Effect of Vessel Type and Platform Relative Wind Direction on Comparison of Buoy and Ship Winds

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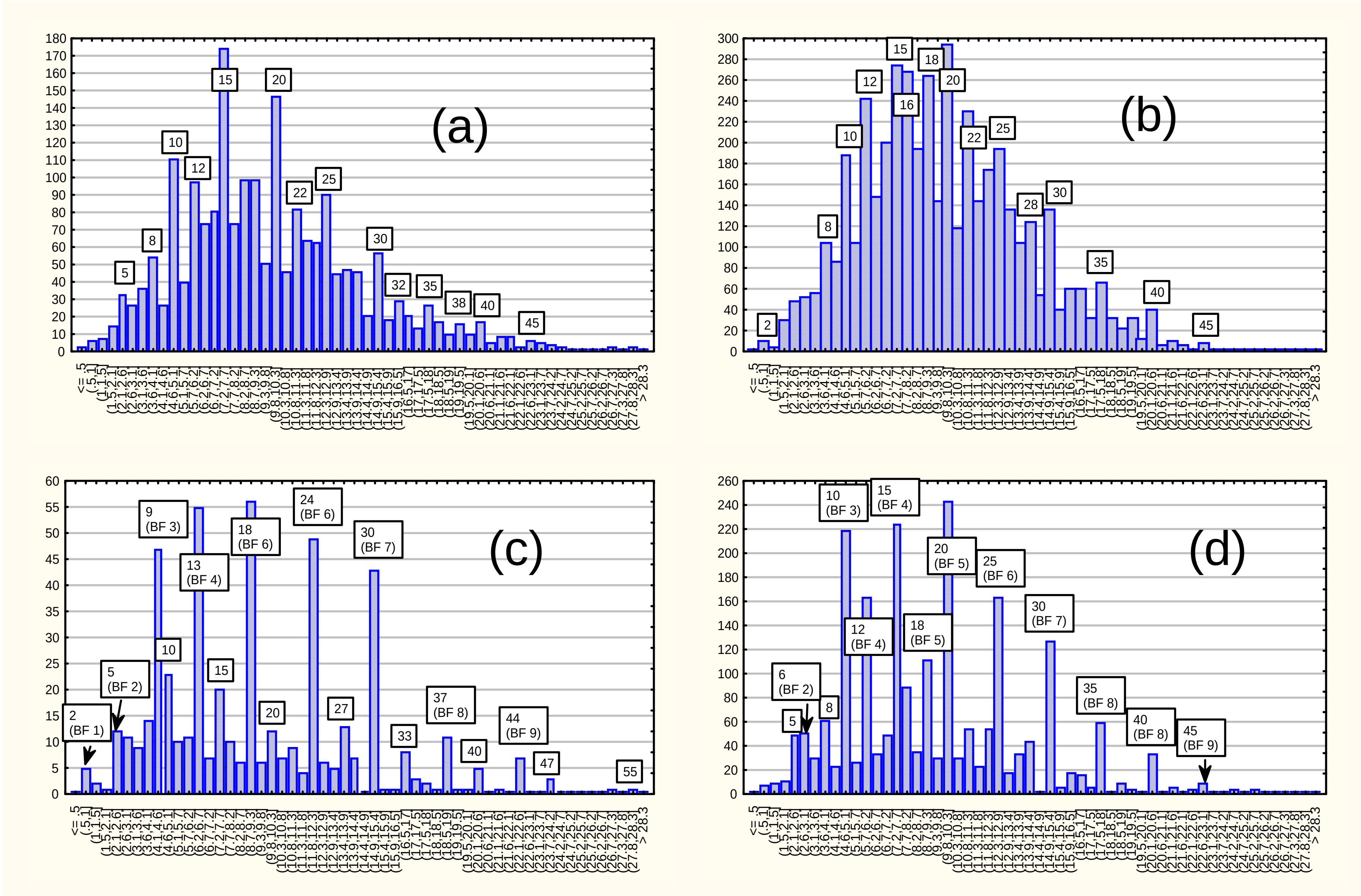
Ship type and country, near the west coast offshore and the east coast moored weather buoys

- Ship reports from COADS database, close to moored buoy reports in space and time, were collected and quality controlled, and adjusted for height if measured, and using Lindau's scale, if estimated, as described in Thomas and Swail (2003a).
- The ship and buoy wind speed data pairs show considerable variability. We are interested in assessing factors that could introduce inhomogeneities in the ship wind data base, that would not affect the buoy winds at all, or not to the same degree.
- The vast majority of ship reports near Canada's 3 offshore buoys on the west coast are from tankers tracking NW or SE. The rest are from either of ships of unknown type, general cargo ships, or container ships, travelling W or NW and E or SE. Of these ships, for each vessel type, the proportion reporting a measured wind speed compared to an estimated wind speed is very roughly 50:50. Almost all estimated wind speeds are from ships recruited by the US. Of the tankers, almost all are recruited by the US. The ships of unknown vessel type, reporting a measured wind speed, in decreasing order of frequency, were recruited by the US, Japan, Russia, and Canada.
- Ships reporting near the east coast buoys are a mixture of large merchant vessels, smaller government vessels (mostly Canadian: CoastGuard and research), with a smaller number of Russian ships, probably fishing vessels. The merchant vessels are primarily containers and general cargo ships, with a smaller number of reports from bulk carriers. German and US recruited merchant ships contributed most of the measured ship winds, and German, US, and Great Britain recruited merchant ships contributed most of the estimated ship winds.
- The US and Germany have somewhat different observing practices for estimated winds, in terms of choosing values for each Beaufort interval (see figure below). Measured ship wind distributions are smoother.



Wind speed distributions (in m/s) for east and west coast measured ship winds (a and b), and for east coast estimated ship winds from German (c) and US (d) recruited ships, for all winds originally reported in kt. Labels in kt.

Assessing factors that affect the relative ship-to-buoy wind speed bias

- To look at effects that could contribute to variability or inhomogeneity in the ship reported winds, we will look at how the relative ship-to-buoy wind speed bias changes, when we group by different categories. Some of the grouping categories are vessel type, recruiting country, wind method, night/day, ship speed, etc. Some of these factors are described in detail by Kent et al (1991).
- We assess the relative ship-to-buoy wind speed bias using the difference in ship minus buoy wind speeds, and the ratio of ship over buoy wind speeds, for paired ship and buoy wind speeds. Winds were adjusted for known sources of inhomogeneity, such as different measurement heights.
- Some of the following tables show both the mean and SD, and the median and inter-quartile range, of the difference in ship minus buoy wind speeds, and of the ratio of ship over buoy wind speeds (RSB). The ratio gives an indication of the percentage bias, by which the ship is greater or smaller than the buoy wind speed.
- The mean RSB tends to be larger than the median RSB. However, the mean RSB is not as robust a way to describe the overall ratio of ship to buoy wind speeds, since it is more affected by outliers. Larger and more frequent outliers are likely as wind speeds decrease, since large RSB can be the result of dividing by a very small number. There could be large values of RSB in stronger winds, if the buoy wind is completely erroneous, but the larger values become much more frequent as the true winds decrease to 0.
- Some of the figures show the distributions of these values in the form of box plots, with the median as a point, the box indicating the 25th and 75th percentiles, the whiskers indicating the non-outlier maximum and minimum values, and the outliers and extreme outliers as points.

Measured ship winds

West coast

- US tankers dominated the numbers of measured ship/buoy pairs. Their winds agreed well with buoy wind speeds. The median ratio of (height adjusted) ship to buoy wind speeds was .99 (ship 1% < buoy) (median difference of -0.1 m/s).
- Japanese recruited ships, of unknown vessel type, were the next largest group. Median RSB for these ships was 1.08 (ship 8% > buoy) (difference .6 m/s).
- The largest ship to buoy ratios were from general cargo ships: 1.10 (US) to 1.19 (Japan and Canada) (differences of .8 to 1.6 m/s).
- Bulk carriers and container ships had similar ship to buoy wind speed ratios, but differed slightly by country: eg. for Japan: 1.03 and 1.01, and for US: 1.10 and 1.06.
- Most tankers and bulk carriers had average anemometer heights of 27 to 34m, and moved at median speeds of 11-15 kt (SS=3). Most container ships, general cargo ships and Japanese ships of unknown type had average anemometer heights of 35 to 37 m, and moved at speeds of 16-20 kt (SS=4).
- Russian ships had the lowest average anemometer height of 17 m. They moved at median speeds of 11-15 kt, and the median RSB was 1.06.

East Coast

- Nearly half of the measured wind reports come from Canadian government vessels. Their median RSB was of 1.15.
- The merchant vessels (mainly containers and general cargo) were recruited mostly by the US and Germany. The median ratio were about 1.07 for container ships, about 1.11 for general cargo ships (similar to west coast values). Average anemometer heights were high: 31 to 43 m. The unknown vessel types (excluding Russian) were probably merchant vessels, given the higher ship speeds and anemometer heights. The median vessel speed for the merchant vessels was 4 (16-20 kt) in most groups, except 5 (21-15 kt) for US general cargo ships, and 3 (11-15 kt) for Canadian bulk carriers.
- The Russian ships had a low bias, with a median RSB of .90, or ship 10%< buoy (~-.5 m/s). These were probably fishing boats, as anemometer heights averaged only 14 m, and the median speed was only 1-5 kt.

Mean anemometer height, median ship speed (coded: 2(6-10 kt); 3(11-15 kt); 4(16-20 kt)) and difference statistics (for DSB_U10N and RSB_U10N) for west coast measured ships, grouped by VT and country.

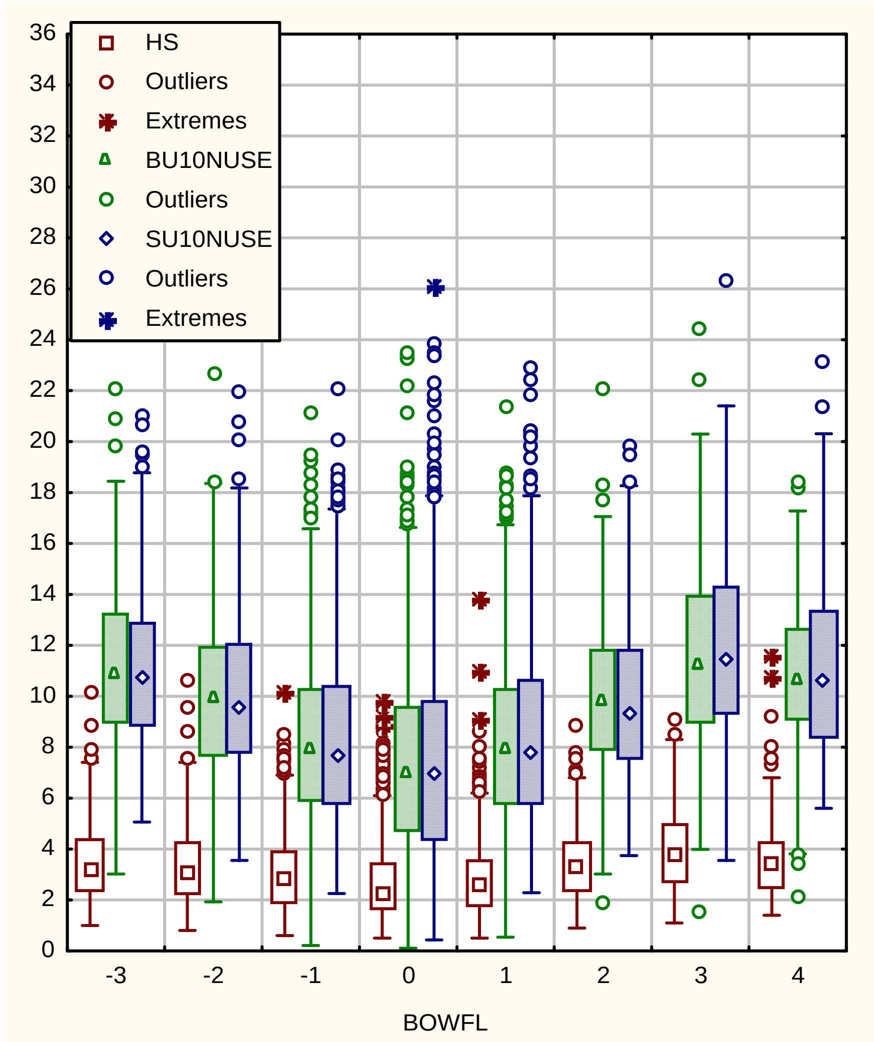
VT	*CCF*	*AH (m)*	*Med SS*	*N*	*Mean DSB*	*SD DSB*	*Med DSB*	*IQR DSB*	*Mean RSB*	*SD RSB*	*Med RSB*	*IQR RSB*
All	All	33.		7241	.30	2.50	.28	3.20	1.15	1.01	1.04	.41
1 ***Tanker***	US	34.	3	2232	-.12	2.51	-.09	3.22	1.07	.67	.99	.40
2 ***BC***	JP	35.	3	233	.25	2.10	.29	2.37	1.06	.31	1.03	.32
2	CA	32.	3	168	.96	2.11	1.06	2.32	1.16	.39	1.11	.31
2	US	27.	3	63	.63	2.52	.75	3.02	1.13	.36	1.10	.37
Container *3*	US	37.	4	352	.41	2.21	.57	2.59	1.22	2.00	1.06	.33
3	JP	37.	4	149	-.01	2.19	.04	2.43	1.06	.35	1.01	.31
3	OTH	36.	4	128	.89	2.63	.78	3.40	1.22	.64	1.09	.42
4 ***GC***	US	35.	4	141	.60	2.67	.80	3.87	1.14	.58	1.10	.45
4	JP	35.	4	67	1.84	2.61	1.62	3.05	1.34	.75	1.19	.35
4	CA	36.	3	41	1.26	2.20	1.63	2.79	1.26	.42	1.19	.47
5 ***GV***	CA	21.	2	105	.58	1.97	.53	1.92	1.10	.30	1.06	.29
6 ***Other***	JP	28.	2	63	.11	2.08	.05	2.51	1.13	.73	1.01	.35
7***Unknown***	JP	36.	4	1858	.66	2.44	.59	3.29	1.20	1.29	1.08	.42
7	US	29.	3	580	.13	2.67	.07	3.32	1.17	.82	1.01	.44
7	RU	17.	3	484	.11	2.54	.01	3.42	1.18	1.27	1.00	.46
7	CA	31.	3	430	.45	2.58	.46	3.22	1.19	.94	1.06	.44
7	OTH	31.	4	98	.09	3.13	-.34	4.16	1.10	.55	.96	.52

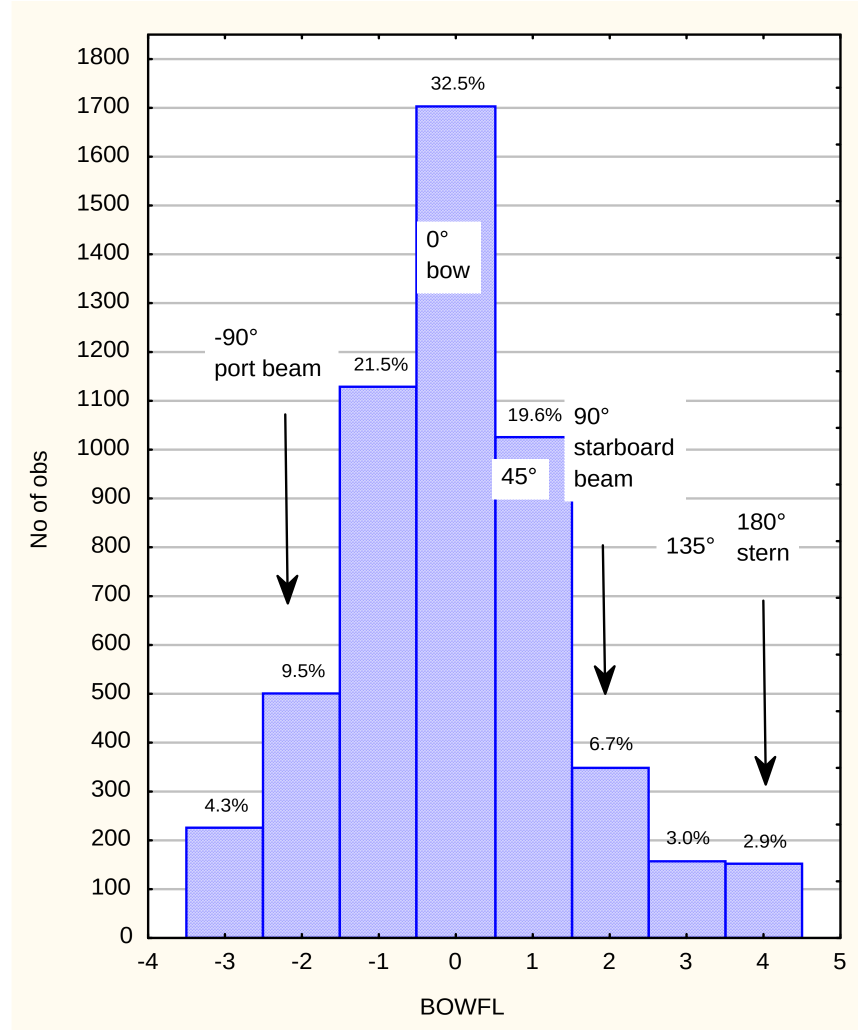
Mean anemometer height, median ship speed (coded: 2(6-10 kt); 3(11-15 kt); 4(16-20 kt)) and difference statistics (for DSB_U10N and RSB_U10N) for east coast measured ships, grouped by VT and country.

VT	*CCF*	*AH*	*SS*	*N*	*Mean DSB*	*SD DSB*	*Med DSB*	*IQR DSB*	*Mean RSB*	*SD RSB*	*Med RSB*	*IQR RSB*
2	CA	30.	3	33	.52	3.14	.28	2.80	1.10	.48	1.07	.43
3	DE	39.	4	120	.43	2.79	.56	3.72	1.13	.46	1.08	.57
3	US	41.	4	218	.56	2.62	.51	3.34	1.20	.79	1.06	.37
3	OTH	43.	4	39	1.22	3.15	1.59	4.48	1.28	.59	1.20	.69
4	DE	31.	4	54	.89	1.99	.84	3.15	1.11	.24	1.10	.29
4	US	35.	5	126	1.29	2.39	1.29	3.19	1.21	.38	1.12	.40
5	CA	21.	2	1048	.99	2.39	1.05	2.98	1.27	.64	1.15	.51
5	DE	18.	2	32	1.64	2.18	2.30	2.70	1.18	.20	1.22	.27
7	CA	28.	3	71	1.35	2.42	1.24	3.24	1.44	.90	1.20	.52
7	DE	38.	4	176	.77	2.41	.88	2.93	1.22	.74	1.10	.36
7	RU	14.	1	161	-.54	2.70	-.70	3.09	1.07	.93	.90	.42
7	US	34.	4	83	1.12	2.42	.78	3.46	1.31	.59	1.17	.62
All	All	27.	3	2377	.82	2.54	.83	3.22	1.23	.65	1.11	.47

Distribution of wind speeds as a function of platform relative wind direction

- The next figure shows west coast measured ship and buoy wind speeds, and buoy Hs, binned on the platform relative wind direction. The bins are 45°, centred on the bow (bowfl=0, +-22.5) and finishing at the stern (bowfl=4, near 180°, +- 22.5).
- The platform relative wind directions were estimated from the reported true wind and the ships course and speed made good over the past 3 hours. For merchant ships, this may be a reasonable estimate of the heading and speed at the time of the wind observation. It will be less useful for government vessels because of different operating characteristics.
- The overall distribution of winds shows decreasing values as platform relative winds come more from the bow, because when true winds are lighter the platform relative winds are more likely to be onto the bow of a moving ship. There are also more very high wind speed reports for bow-on winds, perhaps because a ship is more likely to turn into the winds in extreme storms.
- Generally, when winds are stronger the platform relative wind directions become more likely to be from other directions than the bow.
- This plot illustrates how selecting for bow-on only platform relative wind directions, or binning on platform relative wind direction, can result indirectly in selecting for other quantities such as higher or lower wind speeds.
- When data is restricted to bow-on flows only, a large proportion of the reports are not used.





Box plot showing distribution of Hs, BU10N, and SU10N (left) and frequency distribution of west coast measured ship winds (right), binned on platform relative wind direction.
(Box plot: Median; Box: 25%,75%;Whisker: Non-Outlier Min, Non-Outlier Max)

Mean anemometer height and difference statistics (for DSB_U10N and RSB_U10N) for west coast measured ships, grouped by VT and country, for bow on winds.

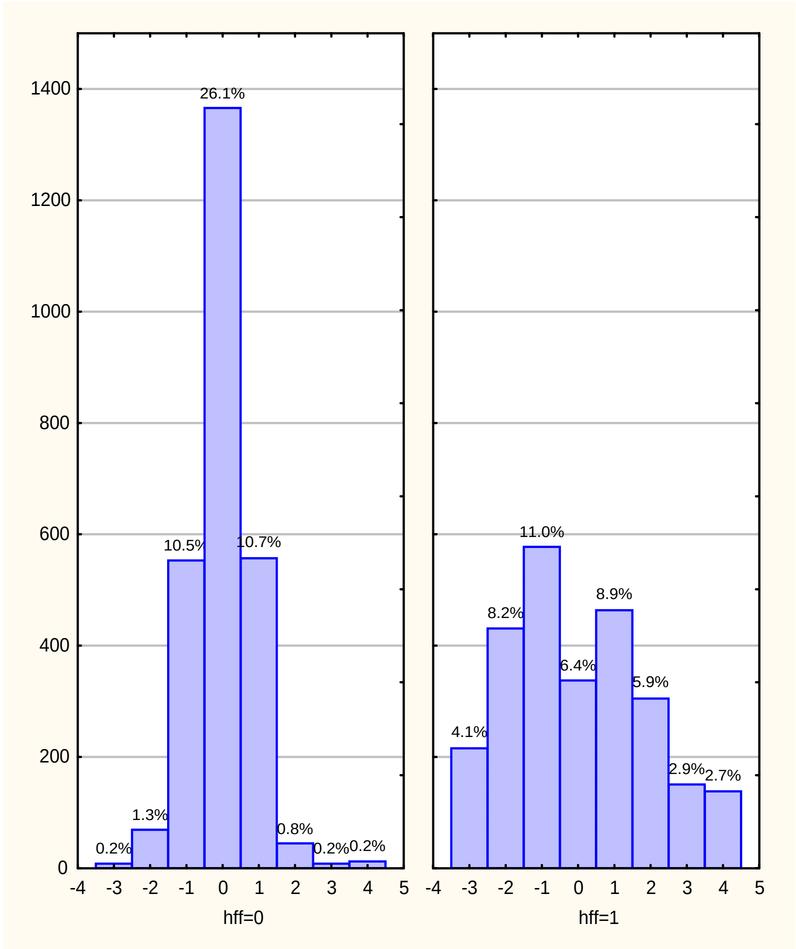
VT	*CCF*	*AH (m)*	*N*	*Mean DSB*	*SD DSB*	*MED DSB*	*IQR DSB*	*Mean RSB*	*SD RSB*	*MED RSB*	*IQR RSB*
All		32.	1702	.12	2.47	.13	3.12	1.15	1.20	1.02	.47
1	US	34.	772	-.05	2.51	-.03	3.24	1.10	.79	1.00	.49
2	JP	36.	35	.44	1.74	.53	2.39	1.07	.24	1.06	.30
3	US	36.	113	.20	2.29	.41	2.51	1.46	3.49	1.06	.45
3	JP	37.	51	.31	2.25	.38	2.64	1.13	.41	1.05	.40
3	OTH	35.	35	.52	2.79	.78	3.67	1.27	.99	1.09	.54
4	US	34.	45	.51	2.57	.47	3.47	1.21	.90	1.09	.51
7	US	29.	181	.23	2.74	.49	3.20	1.31	1.18	1.06	.51
7	RU	17.	148	-.37	2.31	-.30	2.99	1.05	1.12	.95	.48
7	JP	36.	147	.18	2.31	.35	3.33	1.09	.42	1.05	.49
7	CA	33.	50	.51	2.29	.75	2.92	1.17	.43	1.10	.53

West coast measured ship winds, by vessel type and recruiting country, for bow-on winds

- The statistics in the previous table are based on the same groups as the first table, but restricted to those reports where the relative wind direction was onto the bow of the ship (+-22°). Those directions may be associated with increased wind speeds due to flow distortion, depending on the anemometer location (*Moat, 2003*). Other platform relative wind directions might be subject to other effects as well, such as blockage by the ship superstructure (most anemometers are well exposed, but some are sheltered from particular directions).
- Ships that did not report the ship speed and course are not included in this analysis. The restriction to bow-on winds restricts the number of cases to about a third of the original number. There were greater reductions in number of cases in some groups, for which a higher proportion did not report ship heading and speed (eg Japanese and Canadian, unknown vessel type).
- Lighter winds are more likely to be bow-on, due to the faster speed of the merchant ships.
- For US tankers, containers, and general cargo, and for container ships from “other” countries, the median RSB barely changed, by .01 or less.
- Mean values of RSB for these US ship types were higher than median values, and did show more of an increase. Mean values of the difference changed slightly, but there were decreases as well as increases.
- The median RSB for Japanese bulk carriers and containers increased by about .03, from 1.03 to 1.06 (bulk carriers), and from 1.01 to 1.05 (containers).
- There was a decrease in median RSB for Japanese and Russian ships of unknown vessel type, by .03 (Japan) and by .05 (Russia), however there were many fewer bow-on wind cases, so the decrease may be related to a change in the population of ships.

Estimation of Ship Heading Relative to True Wind Direction: True Wind Heading or Following Flag

- When the ship is heading into the winds, the platform relative wind speed (WS) will be greater than the true WS, and when the ship has following true winds, the relative WS will be lighter than the true WS
- The heading/following flag (HFF) is based on the difference between the ship course and the quality controlled buoy wind direction: 0 if absolute difference < 90°, or 1, if it is > 90° (true wind forward or aft of the ship's beam)
- The flag also gives an estimate of whether the ship is heading into oncoming waves, or has a following sea (not a good estimate when swell predominates and the wind direction is not related to swell direction)



Frequency distribution of west coast measured ship winds, binned on platform relative wind direction, for heading and following true winds

Heading or following true winds (for measured ship winds)

- Grouping by heading or following true winds (in addition to grouping by vessel type and country) made a marked difference in the ship-to-buoy bias, for most of the vessel type country groups. With heading true winds, median RSB for these type/country groups were 5-10% greater than with true wind following. This included all groups on the west coast, and on the east coast it included US recruited containers and general cargo ships, and German recruited vessels of unknown type.
- The difference for tankers was 9%. With heading true winds, adjusted tanker winds were 3% high compared to buoy winds, and they were 4% low for following true winds. For US west coast container ships, median RSB for heading group was 1.10; for following, it was 1.00. (4% difference on east coast). For unknown vessel types recruited by the US, Japan, or Russian, west coast, the difference in the median RSB for heading or following true winds was about 6%. With many ship type/country groupings, with following true winds, the median ratio decreased to close to 1.00, suggesting good agreement with the buoy winds.
- For east coast the following groups did not show this variation: government vessels, German recruited container ships, and Russian and US recruited ships of unknown type.

Possible reasons for bias variations, heading/following true winds

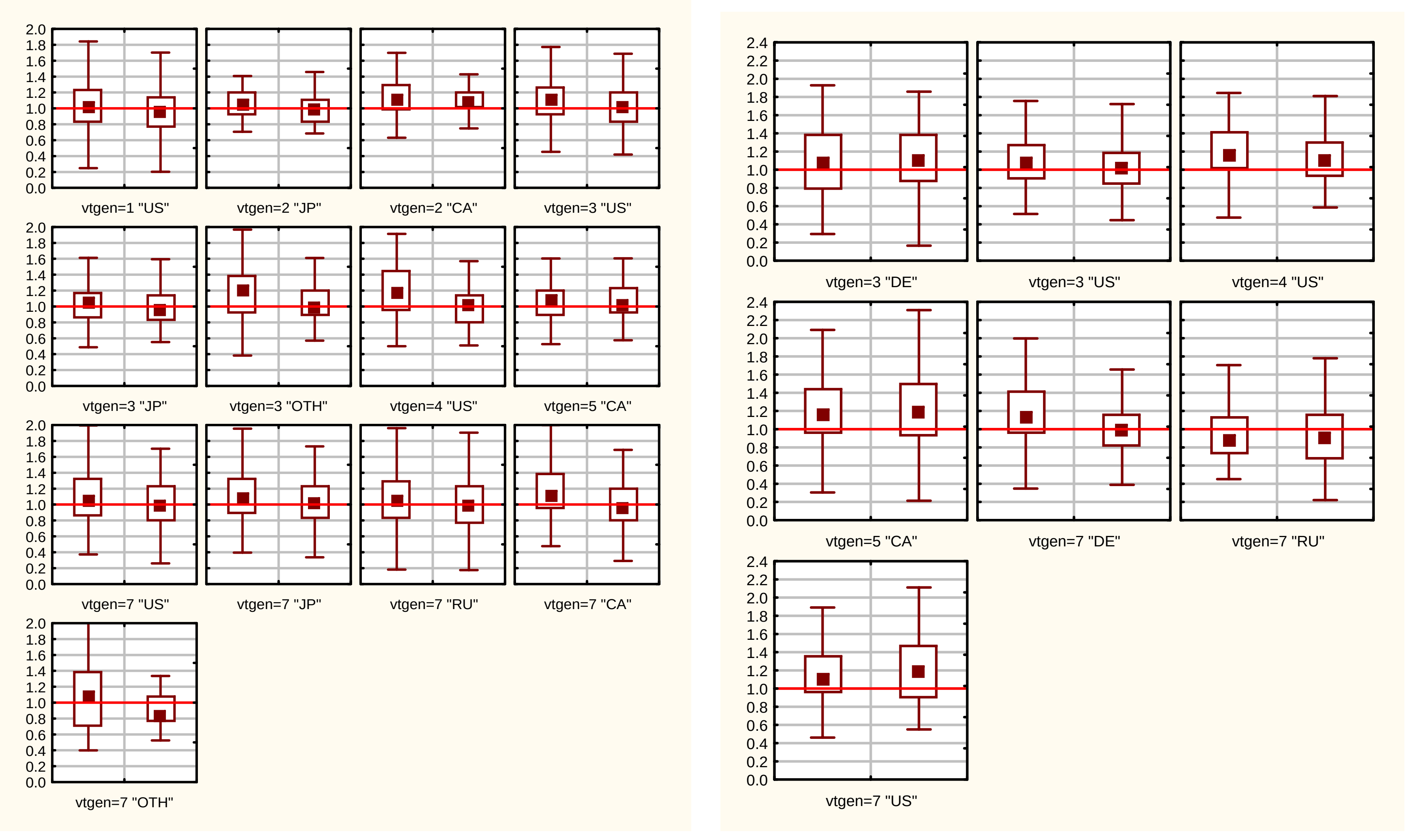
- Incorrect calculation of true wind from platform relative wind: could cause systematic errors with reported true winds stronger (lighter) than actual for heading (following) winds. This error variation would be accentuated by increasing ship speed. This is a likely source of error for measured winds.
- Flow distortion differences: the heading true wind condition includes a predominance of platform relative winds onto the bow, or onto the forward port and starboard quarters; for the following true wind cases, relative wind directions are more uniformly distributed around the ship. If there was pronounced speed up over the bridge (and anemometer) for bow-on flows, this could increase the bias in the heading true wind group, depending on the location of the anemometer. There is a greater chance of poorly exposed anemometers for other relative wind directions; this could affect the statistics for the following true wind category. Relative winds from the sides of the ship rather than the bow would be in an area with a greater “step height”, from the water level to the bridge top, rather than from the deck level to the bridge top.
- Subjective differences due to different motions of ships in oncoming or following large seas: this would be dependent on ship type. This would apply to relatively few cases, so probably would not affect overall statistics. It may be more of a factor for estimated wind speeds.

Difference statistics (for DSB_U10N and RSB_U10N) for west coast measured ships, grouped by VT, country, and HFF=0,1 (heading/following true winds), for n>=30..

VT	CCF	HFF	N	Mean DSB	SD DSB	MED DSB	IQR DSB	Mean RSB	SD RSB	MED RSB	IQR RSB
1 Tanker	***US***	0	1110	.27	2.47	.23	3.28	1.10	.54	1.03	.41
1	***US***	11	1110	-.51	2.49	-.44	3.07	1.05	.79	.94	.38
2 Bulk Carrier	***JP***	0	52	.54	2.10	.49	2.59	1.07	.25	1.06	.27
2	***JP***	1	63	-.03	1.72	-.14	2.53	1.04	.29	.98	.26
2	***CA***	0	42	1.23	2.34	1.06	2.60	1.15	.28	1.11	.30
2	***CA***	1	34	.70	1.63	.68	1.69	1.14	.29	1.09	.20
3 Container Ship	***US***	0	167	.86	2.13	1.03	2.61	1.39	2.87	1.10	.34
3	***US***	1	182	.01	2.23	.02	2.94	1.06	.37	1.00	.35
3	***JP***	0	66	.06	2.24	.32	2.59	1.09	.37	1.04	.34
3	***JP***	1	74	-.10	2.20	-.22	2.40	1.04	.34	.97	.31
3	***OTH***	0	58	1.42	2.83	1.64	3.78	1.25	.47	1.21	.45
3	***OTH***	1	65	.36	2.23	.01	2.24	1.19	.77	1.00	.29
4 General Cargo	***US***	0	70	1.19	2.49	1.52	3.56	1.24	.73	1.16	.49
4	***US***	1	71	.01	2.73	.14	3.45	1.05	.36	1.01	.34
5 Government Vessel	***CA***	0	43	.66	1.96	.65	2.30	1.08	.29	1.09	.30
5	***CA***	1	51	.24	1.54	.20	2.00	1.08	.26	1.03	.32
7 Unknown	***US***	0	294	.40	2.72	.37	3.39	1.21	.85	1.04	.46
7	***US***	1	254	-.10	2.56	-.09	3.13	1.14	.82	.99	.42
7	***JP***	0	257	.56	2.43	.74	3.39	1.14	.42	1.08	.43
7	***JP***	1	284	.15	2.44	.20	3.11	1.11	.49	1.02	.39
7	***RU***	0	219	.32	2.51	.25	3.46	1.19	1.37	1.04	.45
7	***RU***	1	215	-.15	2.54	-.24	3.30	1.13	1.05	.97	.46
7	***CA***	0	88	.75	2.55	.89	2.78	1.18	.40	1.12	.42
7	***CA***	1	77	-.31	2.29	-.26	3.02	1.07	.50	.95	.40
7	***OTH***	0	46	.60	3.47	.51	5.45	1.11	.45	1.07	.65
7	***OTH***	1	49	-.51	2.75	-1.44	2.50	1.08	.64	.85	.31

Statistics for DSB_U10N and RSB_U10N for east coast measured ships, grouped by VT and country, and by true wind heading, following, or not determined (HFF 0,1, or 9), for n>=30.

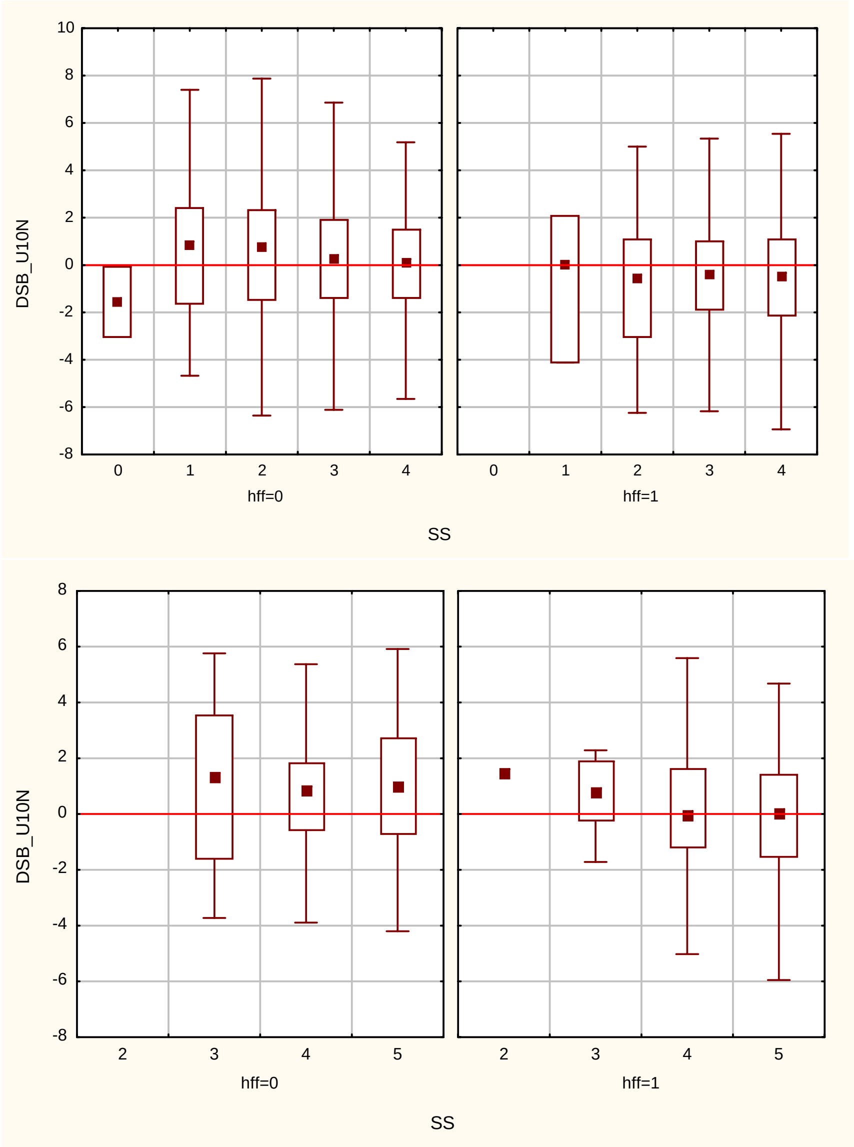
VT	***CCF***	*HFF*	*DSB N*	*DSB Mean*	*DSB SD*	*DSB Med*	*DSB IQR*	*RSB Mean*	*RSB SD*	*RSB Med*	*RSB IQR*
3	**DE**	0	68	.27	2.73	.52	4.11	1.12	.43	1.06	.60
3	**DE**	1	48	.55	2.91	.57	3.42	1.14	.51	1.11	.51
3	**US**	0	117	.84	2.55	.60	3.13	1.22	.65	1.07	.36
3	**US**	1	100	.24	2.70	.30	3.45	1.18	.94	1.03	.35
4	**US**	0	56	1.56	2.45	1.45	2.90	1.24	.40	1.17	.39
4	**US**	1	70	1.07	2.33	.85	2.95	1.19	.36	1.11	.37
5	**CA**	0	454	1.19	2.43	1.18	2.84	1.30	.64	1.17	.46
5	**CA**	1	299	1.29	2.46	1.45	3.46	1.34	.70	1.20	.56
5	**CA**	9	295	.37	2.14	.45	2.65	1.16	.53	1.07	.49
7	**CA**	9	51	1.60	2.23	1.30	2.79	1.42	.62	1.22	.54
7	**DE**	0	116	1.11	2.21	1.23	2.75	1.27	.69	1.12	.44
7	**DE**	1	59	.01	2.55	-.19	3.35	1.02	.42	.98	.36
7	**RU**	0	89	-.63	2.55	-.82	2.74	.99	.55	.87	.39
7	**RU**	1	44	-.90	2.88	-.96	3.79	1.18	1.55	.90	.47
7	**US**	0	42	1.10	2.01	.83	3.29	1.29	.55	1.11	.39
7	**US**	1	37	.84	2.43	.54	3.41	1.24	.52	1.18	.56
All	**All**	All	2377	.82	2.54	.83	3.22	1.23	.65	1.11	.47



West (left) and east (right) coast measured median RSB, grouped by vessel type and country, binned on heading/following flag

Effect of ship speed on measured ship-to-buoy bias

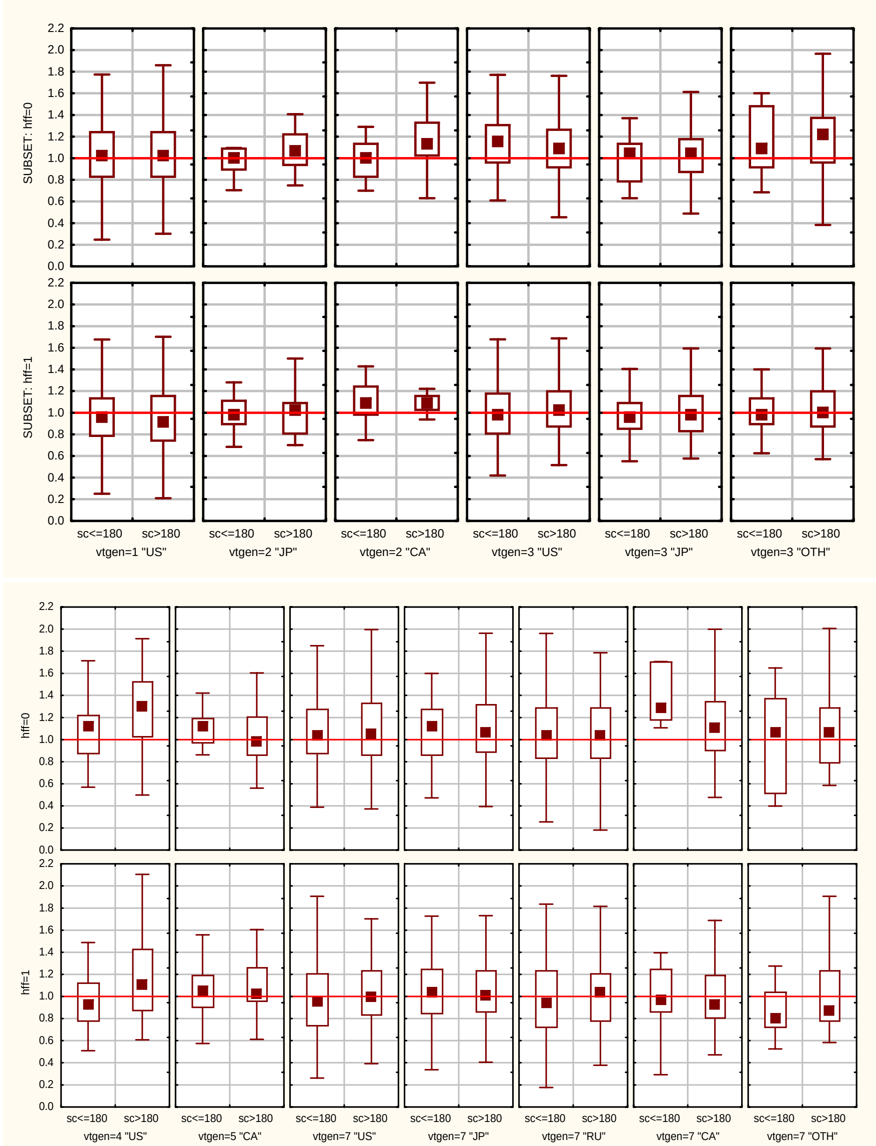
- Is the difference in the overall ship-to-buoy bias with heading or following true winds related to the calculation of true wind from a platform relative wind? These plots show the bias DSB for west coast tankers and containers, binned on ship speed.
- Merchant ships tend to move slower than normal, when sea states are higher. There is a gradual shift to higher sea state conditions in the lower than average speed categories. This could affect the bias statistics. Also, most values are concentrated in just two or three bins.
- For each of the ship type/country groups we assessed the variation of bias with SS, for heading/following true winds. It was difficult to see any trend. A few of the groups showed an upward trend for heading, downward trend for following, but most showed no trend, or even a slight decreasing trend for both.
- Within the limitations of the data, it appears that the majority of ship observers in each group do calculate the true wind reasonably well.



DSB for west coast measured winds, tankers (left) and containers (right), grouped on ship speed code, for heading and following true winds (ship speed top of range =ss*5kt)

Effect of wind wave or swell direction relative to ship course

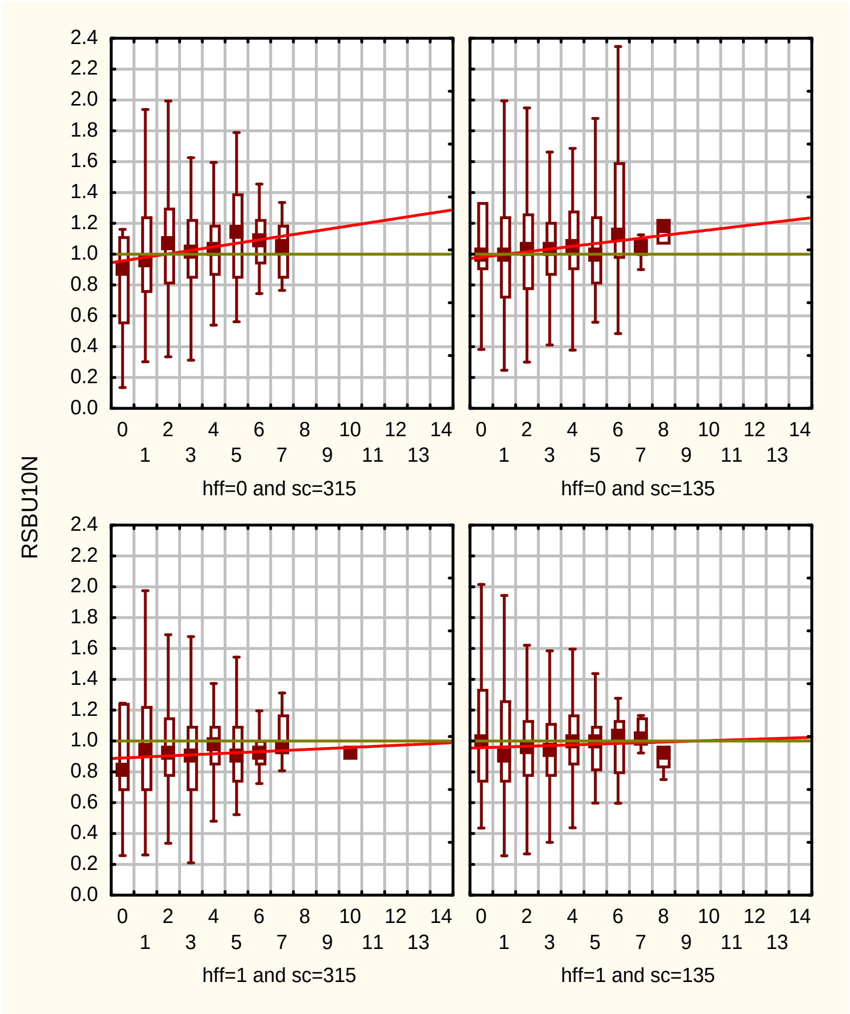
- This plot shows median RSB for west coast measured, for heading and following true winds, binned on SC<=180 and SC>180. Bin 1 contains mostly reports with SC = SE (tankers fully loaded), and SC = E or SE for other ship types; bin 2 contains mostly SC = NW (tankers on ballast), and W and NW for other ship types). Overall, these bins probably represent a majority of cases with either following waves (SC = E or SE) and oncoming waves (SC = W or NW), due to the prevailing winds and swell crossing the Pacific Ocean.
- For measured ship winds, for most VT/country groups, including tankers and the unknown vessel types, the differences between oncoming and following waves is slight.
- For bulk carriers the bias increases, for ship headings of W and NW, to about 1.10 (median RSB) compared to 1.00 otherwise.
- There are increases in the distribution of the bias, especially for values above the median, for some container/country groups.
- There are pronounced differences in the bias for general cargo ships: they show a difference both for heading/following true winds, and for oncoming/following waves. The difference in median RSB for ship headings of E and SE, compared to W and NW, is 15-20% (westerly headings higher). The lowest reports from general cargo ships are for ship headings of E or SE and following true winds: median RSB about .95; the highest for heading true winds and ship headings of W or NW: median RSB about 1.30.



West coast measured, median RSB, for VT/country groups, by heading/following true wind category, binned on SC<=180 and SC>180.

West coast measured tanker winds – variation of bias with Hs and tanker on ballast or fully loaded

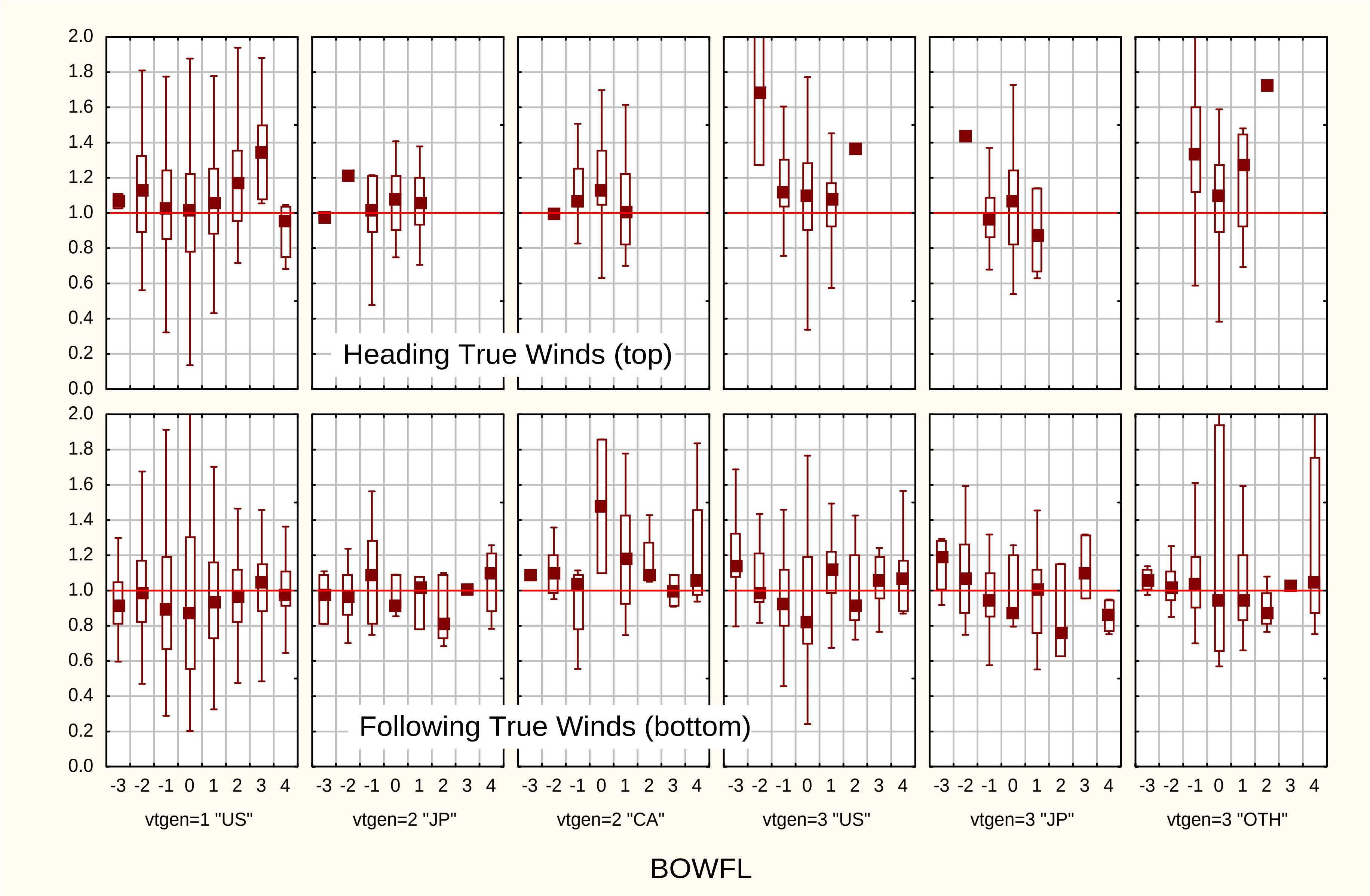
- The graph shows RSB categorized by heading/following true winds, as well by ship course, indicating on ballast (NW) or fully loaded (SE), binned on significant wave height reported by the buoy (Hs).The median values of RSB binned on Hs increasing very gradually with increasing wave height. The increase is most pronounced for heading true winds, ship course NW (on ballast). (ship 10-20% > buoy, for Hs >= 5 m)
- The slight difference in bias between heading and following true winds is evident for all wave heights.
- Overall, the agreement between buoy and ship winds remains fairly good even as wave heights increase, except for heading true winds and waves, for significant wave heights of 5 m or more. There are very few points for Hs>5 m, so results more sensitive to individual cases.
- There are slight differences for ships on ballast rather than fully loaded. With following true winds, the bias for ships on ballast tends to be slightly negative.



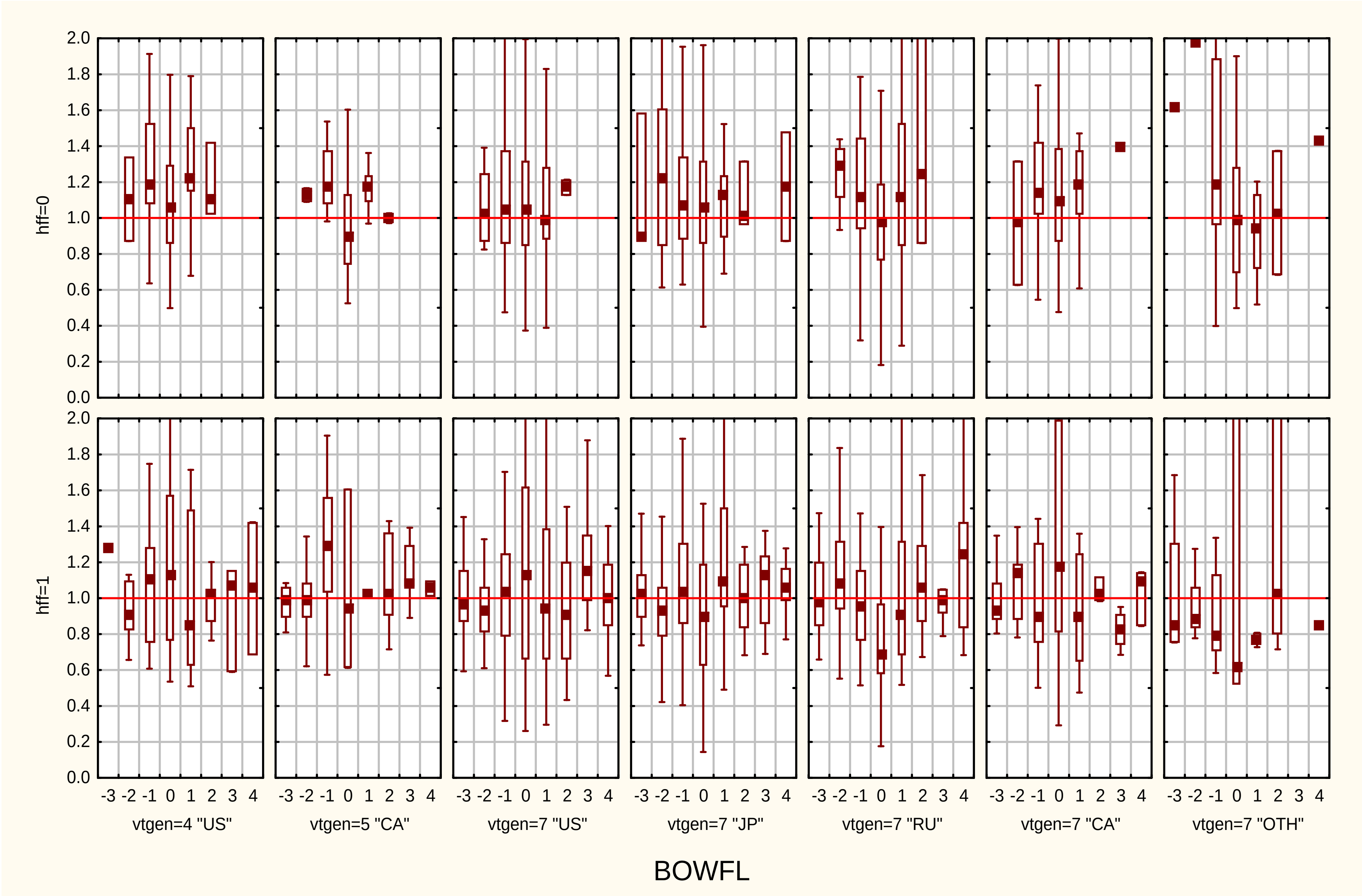
RSB for west coast measured tanker winds, binned on HS (m), grouped by heading or following true wind, and ship course NW or SE
(on ballast or fully loaded)

Variation in bias with platform relative wind direction

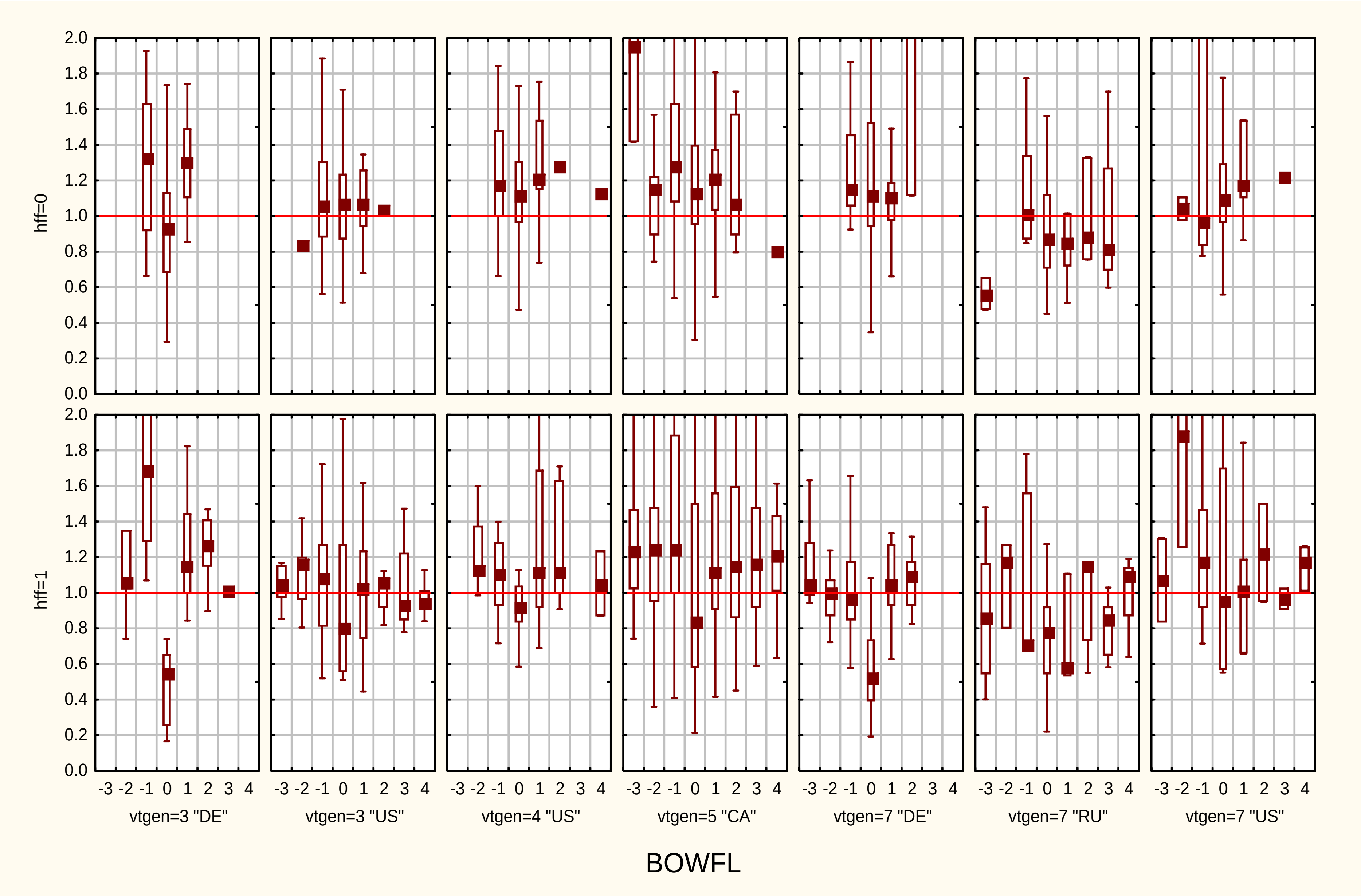
- The following graphs show the variation in DSB or RSB for measured ship winds grouped by recruiting country and vessel type, categorized by heading/following true winds, and binned on the platform relative wind direction: 0: bow-on, +-1: +-45°, +-2: +-90° (beam), +-3: +-135°, 4: 180° (stern).
- Flow distortion modelling and observing work conducted by the Southampton Oceanography Centre (Moat et al) shows that the winds speed up as they move over the bow and bridge of the ship. If the anemometer is in the plume of speeded up airflow, it can measure stronger than the ambient air stream, or if it is below the plume, it can measure decelerated flow. The ideal location is as far to the front of the bridge as possible, and as high as possible. The step height (from deck to bridge, or water level to bridge) is a scaling parameter used to estimate of the amount of acceleration (in terms of percentage of the ambient air).
- Containers and general cargo ships show a high bias (median RSB about 1.20 (DSB~ 2 m/s)) for relative wind directions onto the forward quarters (45° either side of bow), and a decrease in bias, for bow-on winds. The decrease is more pronounced with following true winds. It corresponds to a decrease in the background BU10N winds, for following true winds, but not for heading winds.
- A fully loaded container ship has a much smaller step height from the “deck” (top of the containers) to the bridge, with bow-on flows, than for winds from other directions, which would be from the water level to the bridge. There seems to be more of a “speedup” for relative winds from the sides of the ship.
- General cargo ships have fairly tall cranes along the deck, in line from the bow to the bridge, which might complicate the flow distortion patterns.
- Tankers show a slight variation in bias with platform relative wind direction, much less pronounced than for container or general cargo ships. With nothing on the deck, the deck to bridge top height would be only somewhat higher than the water level to bridge top (relevant for other relative wind directions). The ship-to-buoy bias is only a few percent, suggesting that the anemometers on the tankers are well located.



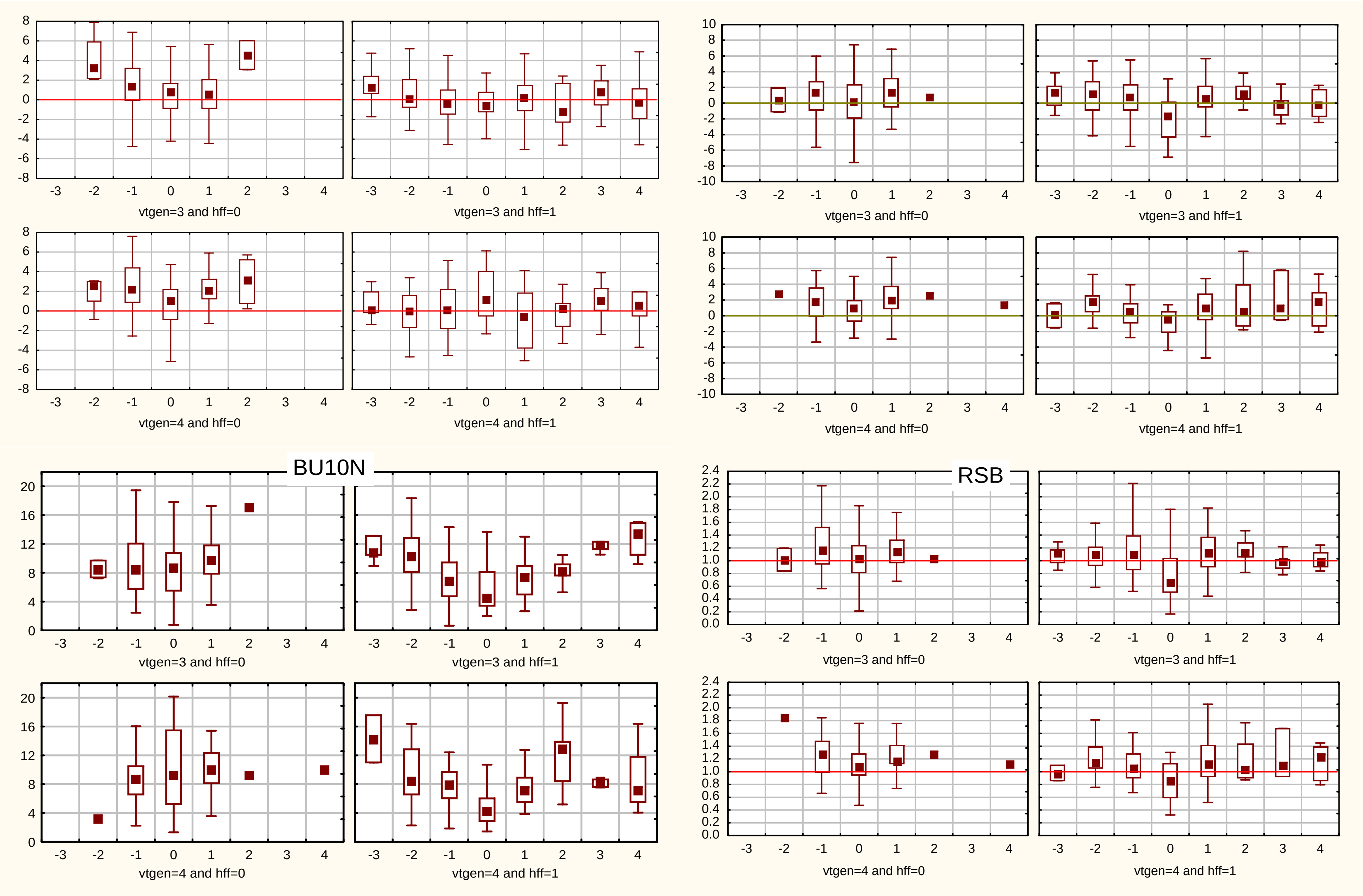
West coast measured RSB binned on relative wind direction, categorized by heading/following true winds, for tankers, bulk carriers, and container ships, recruited by various countries.



West coast measured RSB binned on relative wind direction, categorized by heading/following true winds, for general cargo, government, and unknown vessel types, recruited by various countries.



East coast measured RSB binned on relative wind direction, categorized by heading/following true winds, for container, general cargo, government, and unknown vessel types, recruited by various countries.



DSB (m/s) (top) for west and east coast, and RSB (bottom, right) and BU10N (bottom, left) for east coast, categorized by heading/following true wind, for measured container and general cargo ships, all countries, binned on relative wind direction

Estimated Ship Winds

- We assessed ship-to-buoy biases for various factors using both the unadjusted estimated ship wind speed, and the Lindau-adjusted estimated ship winds speed, compared to the height-adjusted buoy wind speed (RSB and RELB for ratios). The following tables and plots show differences between observations taken by night and by day, for heading and following true winds, and dependent on the ship heading relative to wave direction.
- We did not find consistent differences between different vessel types, but there did seem to be consistent differences between different recruiting countries which would relate to different practices in estimating and reporting the winds.
- All of the west coast US estimated ships, including many tankers (1612 reports), and smaller numbers of container, general cargo, and unknown type, have a median RSB of 1.10 to 1.15. Median RELB values are similar: 1.10 to 1.14. The Lindau adjustment did not changed the median ratio of ship-to-buoy winds. Estimated ship winds are 10 to 15% higher than buoy winds (median differences of about 1 m/s).
- Most estimated reports on the east coast are from German, British, or US recruited vessels, primarily container, general cargo, and unknown vessel type.
- Median values of RELB ranged from 1.02 (German, unknown vessel type and other countries, general cargo), to as high as 1.19 (US, unknown vessel type). US recruited ships seemed to have a slightly higher ship-to-buoy bias (median RELB range 1.10 to 1.19)
- British recruited ships of those same types (container, general cargo, and unknown) were a little lower (median RELB range 1.06 to 1.10). British recruited tankers and bulk carriers were a little higher, median RELB 1.11 to 1.15. These values are similar to the corresponding value for tankers on the west coast. German containers and unknown vessel types had slightly lower biases than British, consistent with the low values on the west coast.
- Overall, the median RELB and the median RSB was 1.09.
- Two groups had many more ships with anemometers than the rest. The proportion of reports from ships with anemometers, compared to ships without anemometers, was 60 % for US container ships (average ht 42 m), 80% for Other countries general cargo ships (average ht 38 m), and only 20% or less for other country and ship type groups.

Mean anemometer height, median ship speed (coded: 3(11-15 kt); 4(16-20 kt)) and statistics for DSB_U10N, RSB_U10N, and RELBU10N, for west coast estimated ships, grouped by VT and country.

VT	*CCF*	*AH*	*SS*	***N***	*Mean DSB*	*SD DSB*	***Med DSB***	*IQR DSB*	*Mean RSB*	*SD RSB*	***MED RSB***	*IQR RSB*	*Mean RELB*	*SD RELB*	***Med RELB***	*IQR RELB*
1	US	35	3	**1612**	.84	3.11	**.76**	3.95	1.27	1.32	**1.10**	.53	1.30	1.41	**1.11**	.51
1	OTH	-	3	**56**	-.24	2.66	**-.18**	3.67	1.01	.38	**.98**	.43	1.03	.38	**.98**	.37
3	US	35	4	**107**	.50	3.07	**.53**	3.56	1.25	.91	**1.09**	.44	1.24	.91	**1.10**	.36
4	US	33	4	**220**	1.06	3.07	**1.08**	4.12	1.20	.56	**1.15**	.47	1.21	.56	**1.14**	.43
7	US	32	4	**665**	.88	2.97	**.80**	3.71	1.30	1.37	**1.11**	.55	1.34	1.49	**1.13**	.53
7	OTH	34	3	**73**	1.47	2.21	**1.33**	3.28	1.36	.95	**1.20**	.48	1.40	1.02	**1.21**	.43
7	DE	27	4	**55**	-.33	2.69	**.04**	3.57	1.10	.61	**1.01**	.46	1.16	.67	**1.05**	.50
7	CA	31	3	**34**	3.07	3.59	**3.08**	4.36	2.42	4.78	**1.55**	.76	2.45	4.88	**1.50**	.85
All	All	34	3	**2884**	.88	3.07	**.80**	3.97	1.28	1.34	**1.11**	.53	1.31	1.41	**1.12**	.50

Mean anemometer height, median ship speed (coded: 3(11-15 kt); 4(16-20 kt)) and statistics for DSB_U10N, RSB_U10N, and RELBU10N, for east coast estimated ships, grouped by VT and country.

VT	*CCF*	*AH (m)*	*SS*	*N DSB*	*Mean DSB*	*DSB SD*	*DSB Med*	*DSB IQR*	*RSB Mean*	*RSB SD*	*RSB Med*	*RSB IQR*	*DELB Mean*	*DELB SD*	*DELB MED*	*DELB IQR*
1	**GB**	-	3	41	.95	3.57	.92	3.93	1.18	.48	1.13	.67	1.22	.47	1.15	.67
2	**GB**	-	3	95	.77	2.67	.61	3.13	1.22	.68	1.11	.40	1.26	.73	1.11	.51
3	**DE**	34	4	161	.58	3.11	.56	3.57	1.14	.64	1.05	.39	1.15	.62	1.06	.38
3	**GB**	-	4	86	.92	2.87	.46	3.60	1.19	.50	1.08	.53	1.22	.52	1.10	.50
3	**US**	42	4	229	.60	2.96	.70	3.99	1.17	.46	1.12	.46	1.20	.48	1.10	.48
4	**CA**	-	3	30	1.47	3.25	.87	4.03	1.30	.68	1.12	.60	1.32	.67	1.14	.59
4	**DE**	-	3	99	.94	3.02	.79	3.77	1.17	.44	1.11	.51	1.19	.45	1.13	.50
4	**GB**	-	4	51	.22	3.38	.23	4.01	1.21	.83	1.03	.57	1.25	.85	1.06	.58
4	**US**	24	4	119	.90	2.80	1.07	3.80	1.24	.55	1.10	.61	1.27	.58	1.12	.61
4	**OTH**	38	3	56	-.08	3.00	-.04	3.66	1.05	.32	1.03	.33	1.02	.35	1.02	.32
6	**GB**	-	6	85	.20	2.52	.28	3.08	1.09	.44	1.03	.40	1.13	.46	1.04	.39
7	**DE**	34	4	225	.38	3.31	.17	3.91	1.16	.62	1.03	.55	1.19	.64	1.02	.50
7	**GB**	-	3	88	.35	3.27	.11	4.34	1.09	.47	1.01	.50	1.12	.46	1.06	.48
7	**US**	32	3	76	1.28	2.80	1.25	4.09	1.37	.79	1.20	.58	1.42	.82	1.19	.64
7	**OTH**	38	3	152	.64	3.25	.79	4.10	1.17	.63	1.09	.55	1.19	.62	1.09	.49
All	**All**	38	4	1679	.67	3.06	.56	3.81	1.18	.58	1.09	.50	1.21	.59	1.09	.49

Effect of Heading/Following True Winds on Estimated Winds

- Estimated ship winds could be affected by whether true winds are heading/following to the extent that the relative wind speed is used in estimating the wind speed (generally at night or in low visibility), and the the true wind is not calculated properly from the relative wind
- True winds can also indicate the direction of waves (excepting cases of swell); heading or following seas could affect the ships motion differently, as wave heights increase; this could influence the observers impression of the wave heights, and hence the estimated wind speed
- The next 2 tables show there was a consistent difference on both coasts in the bias, between heading and following categories; often as much as 10%. This is at least as much a difference as for the measured ship winds. Median RELB for following true winds were about 1.0 to 1.05, and about 1.10 to 1.15 for heading true winds. As for measured ship winds, we assessed changes in the ship-to-buoy bias with increasing ship speed, for heading/following true winds, and we did not find any clear trends.

Night/Day Differences in Estimated Ship Winds

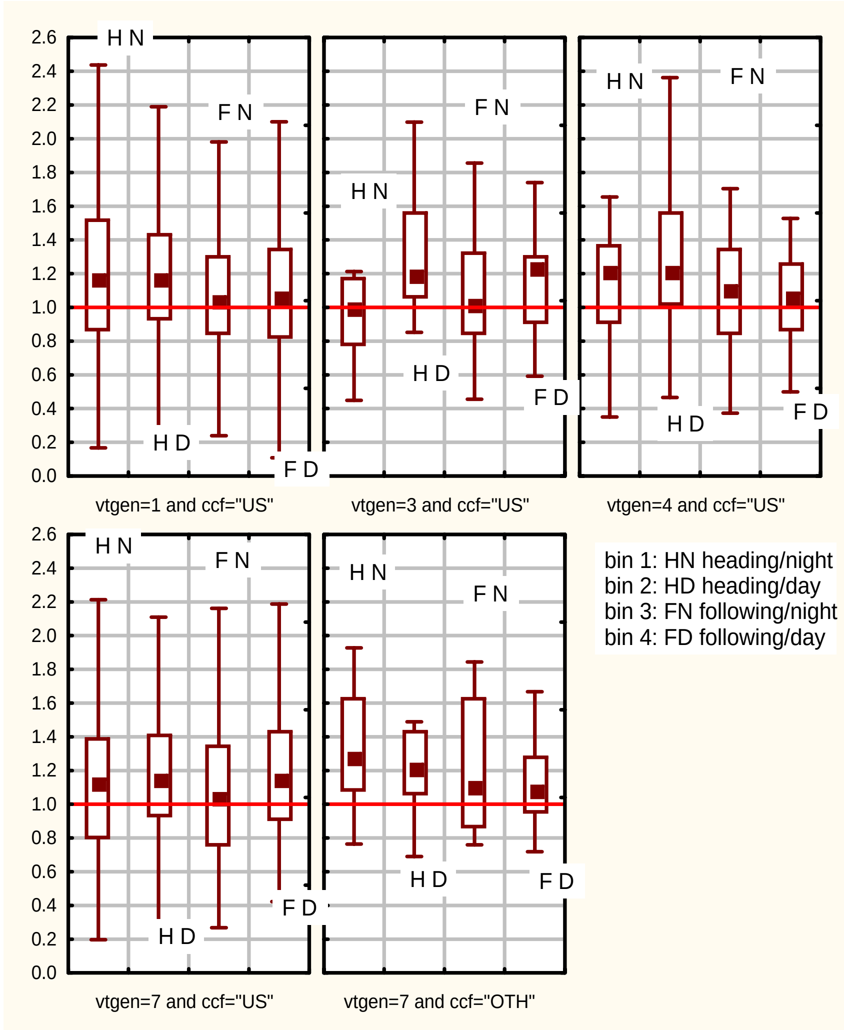
- There were consistent differences in the ship-to-buoy bias for estimated wind speeds, between night and day, that were as large as the differences between heading and following true wind categories.
- The following plots, for the major vessel type/country groups for estimated wind speeds on the west coast and east coast, show the bias (RSB) binned on combined categories of: heading, night; heading, day; following, night; and following day.
- Tankers show little night/day variation, but significant heading/following variation. West coast US recruited containers show significant night/day variation, but little heading/following variation.
- The bias for night reports was lower than or equal to the day reports, for most groups, but some groups did show a higher bias in ship-to-buoy winds at night.

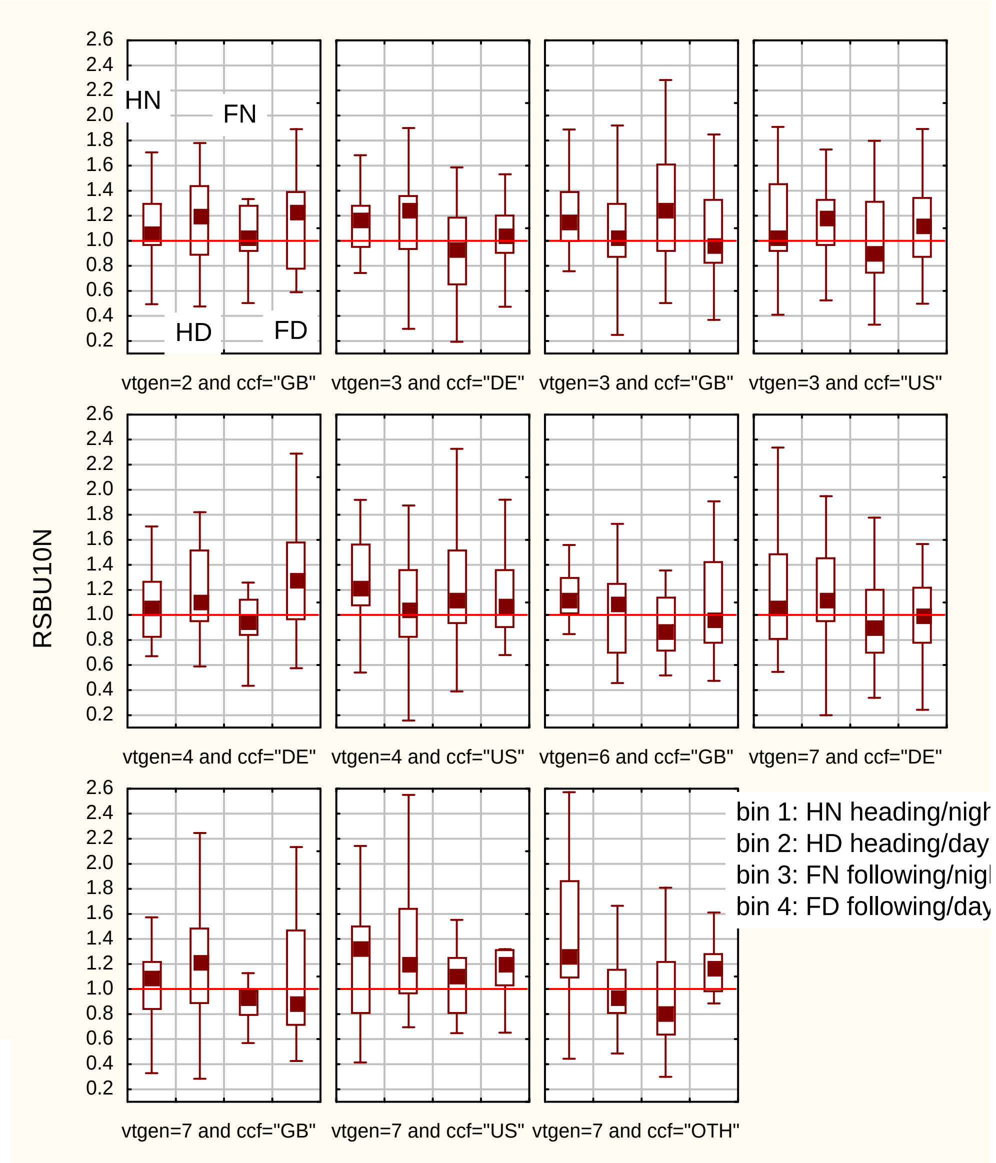
Difference statistics (for DSB_U10N and RSB_U10N) for west coast estimated ships, grouped by VT and country, and by true wind heading, following, or not determined, for groups with 30 or more cases in each heading/following category.

VT	*CCF*	*HFF*	*DSB N*	*DSB M*	*DSB SD*	*DSB MED*	*DSB IQR*	*RSB M*	*RSB SD*	*RSB MED*	*RSB IQR*	*RELB M*	*RELB SD*	*RELB MED*	*RELB IQR*
1	US	0	797	1.32	3.14	1.24	4.06	1.36	1.68	1.17	.56	1.38	1.79	1.16	.51
1	US	1	809	.36	3.02	.36	3.82	1.18	.83	1.05	.49	1.22	.89	1.07	.47
3	US	0	35	.58	2.64	.55	3.27	1.17	.48	1.10	.31	1.21	.47	1.13	.28
3	US	1	72	.45	3.27	.42	3.62	1.29	1.06	1.08	.46	1.25	1.06	1.01	.39
4	US	0	108	1.34	3.21	1.24	3.74	1.27	.64	1.21	.53	1.30	.64	1.23	.48
4	US	1	111	.77	2.93	.70	4.17	1.12	.46	1.09	.46	1.12	.45	1.10	.41
7	US	0	353	1.04	2.92	.97	3.79	1.23	.71	1.14	.52	1.26	.75	1.14	.52
7	US	1	309	.71	3.03	.73	3.68	1.37	1.85	1.09	.56	1.42	2.03	1.09	.57
7	OTH	0	35	1.80	2.11	1.59	2.86	1.28	.33	1.24	.42	1.31	.33	1.25	.38
7	OTH	1	31	1.14	2.19	.48	3.45	1.48	1.40	1.07	.46	1.54	1.51	1.14	.43

Same as above, for east coast estimated.

VT	CCF	HFF	DSB N	DSB M	DSB SD	DSB MED	DSB IQR	RSB M	RSB SD	RSB MED	RSB IQR	RELB M	RELB SD	RELB MED	RELB IQR
2	GB	0	50	1.01	2.86	.65	2.58	1.29	.86	1.09	.37	1.33	.92	1.13	.50
2	GB	1	44	.55	2.46	.86	3.26	1.14	.40	1.12	.44	1.18	.42	1.09	.48
3	DE	0	84	1.42	2.94	1.09	3.62	1.22	.73	1.18	.36	1.22	.69	1.14	.37
3	DE	1	77	-.34	3.05	-.11	3.42	1.05	.51	1.00	.38	1.07	.53	.99	.34
3	GB	0	43	1.22	2.75	1.18	3.28	1.18	.48	1.11	.48	1.21	.51	1.11	.43
3	GB	1	43	.61	3.00	.18	4.82	1.19	.52	1.03	.67	1.23	.54	1.09	.73
3	US	0	113	.82	2.97	.75	3.45	1.20	.44	1.15	.39	1.23	.47	1.14	.39
3	US	1	114	.31	2.92	.51	4.09	1.14	.47	1.10	.51	1.17	.50	1.07	.57
4	DE	0	57	.99	2.50	.79	3.56	1.19	.39	1.10	.59	1.22	.41	1.13	.57
4	DE	1	41	.77	3.61	.67	3.91	1.16	.51	1.11	.46	1.16	.51	1.11	.45
4	US	0	57	.94	2.94	1.13	4.09	1.27	.67	1.12	.68	1.30	.69	1.10	.70
4	US	1	61	.89	2.69	.90	3.41	1.22	.42	1.10	.56	1.24	.44	1.13	.57
6	GB	0	36	.77	2.24	.75	2.45	1.12	.39	1.10	.37	1.16	.38	1.12	.35
6	GB	1	48	-.26	2.67	-.50	3.89	1.07	.48	.91	.47	1.11	.51	.98	.40
7	DE	0	106	1.30	3.35	.79	4.77	1.26	.64	1.11	.57	1.27	.65	1.11	.54
7	DE	1	117	-.43	3.06	-.27	3.28	1.07	.60	.97	.48	1.11	.63	.98	.44
7	GB	0	49	.65	3.33	.74	4.05	1.14	.51	1.10	.43	1.17	.51	1.16	.43
7	GB	1	39	-.03	3.20	-.36	4.43	1.01	.40	.92	.35	1.06	.40	1.01	.35
7	US	0	42	1.45	2.92	1.87	4.22	1.41	.82	1.24	.62	1.45	.87	1.26	.69
7	US	1	32	1.15	2.64	.91	1.89	1.34	.78	1.11	.36	1.39	.79	1.16	.38
7	OTH	0	47	1.15	3.94	1.34	4.88	1.29	.87	1.11	.49	1.29	.86	1.09	.43
7	OTH	1	46	.11	3.23	.13	3.16	1.04	.40	1.02	.50	1.07	.38	1.06	.43

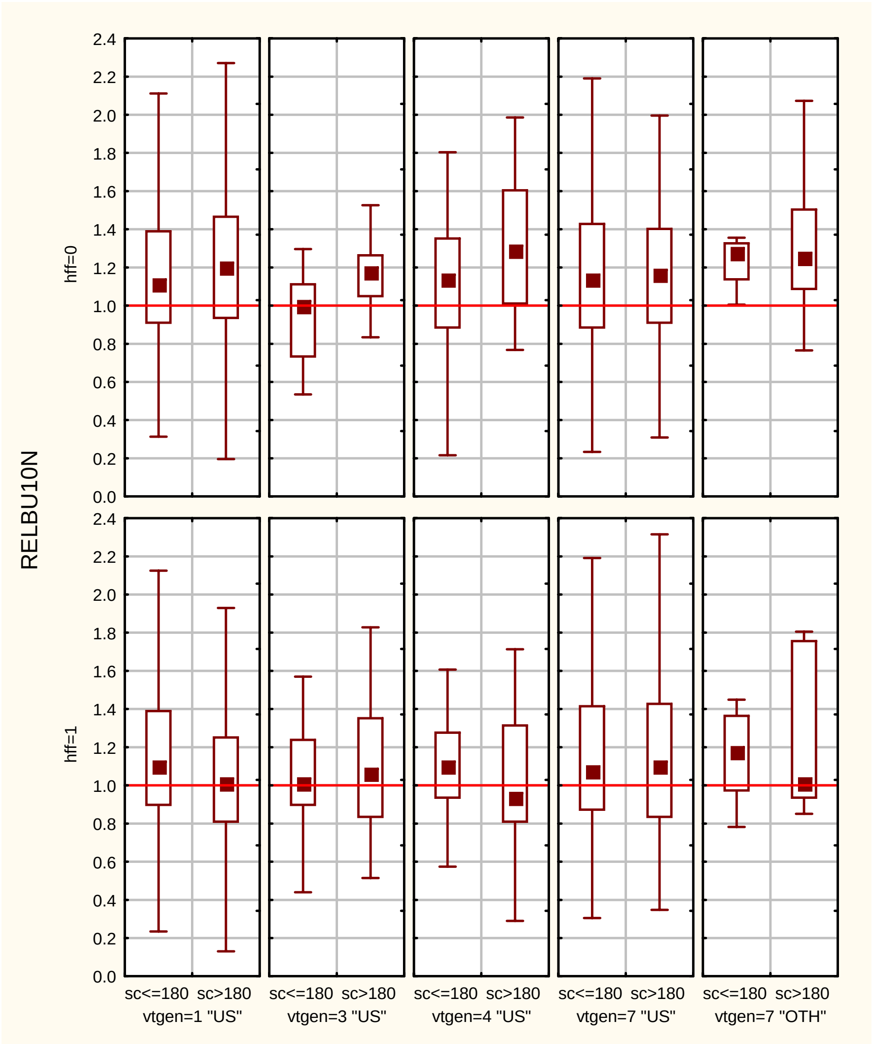




Median RSB for vessel type/country groups, for estimated winds, west coast (left) and east coast (right), binned on combinations of heading (H) or following (F) true winds, and night (N) or day (D).

Effect of wave direction, relative to ship course, on estimated wind speeds.

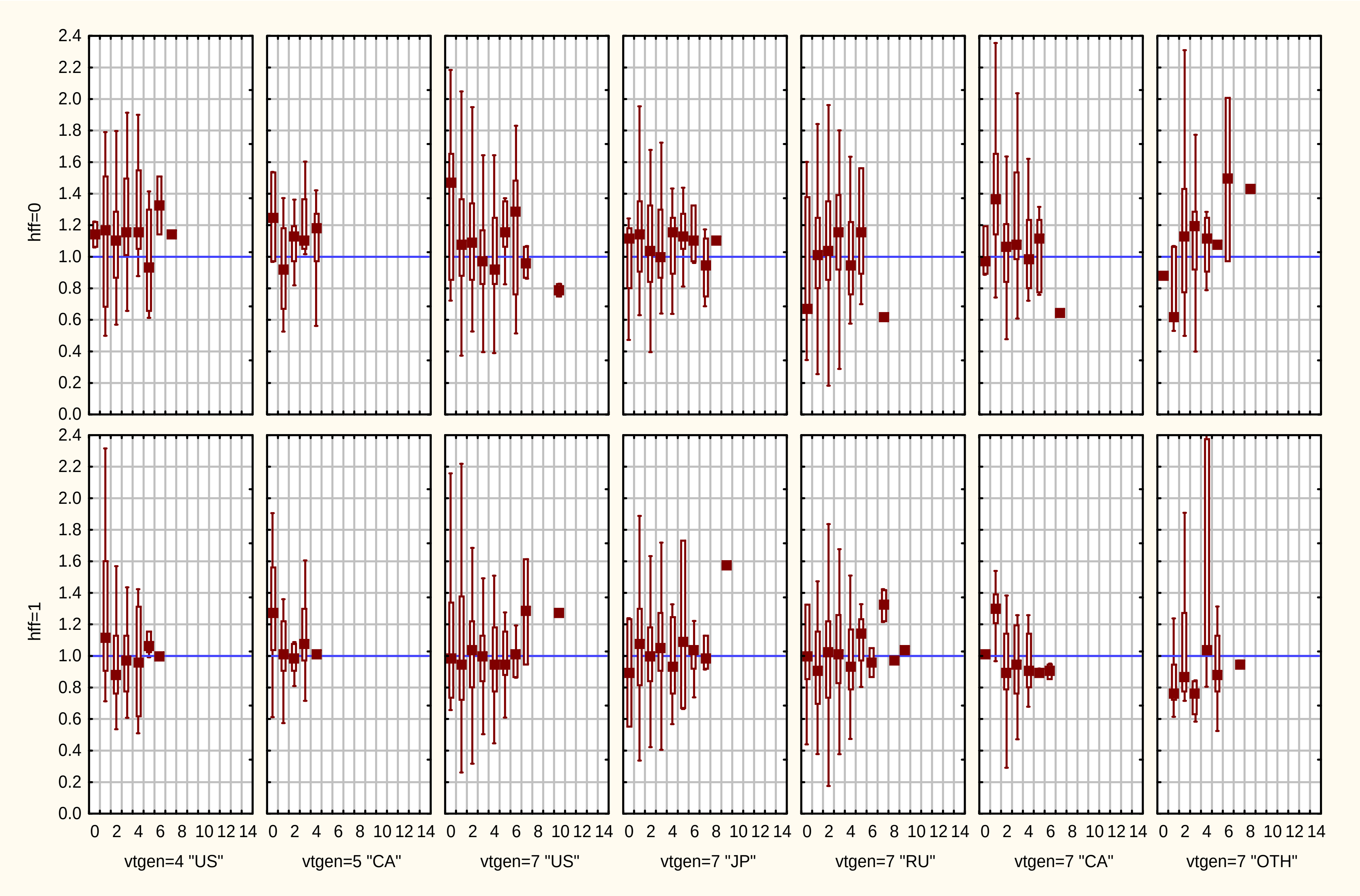
- This plot shows median RSB for the west coast estimated, binned on SC<=180 and SC>180. Bin 1 corresponds to SC of E and SE (SE for tankers) and bin 2 to W and NW (NW only for tankers). We assume bin 1 corresponds, overall, to following swell or wind waves, and bin 2, to oncoming swell or wind waves. Heading or following seas could affect the ships motion differently; this could influence the observers estimate of wave heights and hence the estimate of winds.
- For tankers on ballast, the difference between heading and following winds is increased with oncoming waves (SC NW): median RELB 1.20 compared to 1.00. With following swell, ship fully loaded, median RELB is about 1.10.
- These 2 categories make a significant difference in the container and general cargo ship bias, particularly with heading true winds. The bias increases for ships in heading true winds and heading seas, to median RSB (or RELB) of 1.30 for general cargo ships.



West coast estimated, median RELB for VT/country groups, binned on SC<=180 and >180

Effect of Wave Height on Ship-to-buoy bias

- There is considerable interest in wind observations by ships and buoys at high wave heights, and some concern that buoy measurements might be biased low in extreme sea states. Since there are relatively few points at very high wave heights, compared to other conditions, the values do not impact on most climatological statistics prepared with marine surface winds. However, the large dataset contains enough information that we can examine the ship-to-buoy bias as a function of buoy measured wave height.
- The following plot for a subset of the west coast measured vessel type/country groups show there is no clear trend with increasing wave height. Plots for the other groups, including the east coast, show a similar lack of consistency.
- There is considerable variability especially for higher wave heights, because the number of points in each wave height bin drops off rapidly. Before we can draw useful conclusions from this dataset concerning the reports by ships and buoys in high wave heights, we need to sort out some of the other factors shown to affect the ship-to-buoy bias, that apply only to ship winds, such as heading/following true winds, ship heading relative to prevailing wind/wave directions, etc.



West coast measured RSB, categorized by heading/following flag, grouped by vessel type/country (for general cargo, government, and unknown vessel types), binned on buoy significant wave height.

Summary

Measured ship winds:

- There is a consistent difference in the ship-to-buoy bias for heading and following true winds. The difference is about 5% for tankers, and 10% for containers and general cargo ships. There is no difference in bias for the night and day categories, for most ship type/country groups. Generally for merchant ships on both coasts, the data does not show a trend in the ship-to-buoy bias with increasing ship speed. This suggests that most observers on the frequently reporting merchant vessels do the calculation correctly.
- There was a variation in the bias with the ship relative wind direction, for container and general cargo ships, with bow-on flows showing less speed up than relative winds coming from the forward quarters or beam sides, with differences of about 20% (biases about 1.20 for relative winds on the forward quarters of the ship (45°) and about 1.00 for relative winds on the bow. Tankers showed only a slight variation in bias with the platform relative wind direction.
- For some vessel types, there was a significant difference in ship-to-buoy bias, for ships heading W or NW (overall, oncoming waves), compared to E or SE (following waves), with higher biases particularly for general cargo ships, and somewhat higher biases for bulk carriers and container ships. Tankers were less effected, but showed a slight difference in bias when heading NW, on ballast, between heading/following true winds.
- These factors reveal inhomogeneities in the measured ship winds datasets, that can be accounted for by developing different regression relationships between the ship and buoy winds for each subset of vessel type, heading/following true winds, and for come vessel types, ship heading relative to prevailing winds.

Estimated ship winds:

- As with measured ship winds, there is a consistent difference in ship-to-buoy bias, for heading and following true wind category. There does not appear to be a trend in the bias with ship speed, for each of those categories, so if the observer is using a relative ship wind and ships speed and direction to estimate the true wind, when visibility is poor, it seems to be done reasonably well.
- For some but not all VT/country groups, there is a significant difference in the ship-to-buoy bias for night and for day, with the bias up to 20% higher by day. Depending on the ship type/country group, the heading/following category, or the night/day category makes the most difference in the bias. Overall, estimated winds taken at night with following true winds will show the lowest bias, and those by day with heading true winds will show the highest.
- The ship course relative to prevailing winds and waves also affects the estimated ship-to-buoy bias, by increasing the bias, in oncoming waves (both for tankers on ballast, and for container and general cargo ships, presumably fully loaded)
- Regression relationships developed separately for each of these ship type/country groups, and heading/following true wind/wave and night/day categories, can be used to adjust estimated ship reports to reduce the variability and bias within each subset.

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