Long Term Trend in Wave Height Measurements at Canadian Coastal Locations

B. R. Thomas[1] and V. R. Swail[2]

Climate Research Division, ASTD, STB, Environment Canada
[1] *Halifax, Nova Scotia Canada, email: bridget.thomas@ec.gc.ca*
[2] *Toronto, Ontario, Canada*

Motivation

- Long-term homogeneous wave measurements are important for climate trend and variability studies and for validation of other sources of wave data, such as hindcast datasets.
- Relatively long-term wave measurements from moored buoys in Canadian coastal waters began in 1970, but are limited to only 3 locations: British Columbia (BC), Nova Scotia (NS), and Newfoundland and Labrador (NL).
- With one exception, wave measurements in Canadian deep water locations began later, with most weather buoys first deployed around 1988. (One offshore Pacific buoy, Middle NOMAD, ID 46004, was first deployed off the BC Coast in 1975 by NDBC.)
- The long-term coastal wave datasets have not been systematically analyzed. [The wave climate from deep water weather buoys has been analyzed at US locations, and in Canadian waters in the Pacific (e.g. Gower 2002) but the assessment and adjustment for inhomogeneties has been limited.] This study assesses inhomogeneities and trend in the coastal datasets.
- It is important to first adjust the data series for any changes in location or observing methods that could cause shifts in the long term record. Not all of the changes that could cause shifts in the wave record have been documented, and the effects of some changes, such as changes in hull type or wave processing methods, are not well understood.

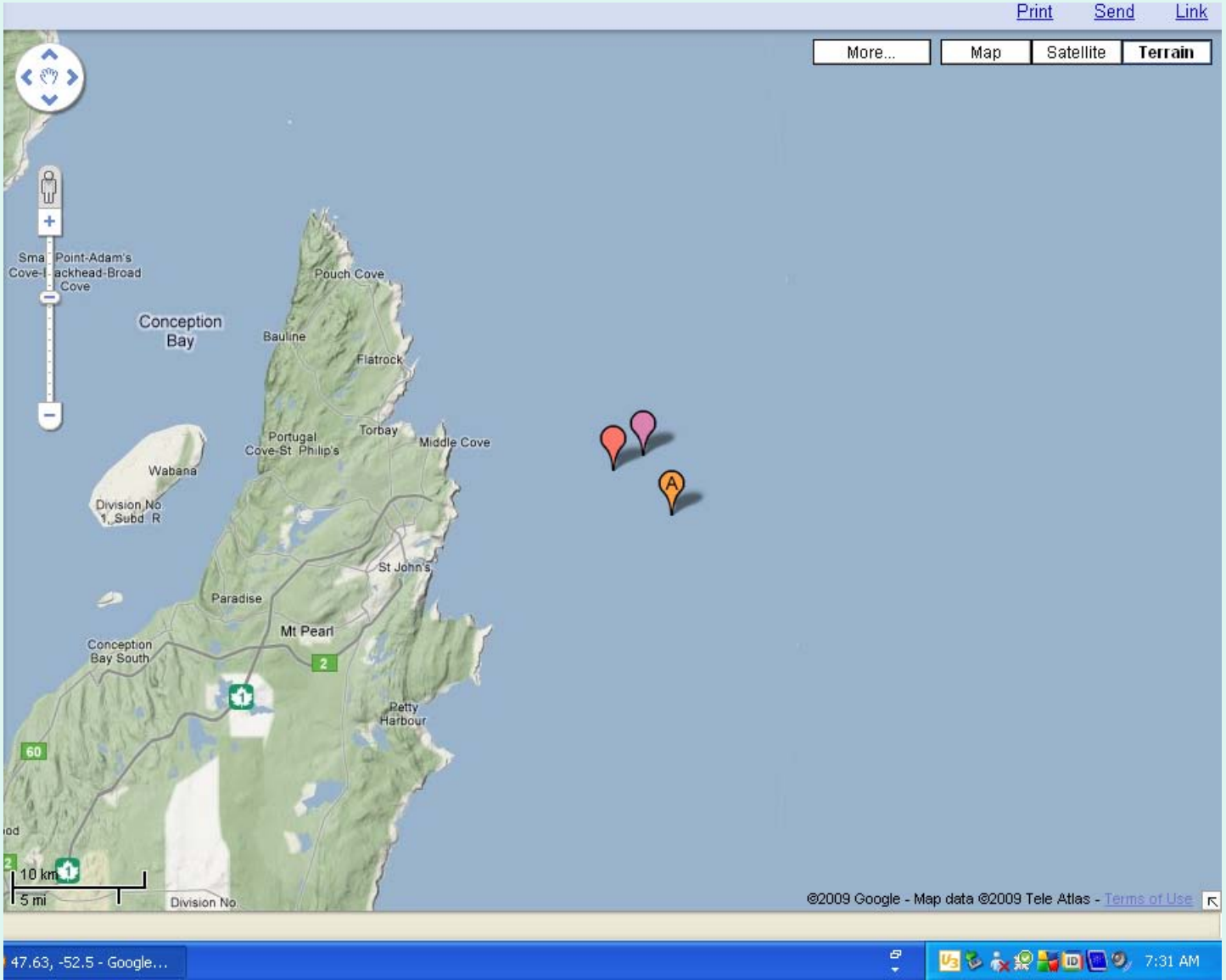
Method

- we assembled wave datasets and metadata at 3 coastal locations (archived data from Integrated Science Data Management Division (ISDM) of Canada's Department of Fisheries and Oceans)
  - Datawell Waverider (WR) near Tofino BC in 40 m water (1970-1999) + La Perouse Bank 3D Buoy 46206 (1999-2008) (25 km away, 75 m)
  - WR near Halifax NS in 55 m water depth (1970-2001) + Halifax Approaches 3D Buoy (2001-2009) (within a few km)
  - WR near St. John's NL in 165 m (1972-1998, seasonal)
- We used ISDM quality control flags + additional QC
- We calculated monthly mean significant wave height (Hs) using weighting factors to account for changes in reporting frequency over the years (for some years the reporting frequency increased 9x in Hs > 5m -> higher monthly means from unweighted data)
- we used a statistical homogeneity test (penalized maximal F test) [Wang et al 2007, Wang 2008 a and b], software name RHTestV2 [Wang and Feng 2007], to detect and adjust for mean non-climatic shifts in the monthly Hs
- for reference series, used: MSC50 (Atlantic), GROW (Pacific)
- we used the homogenized wave data sets to examine long-term trends. This method has been recently applied to long term Canadian wind data (Wan et al.).

Summary

- Changes in reporting frequency related to wave height, 1982 – 1997, resulted in spurious higher monthly means - can be corrected by weighting the observation by the intervals between observations
- position changes of 8+ km in coastal locations caused shifts – can be detected and corrected with RHtest
- an increase in number, range, and resolution of wave spectral bands and wave sampling frequency around 1987 did not appear to cause any significant step changes
- at Halifax the change from a Datawell Waverider to a 3m Discus or 6m NOMAD buoy may have contributed to a significant step change detected by RHTestV2, but slight changes in location may be a contributing factor
- We have not yet adjusted for less significant step changes – need further examination of metadata
- Adjusted time series on each coast have trends of opposite signs
  - at Tofino (Pacific Coast): negative trend, ~ -0.0016 m yr^{-1} (-0.1%yr^{-1})
  - at Halifax (Atlantic Coast): positive trend, ~ +0.0015 m yr^{-1} (+0.1%yr^{-1})

Torbay Waverider mooring locations, outside St. John's, NL, 1972-1997



Metadata for Torbay Waverider-near St. John's NL (June 1972 – February 1997)

Date	*Lat (°N)*	*Long (°W)*	*Change (km)*	*Water Depth (m)*	*Type*	*Reporting Interval [Alternate (s)] (min)*
MEDS037 Waverider						
1972/06	**47.64**	**52.47**		168	WR	180
1976/06	47.60	52.44	5.0	167	WR	180
1978/06	47.62	52.42	2.7	165	WR	180
1979/06	47.60	52.44	2.7	166	WR	180
1981/01	47.63	52.50	5.6	162	WR	180
1982/06	47.63	52.50	0	162	WR	180 [20]
1987/10	47.63	52.50	0	165	WR-FB	60 [30, 180] or 30

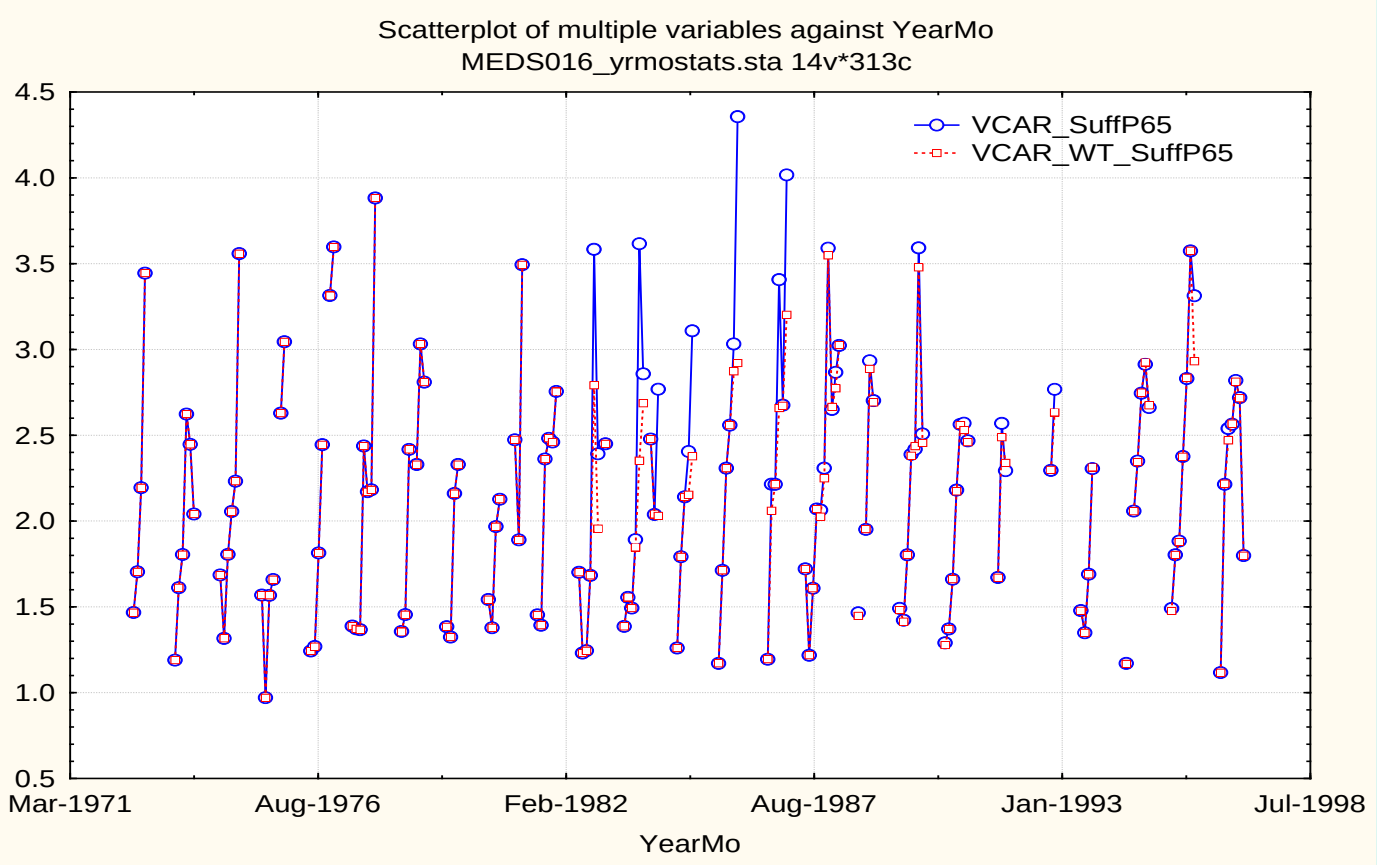
WR-FB = wave spectral frequency bands change, higher resolution

•Give weight 3 for reports with reporting interval 180 min (3 hourly synoptics), wt 1 for intervals of 60 min (hourly reports), wt 0.5 for 30 min, wt 0.333 for 20 min, etc.

•180 [20]: standard reporting 3-hourly, 3x/hr in waves > 5m

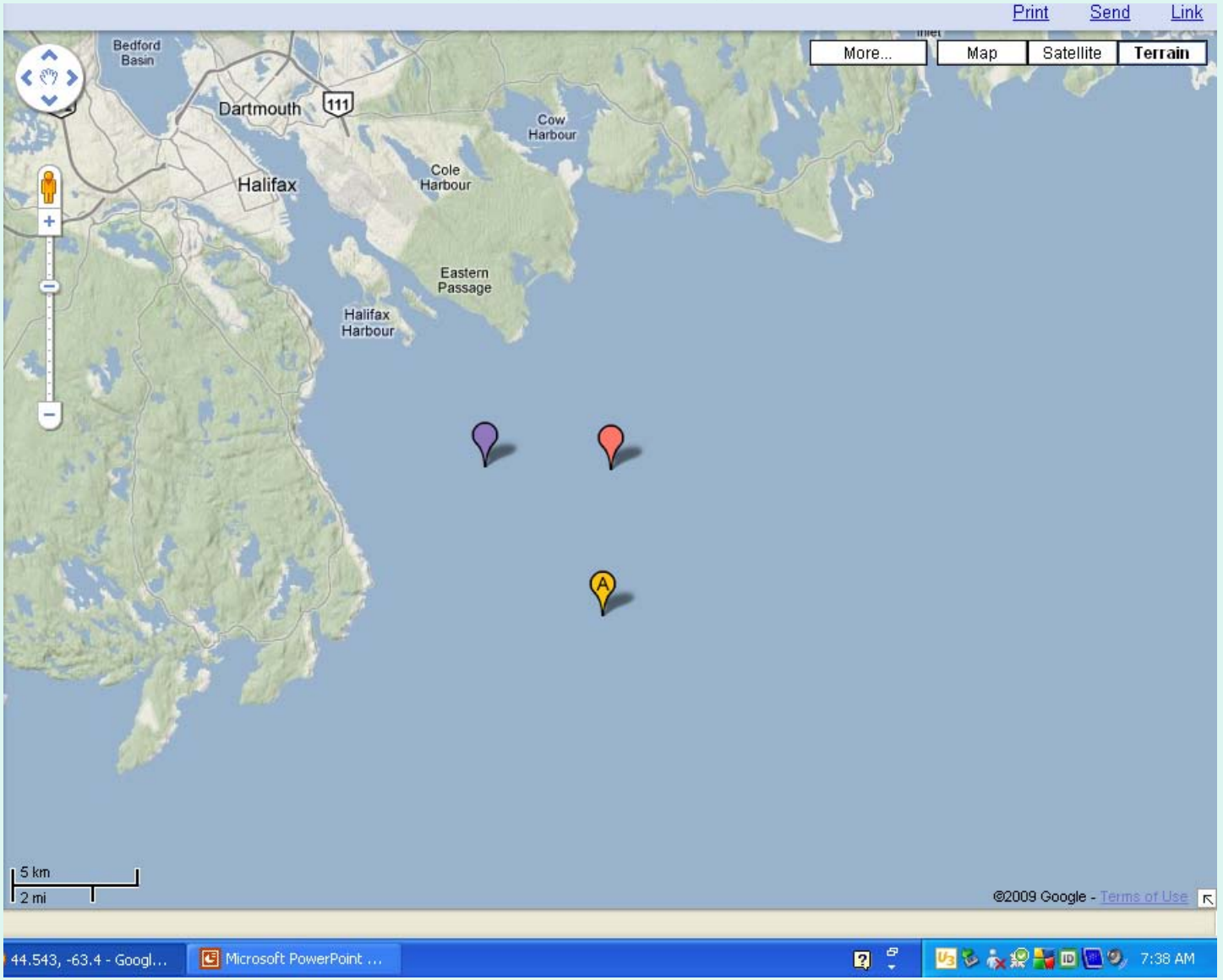
•60 [30, 180]: standard reporting hourly, 2x/hr in high waves, and only 3-hourly in waves < 1m

Torbay (St. John's) Waverider – Weighted and Unweighted Monthly Mean Hs



- Monthly means for months with at least 65% coverage
- 9x higher rate of reporting in Hs > 5 m (1982/06 - 1987/09) biases the monthly means
- Months July to December are well represented (each have 18 to 23 of the total 26 years)

Halifax Approaches buoy mooring locations, 1970 - 2009

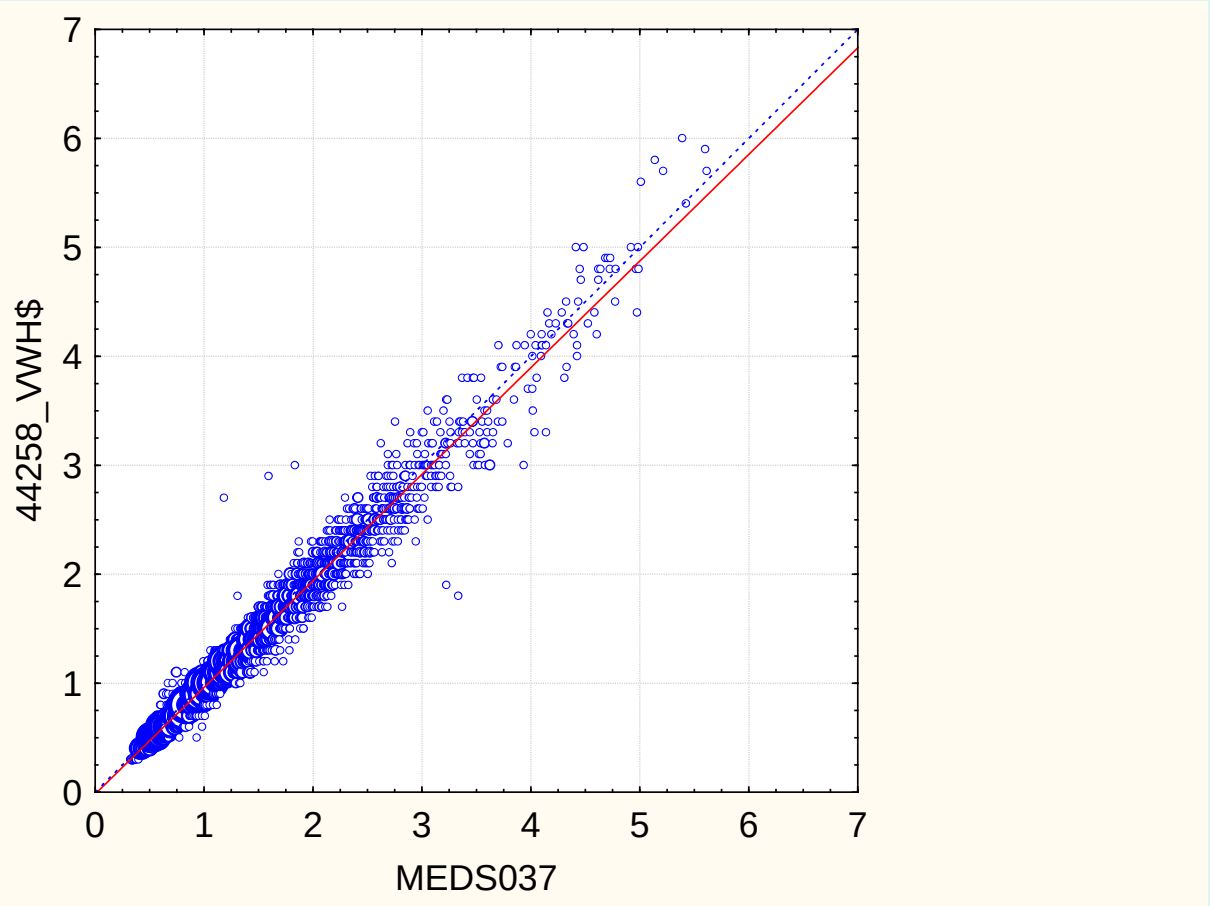


Metadata for Halifax Approaches Buoy

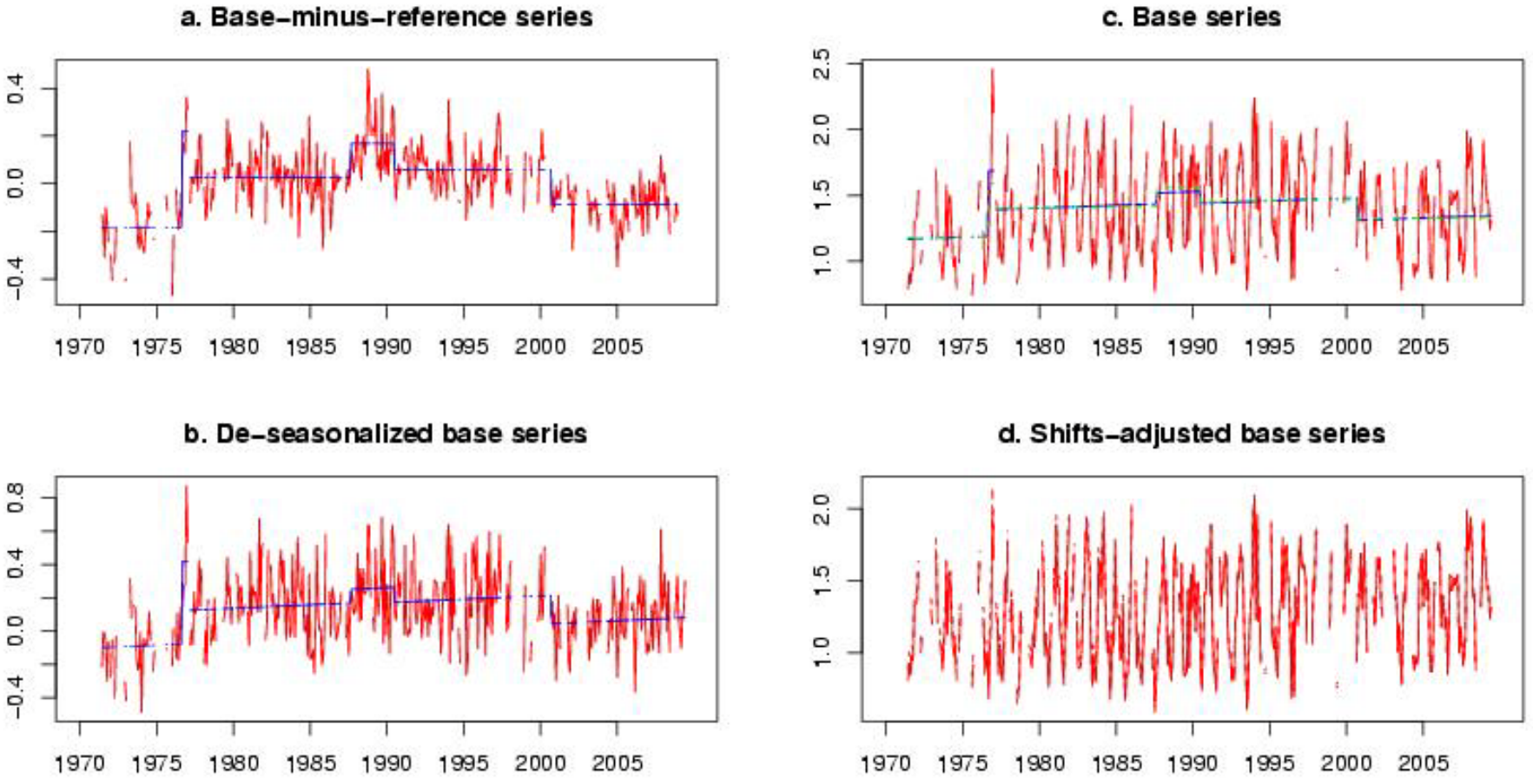
Date	*Lat (°N)*	*Long (°W)*	*Change (km)*	*Water Depth (m)*	*Type*	*Reporting Interval [Alternate (s)] (min)*
MEDS037 Waverider						
1970/12	44.544	63.464		50	WR	180
1976/09	44.490	63.404	7.7	57	WR	180
1982/10	44.490	63.403	0	57	WR	180 [20]
1987/10	44.490	63.403	0	57	WR	60 [30, 180] or 30
1997/10	44.490	63.403	0	57	WR	30
1998/12	44.489	63.416	1.0	57	WR	30
1999/10	44.490	63.403	1.0	57	WR	30
2000/07	44.507	63.405	2.0	57	WR	30
2001/*						30
44258 3m Discus or 6m NOMAD						
2000/03*					3D	60
2001/10	44.543	63.400	4.0	50	3D	60
2002/08	44.502	63.403	4.6	58	6N	60
2005/06	44.502	63.403		58	3D	60

* Data not used in time series

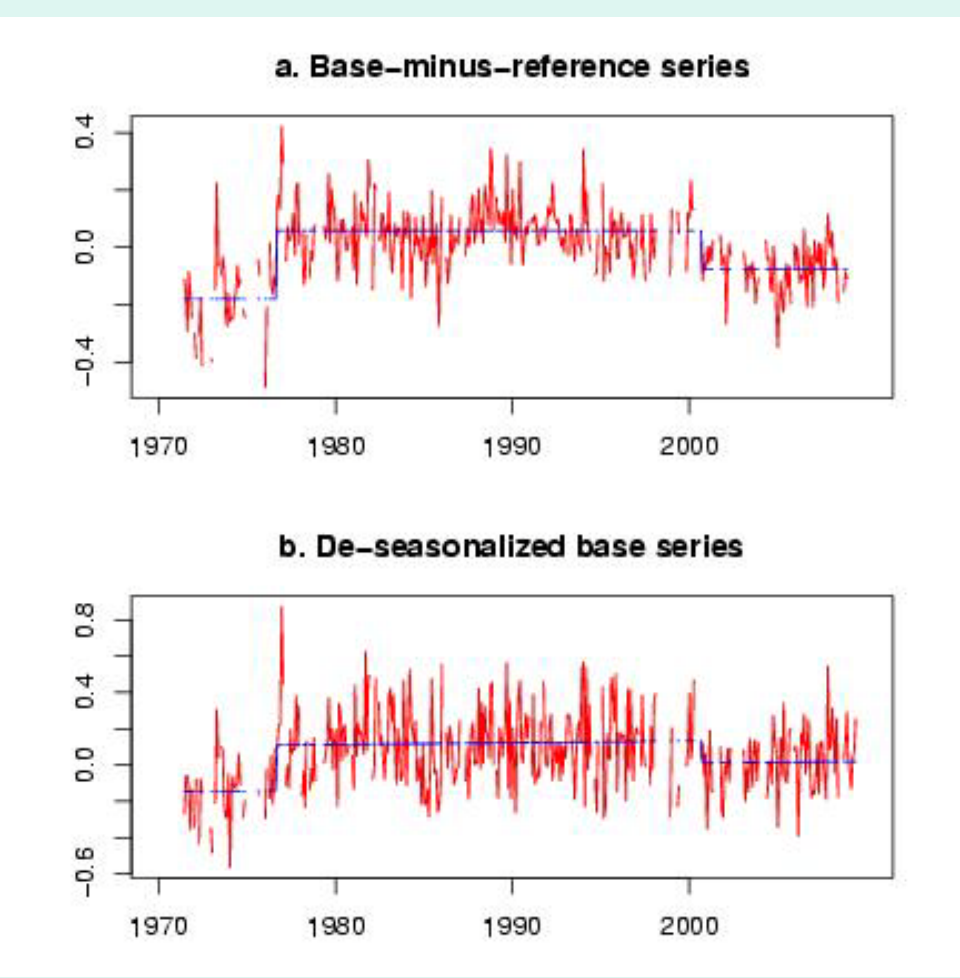
3 m Discus buoy Hs against Datawell Waverider Hs (m), Halifax Approaches, 2000-2001

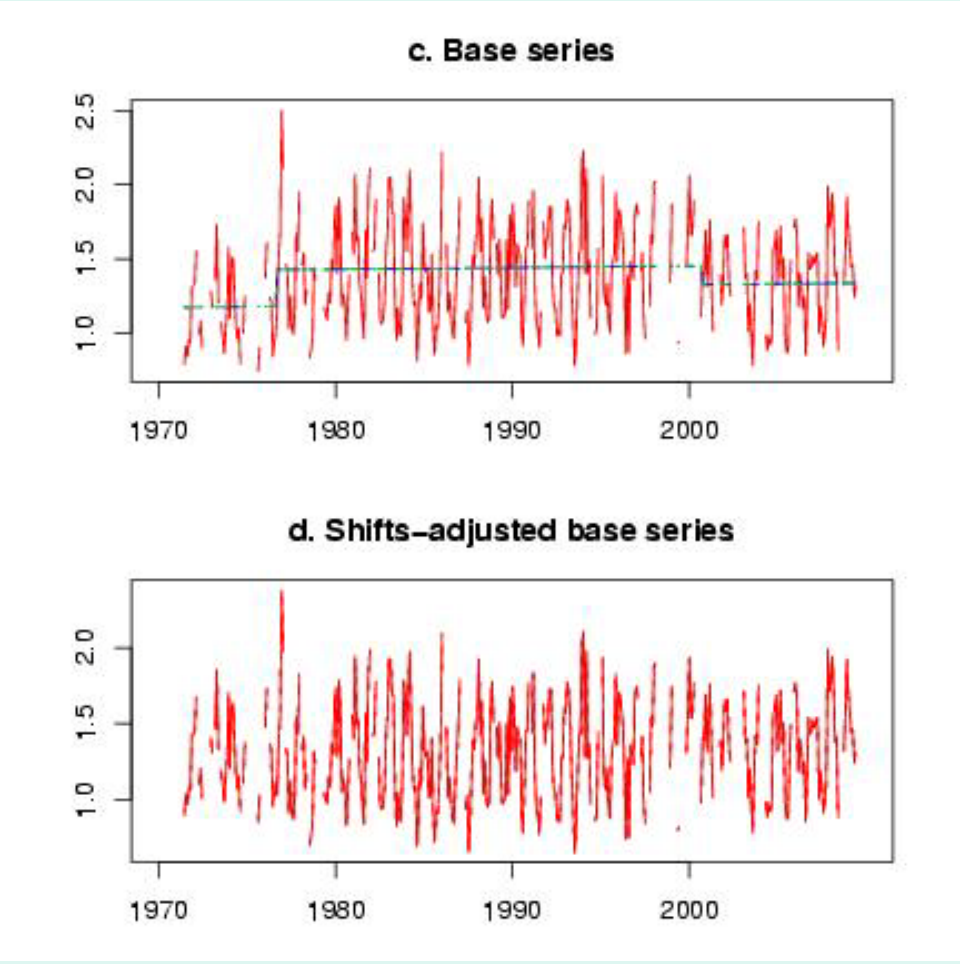


Halifax Approaches Monthly Mean Hs (m) [incorrect weighting for part of period]

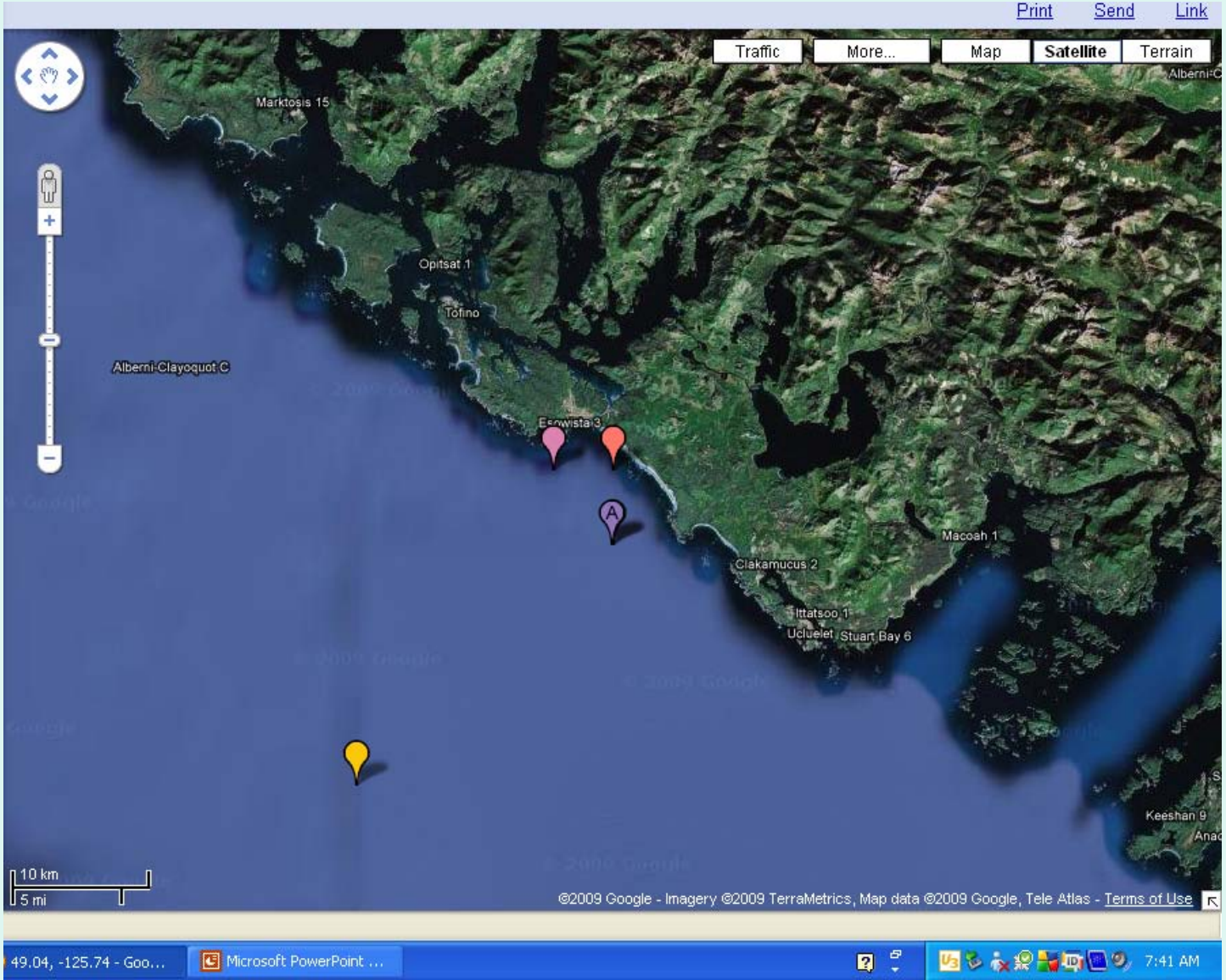


Halifax Approaches Monthly Mean Hs (m) [correct weighting]





Tofino + La Perouse Bank mooring locations, 1970 - 2008



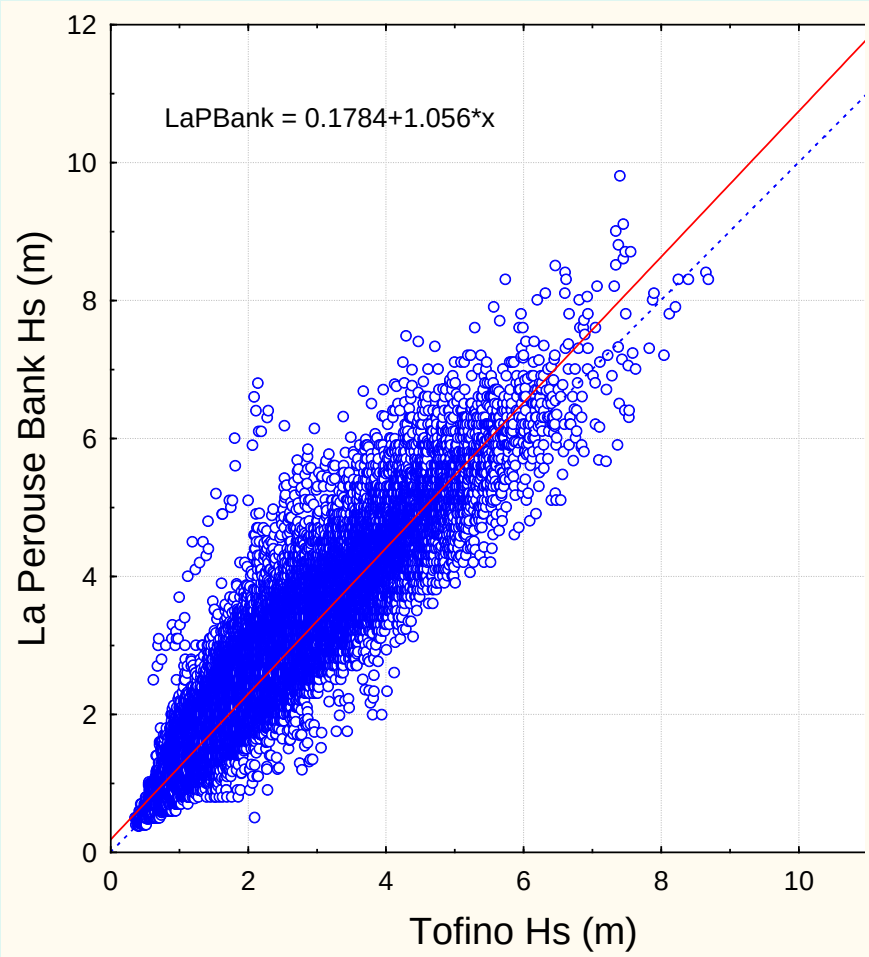
Metadata for Tofino + La Perouse Bank Buoys

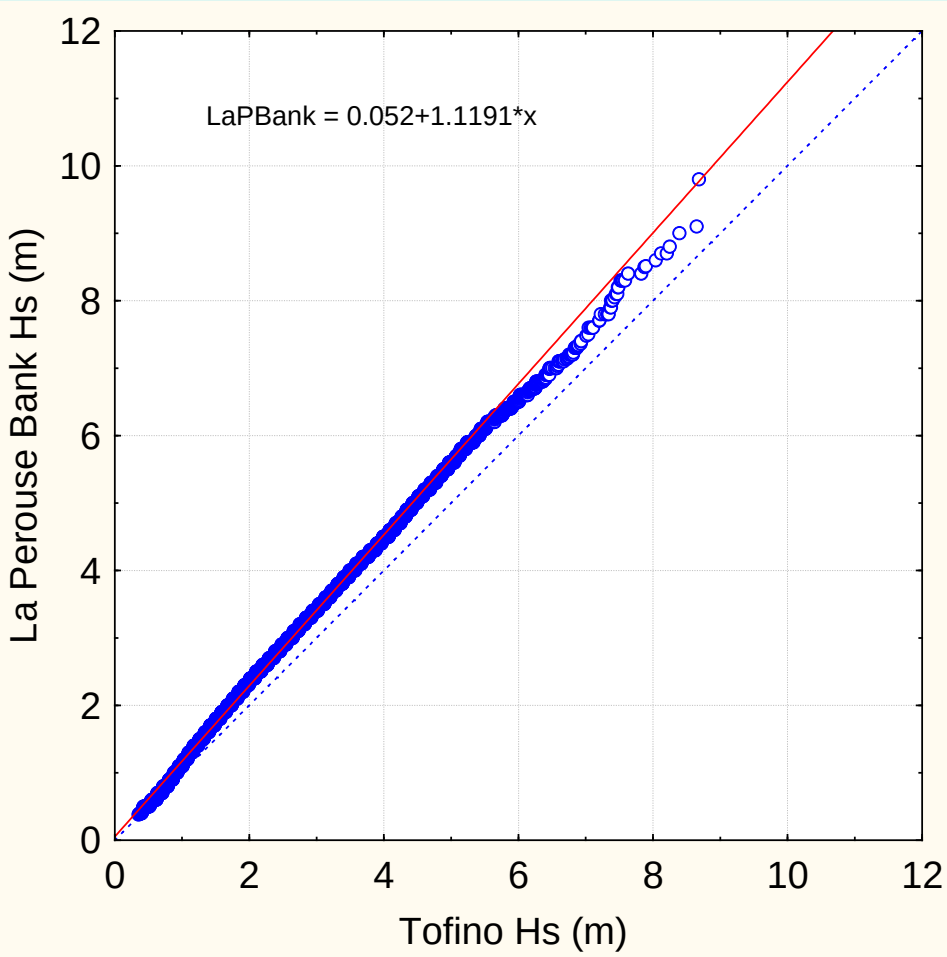
Date	*Lat (°N)*	*Long (°W)*	*Change (km)*	*Water Depth (m)*	*Type*	*Reporting Interval [Alternate (s)] (min)*
MEDS103 Datawell Waverider (+ MEDS303 directional Datawell Waverider, 1998/09-1999/05)						
1970/06	48.99	125.740		40	WR (19.5 s)	180
1976/08	48.99	125.740	0	40	WR (27.31 s)	180 [20]
1983/05	49.04	125.740	5.6	40	WR	180 [20]
1987/01	49.04	125.800	4.4	40	WR	60 [30, 180] or 30
1998/09	49.04	125.800	0	40	DWR	30
46206 3m Discus (first deployed 1988/11*)						
1999/05	48.83	126.00	28	75	3D	60
2002/05	48.83	126.00	0	75	3D-LCF	60

*Data not used in time series

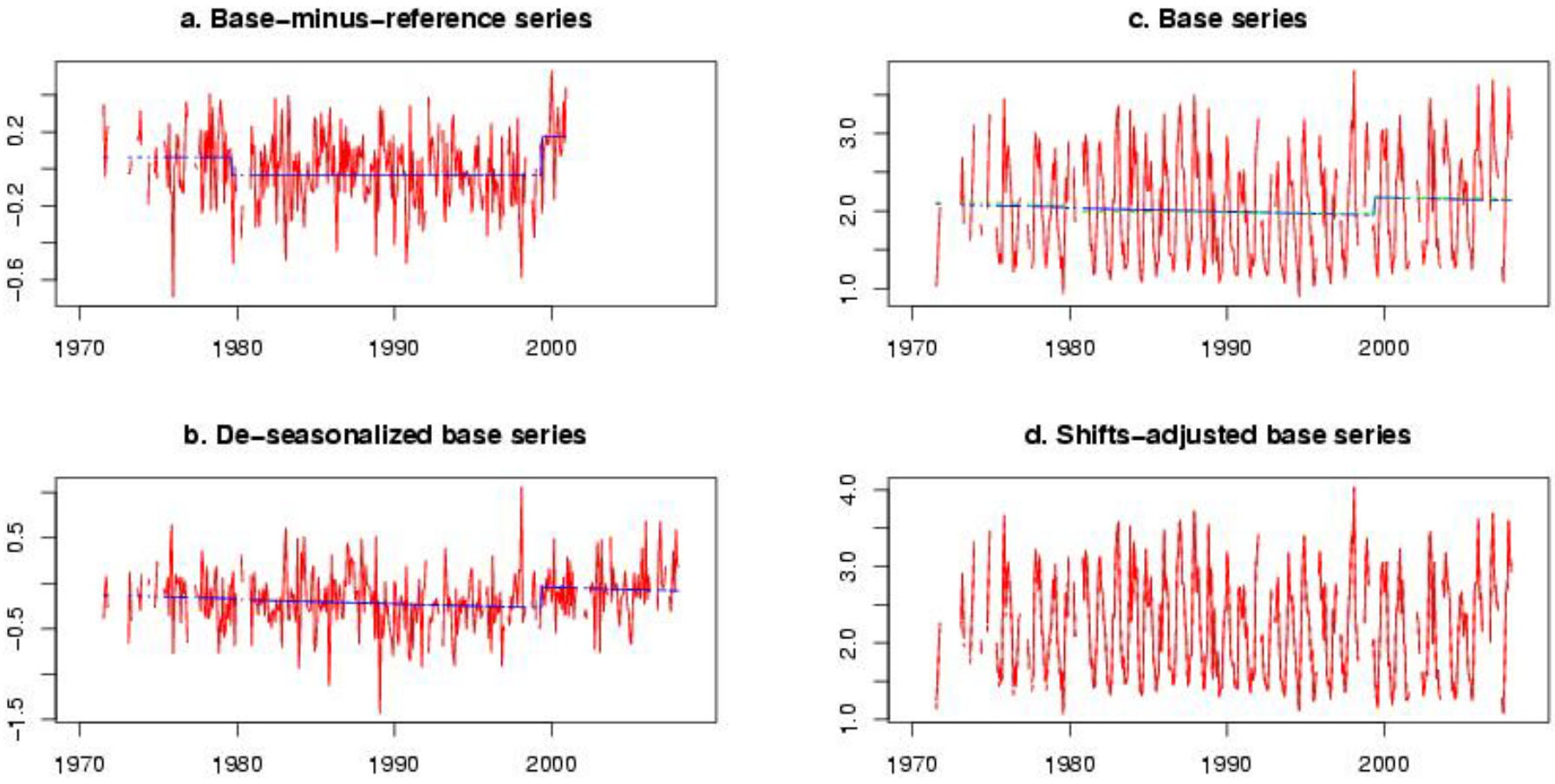
- from 1999/05 onward, used Hs calculated by the buoy rather than ISDM
- Beginning in 2002/05 the onboard wave processor started using a low frequency cutoff of 17s

La Perouse Bank 3D Buoy Hs (m) against Tofino Waverider Hs (m), overlapping period 1988/11 – 1999/05

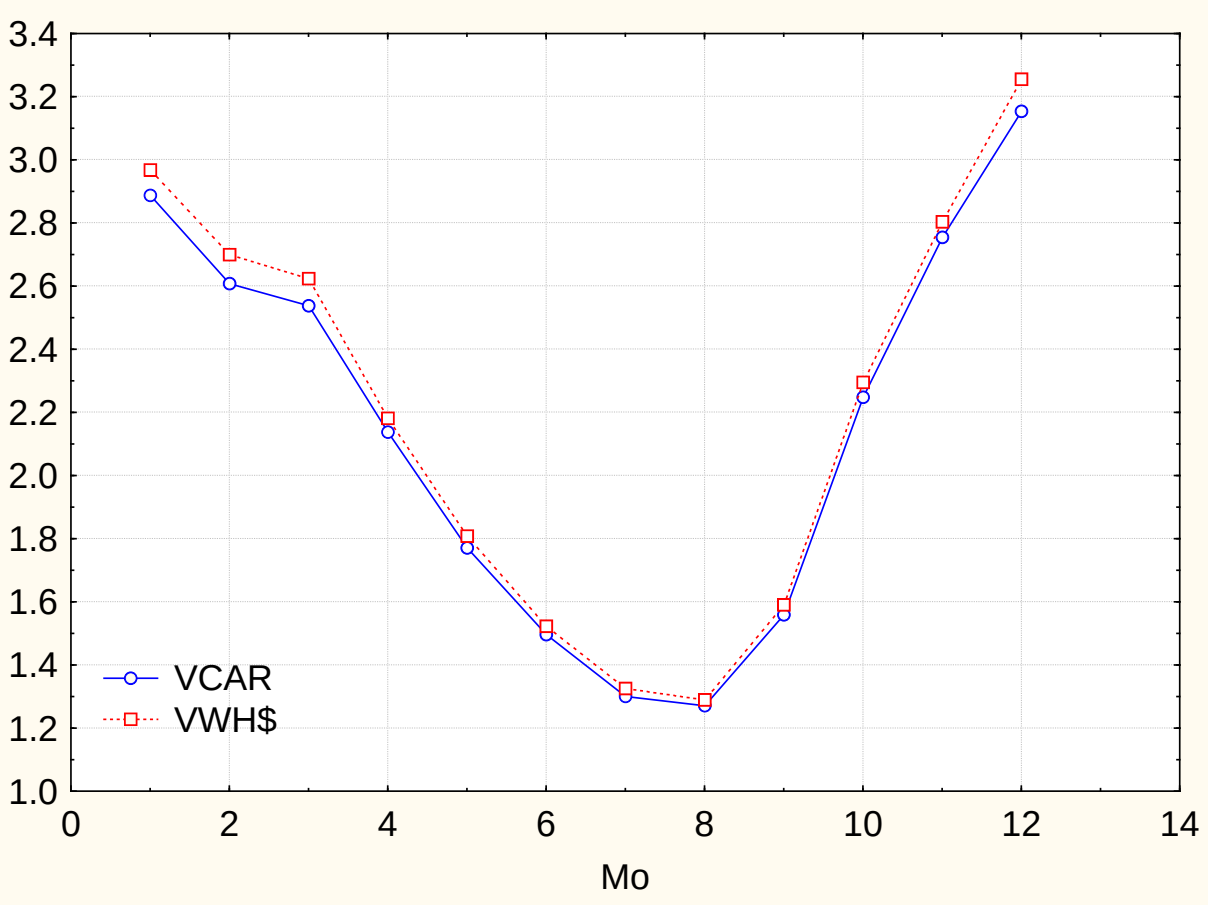




Tofino + La Perouse Bank Monthly Mean Hs (m)



Monthly Mean Hs from ISDM (VCAR) and on-board wave processor (VWH$), at 46206, 1988/11 – 2002/05



•During this period ISDM used a low frequency cutoff (corresponding to wave period of 16 s) in calculation of Hs, while the onboard processor did not. Use of this cutoff seems to reduce winter monthly means by about 0.1 m at La Perouse Bank (energy from very long period swell is not included in calculation of Hs); after this time the onboard processor alsostarts using a cutoff (wave period 17s)

References

- Axys Environmental Consulting Ltd. 1996. *Meteorological and oceanographic measurements from the Canadian weather buoys*. A review of sensors, data reduction, transmission, quality control and archival methods. Final report for Environment Canada, Downsview, Ontario, April 1996.
- Axys Environmental Systems. 2000. *The Canadian buoy network technical meeting*. A review of sea surface temperature measurements, metadata, and wave sensing and processing. Summary report and action items prepared for Environment Canada, Downsview, Ontario, February 2000.
- Gower JFR. 2002. Temperature, wind and wave climatologies, and trends from marine meteorological buoys in the Northeast Pacific*. Journal of Climate* **15**: 3709-3718.
- Wan H, Wang XL, Swail VR. Homogenization and trend analysis of Canadian near-surface wind speeds. Accepted by *Journal of Climate*.
- Wang, X.L., and V. R. Swail, 2001: Changes of extreme wave heights in Northern Hemisphere oceans and related atmospheric circulation regimes. *J. Climate,* **14,** 2204–2221.
- Wang, X.L, and Y. Feng, 2007: RHtestV2 user manual. Climate Research Division, Science and Technology Branch, Environment Canada, Toronto, Ontario, Canada, 19 pp. [Available online at http://cccma.seos.uvic.ca/ETCCDMI/RHtest/RHtestV2_UserManual.doc.]
- Wang, X. L., Q. H. Wen, and Y. Wu, 2007: Penalized maximal *t* test for detecting undocumented mean change in climate data series. *J. Appl. Meteor. Climatol.,* **46,** 916–931, doi:10.1175/JAM2504.1.
- Wang, X. L., 2008a: Penalized maximal *F* test for detecting undocumented mean shift without trend change. *J. Atmos. Oceanic Technol.,* **25,** 368–384, doi: 10.1175/2007JTECHA982.1.
- Wang, X. L, 2008b: Accounting for autocorrelation in detecting mean shifts in climate data series using the penalized maximal t or F Test. *J. Appl. Meteor. Climatol.,* **47,** 2423-2444, doi:10.1175/2008JAMC1741.1.