	1974/12	1976/04	12D	EEP	EEP	SD		
2	1976/07	1979/09	10D	PEB	WSA	"	-0.24	P
3	1979/10	1980/06	"	UDACS (A)	WDA	"	0.22	P
"	1980/07	1982/06	"	GSBP	"	"		
4	1982/06	1990/03	6N	"	"	"	0.19	H
"	1990/06	2006/06	"	DACT	WA	"		
5	2006/05	2010/12	"	ARES 4.4	WPM	"	-0.08	P

46184 North Nomad (EC)

S	Data Start	Data End	Hull	Pay	Wave Proc	Acc	ΔHs (m)	R
1	1987/09	1995/06	6N	Zeno	Zeno	DW		
2	1995/06	1999/05	"	"	"	"	0.16	U
3	1999/05	2000/04	"	"	"	"	-0.20	U
"	2000/04	2002/05	"	WM	WM	SD		
4	2002/05	2002/09	"	"	"	"	-0.29	F
5	2002/10	2003/05	"	"	"	"	-0.27	F
6	2003/05	2009/12	"	"	"	SD	0.41	nF
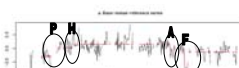
46004 Middle Nomad (EC, except NDBC 1976-1988)

S	Data Start	Data End	Hull	Payload	Wave Proc	Acc	ΔHs (m)	R
1	1976/10	1977/05	10D	PEB	WSA	SD		
"	1978/09	1980/05	12D	PEB UDACS				
2	1981/02	1983/06	"	UDACS (A)	WDA	"	0.32	P
3	1983/06	1988/06	6N	GSBP	"	"	0.12	H
"	1988/06	1999/05	"	Zeno	Zeno	DW		
4	1999/05	2000/02	"	WM	WM	SD	-0.20	A
"	2000/04	2000/05	"	"	"	DW		
"	2000/10	2001/05	"	"	"	SD		
5	2001/05	2002/04	"	"	"	"	-0.66	F
6	2002/05	2010/12	"	"	"	SD	0.59	nF

46036 South Nomad (EC, except NDBC 1986-1987)

S	Data Start	Data End	Hull	Pay	Wave Proc	Acc	ΔHs (m)	R
1	1986/08	1987/09	6N	GSBP	WDA	SD		
"	1987/09	1989/07	"	Zeno	Zeno	DW		
2	1989/07	1994/06	"	"	"	"	0.17	U
3	1994/09	1998/07	"	"	"	"	-0.28	U
"	1998/07	2000/04	"	WM	WM	DW		
4	2000/04	2001/05	"	"	"	"	-0.09	U
"	2001/05	2006/01	"	"	"	SD		
5	2006/05	2007/11	"	"	"	"	0.13	U
6	2007/11	2009/05	"	"	"	"	-0.20	U
7	2009/05	2010/12	"	"	"	"	0.22	U
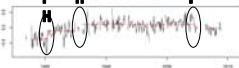
46005 Washington (NDBC)

S	Data Start	Data End	Hull	Payload	Wave Proc	Acc	ΔHs (m)	R
1	1976/10	1978/08	10D	PEB	WSA	SD		
"	1978/08	1980/06	12D	"				
2	1980/06	1981/11	6N	MXVII (MOD)	WDA	"	0.27	P H
"	1981/11	1985/10	12D	UDACS (A)	"	"		
3	1986/02	1990/08	6N	GSBP	"	"	0.21	H
"	1991/01	2004/09	"	DACT	WA			
4	2004/09	2008/12	"	ARES	WPM	"	-0.14	P
"	2010/06	2010/11	3D	AMPS	"	"		
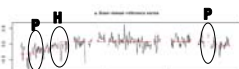
46002 Oregon (NDBC)

S	Data Start	Data End	Hull	Payload	Wave Proc	Acc	ΔHs (m)	R
1	1976/10	1979/04	10D	PEB	WSA	SD		
2	1979/05	1980/09	"	UDACS (A)	WDA	"	0.17	P
"	1980/09	1982/12	"	GSBP	"	"		
3	1983/01	1990/02	6N	"	"	"	0.21	H
"	1990/06	2006/04	"	DACT	"			
4	2006/06	2009/07	"	ARES 4.4	WPM	"	-0.11	P
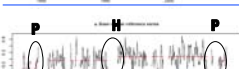
46006 SE of Papa (NDBC)

S	Data Start	Data End	Hull	Payload	Wave Proc	Acc	ΔHs (m)	R
1	1977/04	1979/08	10D	PEB	WSA	SD		
2	1979/08	1985/06	12D	UDACS (A)	WDA	"	0.25	P
"	1985/06	1986/02	6N	GSBP	"			
"	1986/06	1988/03	12D	"	"			
"	1988/08	1991/01	"	DACT	WA			
3	1992/06	1999/12	6N	"	"	"	0.13	U
"	2000/08	2006/12	"	VEEP	"			
"	2007/08	2007/12	"	DACT	"			
4	2008/08	2010/01	3D	ARES 4.4	WPM	"	-0.13	P

SUMMARY OF OBSERVING CHANGES & SHIFTS IN MONTHLY MEAN Hs

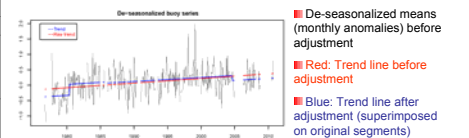| Observing Change	Avg Step Size (m, %)	Org	Buoys
EEP to WSA	-0.24 (-8.9%)	NDBC	46001
WSA to WDA	+0.26 (+9.4%)	"	46001, 46004, 46002, 46005, 46006
10/12D to 6N	+0.17 (+6.3%)	"	46001, 46002, 46005, 46006
WA to WPM	-0.12 (-4.1%)	"	46002, 46005
Unexplained, Zeno	± 0.28 (±9%)	EC	46036, 46184
Datawell Acc. to SD	-0.17 (-5.9%)	"	46036, 46004, 46184
Faulty Sensor	-0.61 (-21%)	"	46004, 46184
Unexplained, WM	± 0.25 (±8%)	"	46036

NDBC

- one of earliest NDBC payload/wave module types, PEB/WSA: mean Hs ~ 9% low - causing a significant positive step when replaced by the WDA system (used by various payloads)
- also biased low compared to the first type of weather buoy to calculate Hs from spectral wave data, EEP
- some uncertainty in timing/attribution of shifts in early years at some stations
- records from the early 1980s to early 2000's relatively homogeneous, no apparent step change from WDA to WA
- present NDBC wave module, WPM: mean Hs ~ 4% lower than previous modules (WA, WDA)
- 6N buoys: mean Hs ~ 6% higher than at the large Discus buoys they replaced

EC

- EC Pacific NOMADs used gimballed Datawells (vertically-stabilized) wave sensors until 1999 - 2001 when replaced by strap-downs – related to ~ 6% decrease in mean Hs (some uncertainty in date of change)
- Change from NDBC operation (GSPB/WDA/strap-down) to EC (Zeno/Datawell-gimballed) not associated with a step (multiple changes cancelling out?)
- unexplained step changes (~ ± 8%), coinciding w/ deployment/ servicing of individual buoys, both in early and recent records
- a faulty wave sensor resulted in mean Hs ~ 20% low

TRENDS IN MONTHLY MEAN Hs, before and after adjustment for observing changes

De-seasonalized monthly mean Hs at 46005 Washington, before adjustment

- De-seasonalized means (monthly anomalies) before adjustment
- Red: Trend line before adjustment
- Blue: Trend line after adjustment (superimposed on original segments)

Buoy	N yrs	Original (Trend: mm/yr)					Adjusted (Trend: mm/yr)				
		Trend	P	Lwr	Upr	±	Trend	P	Lwr	Upr	±
46001	36	4.7	0.99	0.9	8.5	3.8	-2.0	0.86	-5.5	1.6	3.6
46184	22	-14.1	0.99	-25.0	-3.2	10.9	-0.7	0.57	-9.3	7.8	8.6
46004	34	-0.2	0.64	-6.5	6.0	6.3	2.7	0.85	-2.4	7.9	5.1
46036	24	-14.3	1.00	-21.8	-6.8	7.5	0.4	0.55	-6.9	7.8	7.4
46005	34	15.1	1.00	9.2	21.0	5.9	5.0	0.96	0.1	10.5	5.5
46002	33	8.5	1.00	2.6	14.4	5.9	1.7	0.74	-3.6	6.9	5.2
46006	32	10.1	1.00	3.1	17.1	7.0	2.0	0.73	-4.5	8.4	6.5

- V. different trends in NDBC & EC, before adjustments, more consistent after
- Trends of either sign are closer to 0 after adjustments
- Trends in monthly mean Hs, adjusted data, are negative in the Gulf of Alaska, becoming positive ~ 51°N, with the strongest trend at 47°N (Washington Buoy): 0.5 cm/yr, 1976-2010 (compared to 1.5 cm/yr, no adjustments, this study and [4])

SUMMARY/CONCLUSIONS

WAVE PROCESSOR CHANGES:
- Mean Hs from the prototype PEB/WSA (early 1970s) low by ~ 9%
- NO shift in mean Hs: change from WDA to WA (EC); or Zeno to WM (EC)
- introduction of WPM -> 4% drop in monthly mean Hs

HULL SIZE/TYPE CHANGES:
- change in hull size/type from the large 10m or 12m Discus buoys to the 6m NOMAD's (in the 1990s) related to a 6% increase in monthly mean Hs
  - Note: should test for a shift in mean Hs with the change from 6N to 3D, last few years

WAVE ACCELEROMETER CHANGES:
- NDBC wave sensors were strapped-down throughout (at these stations)
- EC 6N,strap-down: mean Hs ~ 6% lower than Datawell (vertically-stabilized)

UNEXPLAINED CHANGES:
- Some statistically significant (Type 1) shifts (± 6%) remain unexplained in both early and recent EC buoy record

TRENDS
- Trends in monthly mean Hs, adjusted data, were negative in the Gulf of Alaska, becoming positive toward the south, with the strongest trend near 47°N (Washington), 0.5 cm/yr (reduced from 1.5 cm/yr, not adjusted)
- It is important to do side-by-side comparisons or compare to a common reference (see www.jcomm.info/WET) when changing observing systems, and to document changes (for adjustment & removal of artificial shifts in the record)
- It is important for the ongoing analysis of wave climate trends and variability and coastal planning, etc, that adjusted wave data be available in the historical wave data archives in NOAA and ISDM, as well as in the International Comprehensive Ocean Atmosphere Data Set (ICOADS).

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