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Factors affecting ship and buoy data quality

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Bruce Ingleby

email: nwp_publications@metoffice.gov.uk

Factors affecting ship and buoy data quality

Abstract

Ship and buoy reports of wind, air pressure, temperature, humidity and sea temperature for 2007 and 2008 have been compared with values from the operational Met Office global Numerical Weather Prediction (NWP) system and accumulated statistics are presented. Ship reports have been categorised by vessel type, recruiting country, anemometer height, manual or automatic and measured or estimated winds. Some aspects of the diurnal cycle and proximity to coasts were also investigated. As expected the results for wind speed show a dependence on anemometer height (inferred from vessel type in many cases). Estimated ship winds from one country are weaker than those from other countries – most are better treated as anemometer measured winds. After height adjustment average ship wind speeds are reasonably consistent with buoy wind speeds but there are some subsets that are weaker or stronger. The global model winds appear to be 6-12% too weak. Ship air temperatures are too warm during the afternoon due to solar heating of the body of the ship. Adjustment of pressure to sea level is a problem for some ships, especially larger ones. Reports from large passenger ships are relatively poor quality for several variables and their winds are rather strong. Automated ship reports and those from research and coastguard vessels tend to be of good quality (but in some cases the winds appear slightly weak). In most respects buoy data has the best quality. As a result of this investigation a number of improvements to the Met Office observation processing system are being made, notably tightening of the quality checks and better height adjustment of winds.

1. Introduction

Ship and, to a lesser extent, buoy data have been extensively studied as part of the climate record and for the calculation of air-sea fluxes. Within NWP systems they have to some extent been taken for granted and either used with minimal adjustment or not used at all. Marine surface air temperature and humidity reports have only recently been assimilated in the Met Office system – one argument against their use is that within the NWP model near-surface temperature fields are fairly tightly constrained by sea surface temperature (SST) over the ocean. This investigation started out from the finding that ship winds were rather stronger than other measured surface winds, and that making allowance for ship anemometer height would reduce the bias. This is true, but only part of a more complex story. Overall, there are now more buoy than ship reports, but in this report (as elsewhere) more space is devoted to ship reports because of their greater complexity.

Section 2 describes the data sources used and section 3 the processing applied. Section 4 presents the results by variable: wind, pressure, air temperature, humidity and sea temperature – with wind speed being examined in particular detail. Section 5 discusses application to data assimilation and the consistency between different wind sources. Section 6 provides a summary and concluding remarks.

2. Data sources

The reports considered here have all been received via the World Meteorological Organisation (WMO) Global Telecommunications System (GTS) in real time. They are transmitted either in SHIP or BUOY code formats. Table 1 summarises the main categories. Note that SHIP format is used for some buoys and other fixed installations, but there is no indicator to distinguish them. Ship call signs have at least one letter whereas buoy identifiers are entirely numeric (five digits long, the third digit is 0-4 for moored buoys, 5-9 for drifters). There are five light vessels in the English Channel, classed as moored buoys in this study as they have numeric identifiers. There are some reports from oil industry platforms, mainly in the North Sea - the reported winds have already been converted to 10m estimates (they are distinguished using a list of known identifiers – Annex A). A distinction could be made between offshore platforms which are fixed and rigs which can be moved to other drilling locations, but here they will all be called "rigs". A few fixed marine stations report in SYNOP code (as used by land stations), they are not considered here.

WMO Format	Type	Anht (m)	Notes
BUOY	Drifter	1-2 or acoustic (few winds)	Global[1] Arctic[2]
BUOY	Buoy_bc	~4	Tropical buoys[3]
SHIP	Buoy_sc	3-10 (15 – light vessel)	N. American[4] European[5]
SHIP	Ship_manual Ship_auto	8-60[6]	Manual Automated
SHIP	Rig	30-120	Report 10m winds

Table 1. Main categories of marine reports, anht denotes anemometer height.

1. http://www.aoml.noaa.gov/phod/dac/gdp_drifter.html Global Drifter Program
2. http://iabp.apl.washington.edu/ International Arctic Buoy Programme (Arctic drifters reported in BUOY format in 2007, SHIP format in 2008)
3. http://www.pmel.noaa.gov/tao/global/global.html Global Tropical Moored Buoy Array
4. http://www.ndbc.noaa.gov/ National Data Buoy Center
5. http://esurfmar.meteo.fr/ E-SURFMAR (European moored buoys/drifters)
6. http://www.wmo.int/pages/prog/www/ois/pub47/pub47-home.htm For large ships anht can vary by ±7m or more depending on loading/ballast

Some SHIP reports are "manual" whereas others are automated (distinguished using the "i_x" indicator in the SHIP format). Some manual reports use electronic logbook software. In this case the observer reads the instruments and types in the readings, the software performs some calculations and quality checks then prepares and sends the SHIP report. The most widespread logbook software is TurboWin, developed in the Netherlands and used by over 700 European, Canadian and Australian ships in 2007. Other logbooks are SEAS (US) and OBSJMA (Japan). Batos, developed in France, is essentially a fully automated system with an option for an observer to add manual elements such as cloud data. (Some other systems are basically buoy packages mounted on ships.) In order to compute true winds, most of the Batos systems are linked to the navigation instruments of the ships on which they are installed. All Batos systems have their own sensors, including anemometers (P Blouch, pers. comm. 2008). In contrast most ship anemometers were fitted by the ship owners and some may be less well calibrated. In 2007 there were 69 Batos systems reporting -

mostly French. Together with 28 Canadian ships using the AVOS system and Vaisala MILOS systems on 15 German ships these provide most of the automated ship reports. Although automated ships make up only about 6% of the total ships they provide about 28% of ship reports, primarily because they report hourly whereas manual reports tend to be six-hourly. There are relatively few automated reports from the tropics and from mid-ocean.

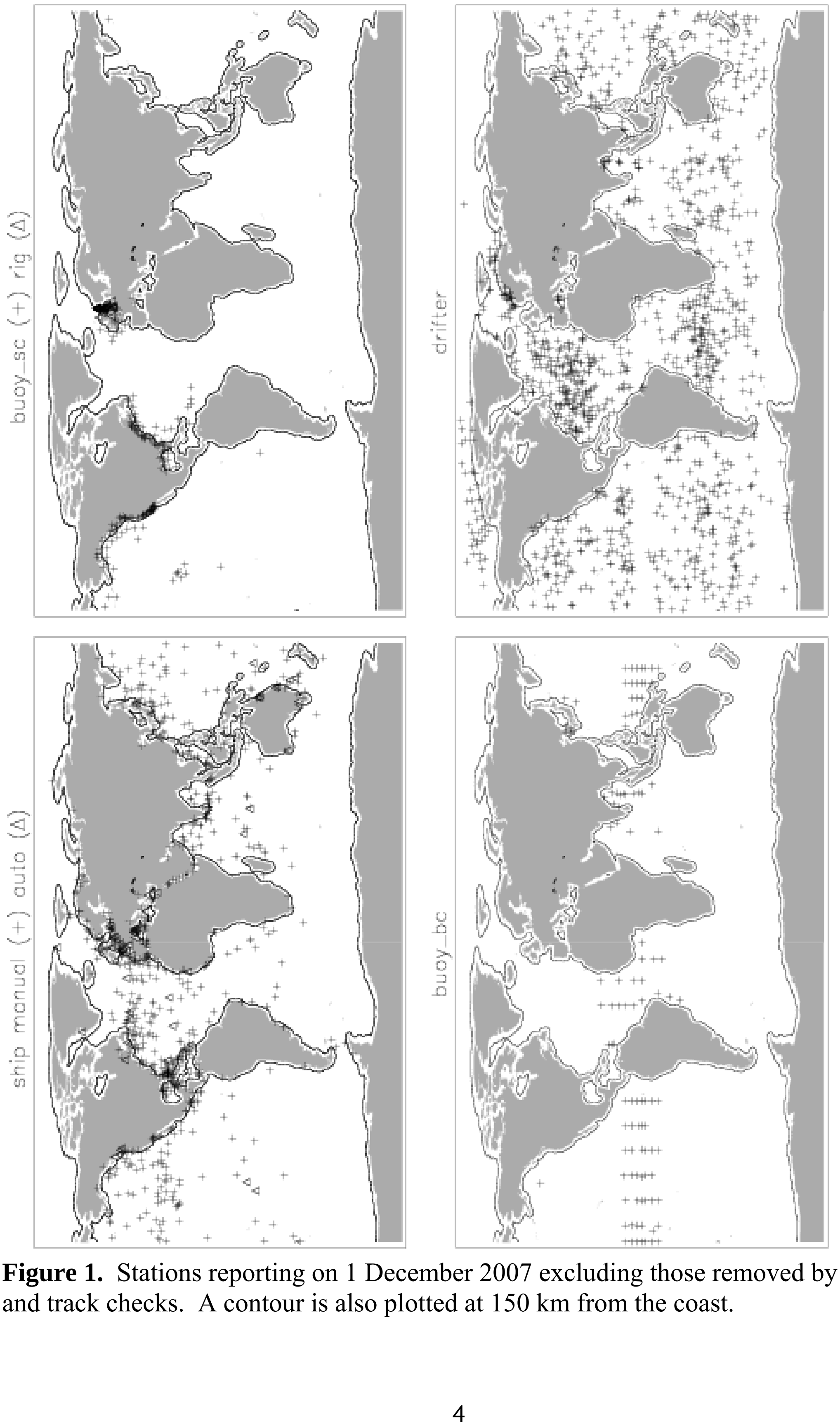

Figure 1. Stations reporting on 1 December 2007 excluding those removed by land and track checks. A contour is also plotted at 150 km from the coast.

As seen in Figure 1 the majority of ship reports are from the Northern hemisphere - there are even fewer in the Southern extratropics in winter. The moored buoys reporting in ship code (buoy_sc) are mainly coastal or continental shelf. The moored buoys reporting in buoy code (buoy_bc) are mainly from the deep water tropical arrays (TAO, TRITON, PIRATA and RAMA). Drifter reports are more evenly spread, but they are densest in the Atlantic and absent from some semi-enclosed seas and areas of upwelling such as the equatorial Pacific.

Whilst most stations are easy to categorise a few give problems. For example about 15 stations originally classed as ships were stationary for months on end and they were reclassified as either rigs or buoys. There are also a few "drifters" reporting humidity – probably moored buoys. There are some stations on the boundaries of categories: light vessels (ships or buoys?), floating production and storage vessels (FPSOs – often converted oil tankers – ships or rigs?). The de facto definition of rig used here is that the station is (almost) stationary and reports wind adjusted to 10 m.

2.2 Ship and buoy metadata

The main repository of ship metadata is WMO Publication No. 47 (WMO Pub 47). This is issued quarterly, but 6-12 months in arrears (E-SURFMAR maintains a database of European ships in the same format but updated monthly). Kent et al (2007) analysed the contents of WMO Pub 47 in some detail. For the 2007 and 2008 data used in the current study the version dated 31 December 2007 was used and five variables in particular were examined: recruiting country, vessel type, anemometer height (anht), temperature/humidity exposure and SST sensor type. The recruiting country determines the reporting practices and, to some extent, the instruments used (the ship can be registered in a different country but only recruiting country is used in this study). Vessel type and anht are discussed in section 4, here we note that anht, and other ship dimensions, are missing for many vessels in WMO Pub 47 (notably US ones). The US has the largest number of ships reporting, but most months comes second to Germany in the numbers of reports received. Some countries have sizable fleets according to WMO Pub 47 but very few reports on the GTS. This occurs partly because ship entries persist indefinitely if not updated by the recruiting country. Approximately 25% of ships reporting on the GTS are not listed in WMO Pub 47.

The link between the SHIP report and WMO Pub 47 is the "call sign" which is a unique identifier for each ship. Unfortunately, to avoid possible piracy or for reasons of commercial confidentiality, some ship owners/crews prefer not to have their ship position/track identifiable. Thus there has been a recent trend to either a) stop reporting on the GTS, b) report as "SHIP" or c) report using a "masked" call sign. Some European systems have generic call signs of the form tttccnn where ttt represents the software used aboard, cc is the country code and nn is an increment from 00 to ZZ – effectively a masked call sign. The abbreviations used are TBW for TurboWin and BAT for Batos; also MIN for Minos (air temperature and pressure only) and BAR for Baros (pressure only) – these latter two are automated systems used by small numbers of ships. For reports with call sign "SHIP" no track check is possible and no metadata are available. In case c) the link between the masked and real callsign has to be known in order to use the metadata from WMO Pub 47. These links were obtained for the British and French fleets and a handful of other ships.

If ship metadata are patchy there is at least a central repository. For buoys the main sources are web sites from deploying agencies (see notes to table 1) which were used to find anemometer heights. Most buoys fit into a relatively small number of platform/instrument types. Moored buoys tend to report the full set of variables examined in this study, except that about half don't report humidity. Drifters (or drifting buoys) were originally developed for the study of surface currents and early versions only reported their positions. Many drifters now report SST and almost half report pressure but only a few (discussed in the relevant sections below) report wind or air temperature.

2.3 Model data

Most of the comparisons presented here involve the Met Office global model with a four-dimensional variational data assimilation scheme (4D-Var, Rawlins et al, 2007). Some comparisons involve the Met Office "North Atlantic/Europe" (NAE) model (Bush et al, 2006). For the period considered these have mid-latitude grid spacing of about 40 km and 12 km respectively and 50 levels (Global) or 38 levels (NAE) in the vertical. The lowest wind level is at 10 m, with the lowest temperature/humidity level at 20 m. "Screen level" (1.5 m) temperature and humidity values are calculated using similarity theory and these are used for comparison with both land and marine surface stations.

The OSTIA daily, high resolution SST analysis (Stark et al, 2007) became operational at the Met Office in October 2007, earlier pre-operational fields were also used. It includes ship and buoy SST but much of the high resolution detail comes from bias-corrected satellite data. In the atmospheric assimilation prior to 1 April 2008 ship, rig and moored buoy pressure and wind were used operationally, after that date ship, rig and moored buoy air temperature and humidity were also assimilated (along with increased use of land surface station data). For drifters pressure is assimilated, but not other atmospheric variables. In general there is sufficient other data (including ocean surface winds from satellite) and sufficient meteorological development from one analysis time to the next for the 3-9 hour forecast fields (known as "background" fields in data assimilation) to be independent of observational errors. For comparison with the observations atmospheric model fields are stored every three hours and interpolated linearly in time and bi-linearly horizontally to the observation locations.

In section 4 mean and root-mean-square (rms) observation-minus-background (O-B) differences are presented. The O-B differences can be thought of as having three sources: background error, measurement error and representivity error. Representivity error is due to resolution or other constraints in the forecast model. In the open ocean it is fairly small (except possibly near very intense storms), but it can be a major issue near coastlines especially mountainous ones. Data assimilation systems usually combine measurement and representivity errors as "observation error" - with standard deviation σ_o that has to be specified in the DA system. Assuming that background errors are independent then rms O-B provides an upper bound for σ_o, and rms/$\sqrt{2}$ is sometimes used as a first approximation to σ_o. The ship σ_o values can be compared with the error estimates of Kent and Berry (2005) especially the estimates from more recent data (see their figure 2), although there will be some differences due to data sampling, quality control and other factors (Ingleby, 2001).

3. Processing

For 2007, 10.6 million BUOY reports and 3.6 million SHIP reports, with associated model values were extracted from the Met Office archives. They were subject to:
a) Thinning, so that the minimum gap between reports from the same station is 1 hour
b) Track check – using the algorithm of Ingleby and Huddleston (2007) originally developed for sub-surface reports from ships
c) Land check – using OSTIA 1/20° latitude/longitude land mask
Statistics for 2007 and 2008 have been produced. In general the 2007 statistics are presented because they have been examined in greater detail and surface data assimilation changes in 2008 may make the 2008 statistics slightly less homogenous. The main features can be seen in the statistics for either year, there are occasional comments on differences.

The track check examines a month's position data for each station and if the implied speed between two adjacent reports is excessive (over 15 m/s for ships, 2 m/s for other stations) then one, or occasionally both, of the reports is rejected. This is repeated until the remaining track is consistent. Reports with the call sign "SHIP" cannot be checked. As expected manual ships had the highest track rejection rate of 1-2%, for automated ships it was mainly around 0.1%, with 0.4% one month. Automated ships and buoys are sometimes unable to obtain a current Global Positioning System (GPS) "fix" in which case they report their previous position, this gives minor track problems. For moored buoys the track rejection rate was generally very low, but the tropical moored buoys had 1% rejections in June and August 2007. Drifter track rejections were between 0.2 and 0.7%.

The OSTIA daily SST fields (Stark et al, 2007) have a resolution of 1/20° (~ 6km). These were interpolated horizontally to the observation locations. If any of the four surrounding points does not have an SST then the report is classed as land. This excludes some reports that are very close to the coast (sometimes in port) or on the North American great lakes as well as some track errors. Both the track and the land check could be described as moderately strict, but there are particular problems comparing marine reports and model values near the coast (and over land!) – discussed further in sections 4.1.4 and 4.3. For manual (automated) ships overall the preliminary processing removed about 8% (18%) of the total reports – most of this coming from the land check. The Canadian fleet has a large proportion of coastguard vessels and 40% of Canadian reports were excluded by the land check. For moored buoys in SHIP (BUOY) code the figure was about 25% (10%) and for drifters about 30% - mostly from the temporal thinning. (Some drifters report every few minutes but only reports with a satellite overpass reach the GTS giving rather irregular times, other drifters repeatedly transmit their last hourly report.)

For each variable a tolerance is set and if the magnitude of the O-B difference exceeds this then that datum is not used in the statistics. The tolerances were initially set to 15 hPa for pressure, 15°C for temperature, 15 m/s for wind speed, 50% for RH (all as used for regular monitoring reports) and 5°C for SST. These reject a very small proportion of values and some statistics were produced with halved tolerances for pressure and temperature.

3.1 Wind adjustments

To make wind measurements at different heights more compatible a number of different adjustment algorithms have been proposed. In the next section we use the logarithmic profile – eqn 1 of Thomas et al (2005) – used in TurboWin when stability information is not available (only used for rigs currently, but between about 2002 and 2004 used for all TurboWin reports, see http://www.knmi.nl/turbowin/history.html). Table 2 shows how the wind profile changes as a function of height assuming this equation. For comparison a profile from Hsu et al (1994) with 0.11 as the exponent is also shown. For our purposes the two are very similar over the range of heights considered. Note that under very stable conditions the wind speed increases more sharply with height. For visual (or sea state) estimate winds the Lindau "Beaufort equivalent scale" as expressed by eqn 2 of Thomas et al was tested – see section 4.1.3.

Ht(m)	TBW	Hsu
1.0	0.74	0.78
3.0	0.86	0.88
5.0	0.92	0.93
10.0	1.00	1.00
15.0	1.05	1.05
20.0	1.08	1.08
25.0	1.10	1.11
30.0	1.13	1.13
35.0	1.14	1.15
40.0	1.16	1.16
45.0	1.17	1.18
50.0	1.18	1.19
55.0	1.20	1.21
60.0	1.21	1.22

Table 2. Wind speed as a function of height.

4. Results

For some of the results shown statistics were accumulated by station and then combined (weighted by the number of reports) by category – such as vessel type or country. Statistics by latitude band, ocean basin, stability or distance from coast were calculated directly. Solar zenith angle was computed for each report and separate day/night statistics were also produced.

4.1 Wind speed

For the other variables results are presented for <o-b>, where <.> denotes the mean, however for wind speed the ratio <o>/<b> has advantages. Errors in height assignment should directly affect the speed ratio (section 3.1). Also wind speeds and their errors tend to be largest in mid-latitudes – especially in winter – and normalising by background wind speed takes some account of this. Table 3 summarises the wind speeds and their ratios for different categories of reports. Almost all categories are stronger than background – before height adjustment ship_manual is 21% stronger. The 2008 ratios are very similar except for drifter (1.08) and some of the smaller buoy subsets.

N Stn	N Rep	Mn o	Mn b	Ratio	RatioA	
2481	697252	8.13	6.74	1.21	1.08	ship_manual
130	196186	8.11	6.81	1.19	1.07	ship_auto
62	218909	8.08	8.36	0.97	0.97	rig
183	1101286	6.77	6.69	1.01	1.10	buoy_sc
122	268690	5.69	5.77	0.99	1.11	buoy_bc (~4 m)
35	31257	8.49	6.96	1.22	1.23	drifter
Breakdown of buoy_sc results:						
5	42862	8.65	7.56	1.14	1.09	light vessels (15m)
26	127299	7.39	7.76	0.95	1.11	European (~3m)
7	45308	6.89	6.48	1.06	1.06	N American (10m)
85	503663	6.29	6.24	1.01	1.10	N American (5m) - Atl
56	364352	6.92	6.82	1.01	1.10	N American (5m) - Pac

Table 3. Wind speed statistics for 2007 for reports in SHIP and BUOY code (excluding reports with model height over 50m). For buoy categories anht is given – taken from http://www.ndbc.noaa.gov/bht.shtml for N American buoys. Columns give the number of stations and total number of reports, the mean reported wind speed, mean 10m background wind speed, and the ratio of the two. RatioA is the ratio after the reported wind speeds have been adjusted to 10m.

4.1.1 Buoy and rig winds

For moored buoys and ships the ratio of the adjusted and background wind speeds is fairly consistent – suggesting that the background is 7-10% too weak. Rig winds are slightly weaker than background – this could be related to flow distortion by the rigs, or to the adjustment to 10m including the possibility that the rig anemometers are on occasion above the surface layer where the adjustment is valid. For buoy_sc there is a distinct stability dependence: ratio after adjustment of 1.10 for all reports, 1.06 for reports with AirT ≥ SST and 1.03 for reports with AirT ≥ SST+2. This suggests that stability dependence should be included in the adjustment to 10m for buoy winds (stability dependence is less clear for ship winds, especially ship_manual). It is not directly related to day-night differences which are generally small for wind speed ratio. All the indications are that moored buoys provide generally good quality winds (although there are questions over whether they may underestimate very strong winds, see discussion in section 5.1). Looking at time-series of individual buoys compared to background there are occasional possibly spurious calms reported - sometimes preceding complete sensor failure, but temporary in other cases. Occasionally the wind speed becomes "stuck" at a non-zero value, and in July 2007 a handful of buoys appeared to have a maximum speed of 9 m/s. For some moored buoys the reported wind speeds are somewhat stronger than the background – most of these are coastal or inland, about one third of them are removed by the land check. It should be emphasised that many other moored buoys show remarkably good agreement with background wind speeds, see Figure 2a for example. Figure 2b shows a tropical buoy with generally good agreement but occasional sharp deviations – these may be real squalls/lulls not represented by the model.

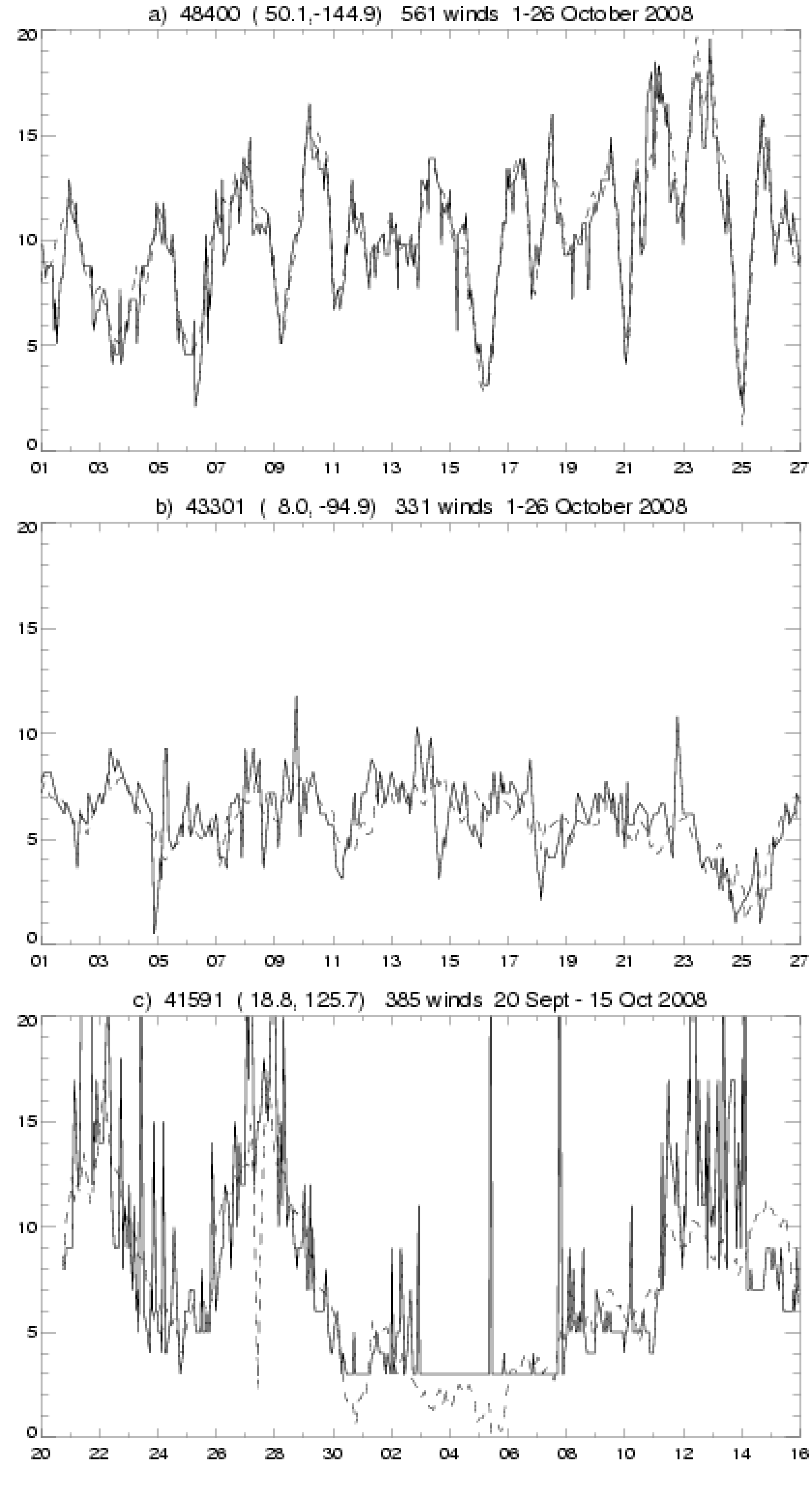

Figure 2. Examples of buoy and drifter wind speed (m/s) time-series – solid line; background – dashed line. a) and b) are moored buoys, reporting wind hourly. c) is a drifter, which started reporting on 20 September (position of first report in brackets), presumed to be measuring acoustically, only about 25% of its 1550 reports in this period contained wind. It appears to have sampled Typhoons Hagupit and Jangmi (including its eye), by 27th 41591 had drifted north to (21.0, 124.7).

In 2008 a group of fixed stations in the southern Baltic Sea with call signs BSHnn (with nn between 50 and 70) started reporting, they are better classified as buoys despite the character call signs. Three or four are moored buoys, the other eight or so are pole mounted instruments in shallow water (Henry Kleta, pers. comm., 2008) – these latter give very weak winds compared to the background.

The numbers of drifters reporting wind have declined in recent years (to 3-50). Early drifter winds used conventional "cup and vane" anemometers 1 or 2 m above the surface. It seems that most/all drifter winds now come from Minimet drifters (Milliff et al, 2003), some of them dropped just in advance of tropical storms. Unfortunately there is nothing in the BUOY message to indicate the type of buoy or wind measurement. Minimet wind speeds at a nominal 10 m are inferred from underwater acoustic spectra, and a vane at about 0.5 m height is used to infer wind direction. Currently absolute calibration of the wind speeds is not possible - there is dependence on both the deployment location and the individual instrument. The acoustic spectra can be used to infer both wind speed and precipitation, but undetected precipitation or noise from shipping or other sources can cause erroneous winds (Nystuen and Selsor, 1997). Looking at time-series of drifter wind speeds there are many very large spikes and quite often offsets from background wind speeds that may be due to calibration problems. Some drifters appear to have a minimum speed (typically 3 m/s). A few, mainly mid-latitude, drifters produce good quality relatively spike-free winds, but even these can be subject to sudden quality deterioration. Figure 2c illustrates both spikes and a minimum speed. In this case there is clearly some meteorological signal but the task of using these noisy data in an automated system is daunting especially as there can be calibration problems as well. Due to such problems these acoustic drifter systems are being discontinued (Niiler, 2009, pers. comm.) and drifter winds will continue to be monitored but not assimilated in the Met Office system for now.

4.1.2 Measured ship winds

Ideally measured ship winds should be ten minute averages from a fixed anemometer (hand-held anemometers are now deprecated) with the ship motion taken into account. They should be reported without adjustment to a standard height. Table 4 shows wind speed as a function of anemometer height and in general, as expected, wind speed increases, relative to background, for higher anemometers. It also shows that for 67% of measured ship winds we don't know the anemometer height. The winds are adjusted to 10 m using the TurboWin equation (see section 3.1) using 30 m when anht is missing. In general the ratios for the adjusted winds are around 1.10 but with 1.05 for the 11-20m anht category.

N Stn	N Rep	Mn o	Mn b	Ratio	RatioA	anht
1472	440227	8.37	6.86	1.22	1.09	not known
12	12340	7.49	6.81	1.10	1.12	1-10m
117	49089	7.44	6.70	1.11	1.05	11-20m
107	58299	7.96	6.58	1.21	1.10	21-30m
116	77310	8.60	6.77	1.27	1.11	31-40m
65	14864	8.62	6.81	1.27	1.09	41-50m
15	2790	7.77	6.54	1.19	0.99	51+m

Table 4. Measured ship wind speed statistics for 2007 by anemometer height, columns as table 3.

The solution adopted here is to calculate an average anemometer height for each vessel type and to use that if the vessel type is known but the ship anemometer height is not. This is based on work by Kent et al (2007), but without their refinement of using vessel length (if available) as an additional predictor. The second column of Table 5 shows the estimates of anemometer height used. The highest anht values are from passenger ships followed by liquid tankers, container ships, bulk carriers and ferries. The lowest values are from trawlers, research vessels and coast guard vessels. Support vessels and yachts seem to be particularly disparate in terms of size. These estimated heights were derived subjectively after inspection of values from Kent et al (2007), WMO Pub 47 (December 2007) and the subset of WMO Pub 47 corresponding to ships reporting in July 2008. This subset gives higher mean anht for some vessel types than the earlier estimates, probably reflecting a continuing increase of anht with time. Average anemometer height increased from about 21 m in 1970 to about 32 m by 2002, with the greatest increases in the early 1990s (Figure 4 of Thomas et al, 2008). However the rate of increase may slow down due to infrastructure constraints (S North, pers. comm. 2008). For unknown vessel type 30m is used. (For comparison ECMWF – European Centre for Medium-Range Weather Forecasts - use 25m for all ships without anht, Uppala et al, 2005, Andersson, pers. comm. 2008.)

Vessel type

	anht	<---- measured winds ---->				<---- estimated winds --->			
Vssl	def	NStn	N Rep	Ratio	RatioA	NStn	N Rep	Ratio	RatioA
CS	37	645	125320	1.25	1.09	562	80767	1.18	1.03
GC	25	97	24398	1.21	1.10	153	26135	1.04	0.99
LT	38	118	18580	1.21	1.05	115	16403	1.13	1.02
BC	34	58	13142	1.25	1.10	59	7911	1.18	1.05
RR	30	50	17247	1.22	1.09	47	7542	1.23	1.09
SV	25*	49	18797	1.18	1.08	57	5406	1.26	1.14
GT	23	80	20483	1.16	1.05	43	5206	1.07	0.98
RV	18	61	120210	1.08	1.01	15	4101	1.14	1.07
RS	25	12	1884	1.33	1.23	52	16512	1.10	1.03
PS	45	85	39216	1.45	1.24	62	7360	1.40	1.21
FE	34	23	37254	1.34	1.18	6	592	1.40	1.32
TR	15	39	18173	1.11	1.09	1			
CG	20	16	19252	1.15	1.07	1	490	1.21	1.12
YA	25*	9	1956	1.47	1.31	7	1715	1.15	1.03
LC	37	1				7	1314	1.16	1.01
OT	30*	39	27353	1.24	1.10	30	4905	1.08	1.04
xx	30*	523	151880	1.23	1.10	375	49479	1.19	1.06
manual		1778	459379	1.23	1.10	1588	235531	1.16	1.04
auto		127	195837	1.19	1.07	4	318	1.08	0.95

Table 5. Ship statistics for 2007 by vessel type and measured or estimated winds. The second column gives the default anemometer height (in m) used in this study - rather uncertain values are marked with an asterisk. Other columns as in Table 3. Ratios not given if less than 200 reports. The vessel types (from WMO Pub 47) are: CS Container ship, GC General Cargo, LT Liquid Tanker, BC Bulk Carrier, RR Ro Ro cargo ship, SV Support Vessel, GT Gas Tanker, RV Research Vessel, RS Refrigerated Ship, PS Passenger Ship, FE Passenger Ferry, TR Trawler, CG Coastguard, YA Yacht, LC Livestock Carrier, OT Other (known), xx Unknown.

Table 5 shows statistics by vessel type. Passenger ships (PS) and ferries (FE) have rather large ratios (for both measured and estimated winds), measured yacht (YA) winds are also very strong. Note that about 10% of measured winds (25% of estimated winds) come from unknown types of vessels. RatioA gives the speed ratios after adjustment to 10 m (see section 4.1.3 for details regarding estimated winds) and it shows improvements compared to the unadjusted ratio. Passenger ship and ferry winds still appear anomalously strong, as do refrigerated ship and yacht winds. Measured research vessel winds (RV - numerous due to high reporting frequency) after their modest adjustment are only 1% stronger than background (about 6% without the land and track checks; coast guard winds were relatively weaker without the removal of land/coast points). Other ship types have measured winds with ratios between 1.05 and 1.10 – consistent with buoy winds. In general there is a tendency for larger and faster vessel types to have stronger winds relative to the background. These results suggest that although the adjustment significantly reduces disparities related to anemometer height and/or ship type that some residual disparities remain (possibly related to larger speed gradients in stable conditions and/or some of the higher measurements being outside the surface layer).

Automated reports

The bottom two rows of table 5 show that ship_auto ratios are slightly lower than those from ship_manual, both before and after height adjustment. The four most common ship_auto types are research vessel, passenger ferry, container ship and coastguard. After adjustment automated reports of these types are 5%, 17%, 2% and 5% stronger than background respectively (2007 statistics). The main countries reporting automated winds are France (11% stronger than background after adjustment), Canada (2%), Germany (1%), Australia (21%) and GB (4%). Most of the German automated ships are coastguard or research vessels in the southern North Sea or Baltic, they can be quasi-stationary for extended periods (sometimes in port). Many of the Canadian reports are from coastguard vessels and their statistics are sensitive to the details of near-coastal exclusions. The passenger ferry reports are mainly from French vessels in the Mediterranean. Coastal effects are discussed further in section 4.1.4. Thus although the mean ship_auto ratio looks reasonable this hides both rather low and rather high speed ratios from particular subsets.

Results by country

Table 6 shows speed ratios by country before and after adjustment. After adjustment many countries have ratios between 1.04 and 1.11. The two largest fleets Germany and the US come at opposite ends of this range. The US has no anht values in Pub47 and a large proportion of unknown ship types so the US results are moderately sensitive to the default heights used. Canada and the Netherlands have the lowest ratios: as just mentioned many of the Canadian reports are coastal and also automated; the Canadian ratios are smallest in winter – other countries show little seasonal variation. The Netherlands is discussed in section 4.1.3 on visually estimated winds. Russia has the highest ratio after adjustment. The Russian reports are predominantly near-coastal (and many have anht less than 20m), with the largest ratio north of 60°N. For most countries there is no clear latitudinal variation of the speed ratio. 2008 results are similar except that RatioA for New Zealand increases to 1.14. Table 6 also shows the leading vessel types for the countries listed. Container ships make up 521 of the ships in the German fleet. Most fleets are much more varied.

N Stn	N Rep	Mn o	Ratio	RatioA							
594	211755	7.79	1.16	1.04	DE	521	CS	53	GC	11	LT
657	184805	8.39	1.25	1.11	US	254	xx	121	CS	72	LT
240	70467	8.23	1.23	1.08	GB	65	CS	37	LT	28	GC
172	39867	7.06	1.06	1.03	NL	68	GC	34	RS	22	LT
158	26686	8.59	1.21	1.14	RU	48	GT	36	TR	22	xx
78	27156	8.60	1.27	1.12	AU	26	CS	14	GC	13	BC
66	106861	8.16	1.23	1.11	FR	20	FE	11	RV	5	TR
31	22994	7.23	1.12	1.02	CA	14	CG	5	RR	5	GC
34	12138	8.30	1.21	1.09	NZ	18	CS	5	GT	2	RR
55	25882	7.76	1.19	1.07	JP	16	CS	9	RR	8	BC
9	22840	9.05	1.15	1.05	NO	5	RV	2	OT	1	SV
1	28087	7.73	1.19	1.06	SH						
356	68407	8.53	1.22	1.09	xx						

Table 6. Ship statistics for 2007 by recruiting country (both measured and estimated winds). Countries reporting less than 10000 reports omitted. (Countries: DE – Germany, US – United States, GB – Great Britain, NL – Netherlands, RU – Russia, AU – Australia, FR – France, CA – Canada, NZ – New Zealand, JP – Japan, NO – Norway, SH – "SHIP" callsign, xx – unknown country). Columns as in Table 3. For each country the top three vessel types are given at the right hand side.

Calculation of true wind

Kent et al (1993a) found that "the conversion of anemometer winds to true winds was also a significant source of error". The subtraction of the ships velocity from the measured relative wind was only performed correctly about 50% of the time. This result was for a relatively small sample of Western European and North American ships in the North Atlantic between 1988 and 1990 – as part of the VSOP-NA project extra data were collected. Gulev (1999) distributed a questionnaire to Russian officers and found 'that 19% of officers do not know about the technique of the evaluation of the true wind, 21% know but do not do it usually, 33% do it either episodically or using the "approximate course and ship velocity," and only 27% do it correctly.' If no adjustment is made for the motion of the ship then on average the reported wind speed will be too strong. For ship_manual reports in 2007 that included ship speed and heading the mean reported wind speed is 8.2 m/s, the mean air-speed relative to the ship (as measured by an anemometer) is 11.3 m/s – 38% higher. (The relative speeds were calculated from reported ship motion and winds – taking the reported wind as the true wind. There is an element of circularity here, but it seems very likely that relative wind speeds are higher than true wind speeds.) This might explain the larger biases from passenger ships and ferries – fairly large, fast ship types – however these vessel types also spend a relatively large proportion of time close to the coast (see section 4.1.4). Note also that if an anemometer reading influences an "estimated" wind (see next section), then the ship motion is even less likely to have been correctly removed. Gulev's survey suggests that the large ratio for Russian ships may be partly due to reporting of relative rather than true winds in some cases – other counties will also be affected to some extent. Kent and Berry (2005) suggest that measured winds from some ships suffer from calibration/bias problems, but that well-calibrated measured winds may be better than estimated winds.

Reporting units and rounding

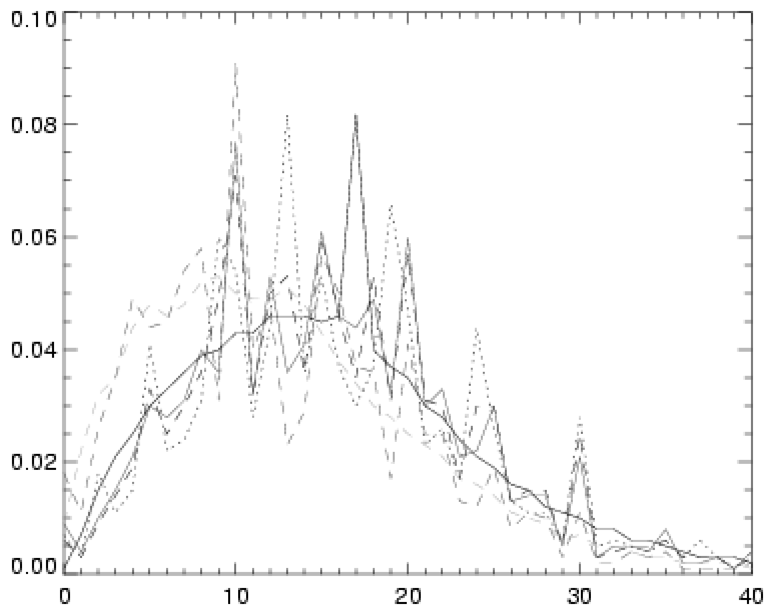

Figure 3. Frequency of different reported speeds in knots by recruiting country. (Elsewhere in this paper all speeds are in m/s.)

In the SHIP format wind speeds can be reported in either knots or m/s – whole numbers in either case. Most countries report in knots either from tradition or because it allows higher precision. The choice of knots or m/s gives a risk of error (some ships report in both units). Figure 3 shows the frequency that different wind speeds in knots were reported by ships of different countries – no height adjustment has been applied. There is clearly a preference for round numbers 0, 10, 20 and 30 knots, and to some extent 5, 15 and 25 knots, with some differences by nationality. The reports in m/s display a lesser degree of rounding (only Russia, Germany and Netherlands report sufficient winds in m/s to give reliable distributions – not shown). The more automated countries Canada and France (latter is solid black line) have smoother distributions, closer to Weibull distributions (as does the background – not shown). The French distribution has a large spike at 17 knots - Batos winds are calculated as multiples of 0.5 m/s then rounded to the nearest knot for reporting, both 8.5 and 9.0 m/s round to 17 knots; Batos will report in tenths of a m/s when SHIP code is replaced (P. Blouch, pers. comm. 2008).

4.1.3 Estimated ship winds

N Stn	N Rep	Mn o	Mn b	Ratio	Mn L	Ratio L	
405	53000	7.76	6.52	1.19	7.92	1.21	DE
435	62473	8.00	6.58	1.22	8.14	1.24	US
201	36886	7.59	6.61	1.15	7.75	1.17	GB
165	31798	6.73	6.63	1.01	6.93	1.04	NL

Table 7. Similar to table 3 for ships reporting estimated wind by recruiting county. The last two columns are for the reported winds adjusted using the Lindau scale.

Historically sailors have estimated winds by looking at the sea state and the effect of wind upon the ship using the Beaufort scale. Since about 1950 there has been a trend towards use of anemometers, but almost 30% of manual ship reports still indicate use of visual estimates. (According to their reports in SHIP format a handful of buoys and rigs also use visual estimates – indicating a coding problem.) Most of the estimated winds come from ships recruited by four countries – see Table 7. About 25% of German and US winds are estimated, about 50% of GB winds and over 80% of Dutch winds.

In principle the conversion from Beaufort force to wind speed gives 10m equivalent speeds, but it seems clear from Table 7 that they are overestimates in general. The other clear signal from Table 7 is that Dutch winds are much weaker than those from the other countries. Assuming that the background is 7-10% weak the Dutch estimated winds are too weak, the others are too strong. The Lindau adjustment (see section 2.1) only makes a small modification – tending to slightly increase the speeds overall. The weaker Dutch winds date back to 2002 at least – probably longer. Thomas et al (2008, p 759): "[previous authors] suggested that separate Beaufort equivalent scales would be required for each country, since observing practices appeared to vary significantly from one recruiting country to another." Thomas et al also note that estimated wind speeds have become stronger - possibly related to observers checking their estimate against an anemometer where fitted (as discussed above most anemometers are higher than 10m and their winds include the effect of ship motion). The Dutch winds show a relatively large proportion of winds less than 2.5 m/s: for very weak winds visual estimates may be better than anemometer measurements from a moving vessel.

The large biases for most estimated ship winds present a problem which is not addressed by the Lindau scale. The approach adopted here is a) to leave the estimated Dutch winds unadjusted and b) to treat all other winds as measured and to adjust them as in the previous section. The adjusted winds in Tables 3 and 5 have been processed in this way and table 5 shows that this adjustment reduces the ratio for estimated winds to about 1.04 on average. This procedure seemed to be the least arbitrary available and there is circumstantial evidence, at least, that some “estimated” winds are influenced by anemometer readings (the trends in night-time winds noted by Thomas et al and the variation with vessel type in table 5).

4.1.4 Geographical and model factors

From a data assimilation point of view the fact that the background winds seem to be 7-10% too weak on average is of some concern. In some respects the model “10m” wind is better regarded as a layer average from 0-20m (J. Edwards, pers. comm., 2009) – using the TurboWin profile (section 3.1) gives a layer mean wind 2% weaker than the point 10m wind. Model resolution may also play a role - a coarse resolution model may underestimate pressure gradients and hence winds. To get some feel for the magnitude of the issue Table 8 compares global model speed ratios and those from the NAE (grid spacing of about 40 km and 12 km respectively).

	North Atlantic Global	North Atlantic NAE	Mediterranean Global	Mediterranean NAE
ship_man	1.08 (140)	1.06 (107)	1.09 (21)	1.08 (22)
ship_auto	1.03 (46)	1.00 (39)	1.14 (38)	1.10 (38)
buoy_sc	1.05 (236)	1.02 (129)	1.24 (15)	1.10 (15)
rig	0.97 (160)	0.95 (161)		

Table 8. Speed ratios (reported speed adjusted for anht divided by background speed) for 2007 comparing Global and NAE models for the North Atlantic (north of 30°N) and the Mediterranean. (Numbers of reports, 1000s, in brackets.)

In the North Atlantic the NAE winds are 2 or 3% stronger than in the global model (there are fewer reports in the NAE because it does not cover part of the western North Atlantic and it has a slightly earlier cut-off time; there are also minor gaps in the archives). In the Mediterranean the numbers of reports agree fairly well, the ratios are higher than for the North Atlantic, but on average they are reduced slightly more by the NAE – by 4% for ship_auto, mainly French ferries (and 14% for buoys, but as there are only two buoys in the Mediterranean sampling effects may be large). The most likely explanation lies in the land-locked nature of the Mediterranean: the global model is likely to spread coastal effects, i.e. slower wind speeds, over a larger proportion of the sea. (The Mediterranean is quite close to the NAE lateral boundary, but this would be more likely to reduce wind speeds if it was a major factor.) In the global model the speed ratio (after adjustment to 10 m) for the North Pacific is slightly larger (by about 0.02) than that for the North Atlantic.

Wind speeds over land are significantly lower than those over the ocean, so that comparing reported marine winds with land-affected model winds is fraught with problems. Some mismatches will happen because the model has to represent the real coastline on its grid scale. For near-coastal reports we might expect the model winds to be significantly weaker, and this seems to be happening in the Mediterranean. However many coastal reports from Canada and Germany have weak winds compared to the model. In the Canadian reports there is a clear seasonal signal, with the normalised reported winds being weakest in February and strongest in summer.

The exclusion of land points using the OSTIA mask (section 3) reduces the adjusted speed ratio by about 1%, exclusion of all points with interpolated model height over 50m gives a further reduction of up to 1% (these reductions are somewhat larger for the US and Russian fleets). These exclusions have been applied in all the wind tables. A large proportion of ship_auto reports are near-coastal – partly because of the types of vessels with automated systems, partly because they may continue transmitting even when the vessel is in port.

Figure 4 shows speed ratios for European buoys. There is plenty of station-to-station variability, but on average the buoys to the west (windward) are perhaps 5% stronger than background whereas those closer to the coast or in the North Sea have larger ratios – probably reflecting weak background winds. The North American buoys show similar features except that some of the buoys close to shore have more extreme ratios: mostly large but sometimes small. The westernmost buoy in Figure 4 reported 1 m/s every hour for part of January then stopped reporting wind speed so its ratio can be ignored (it also dragged its mooring later in the year).

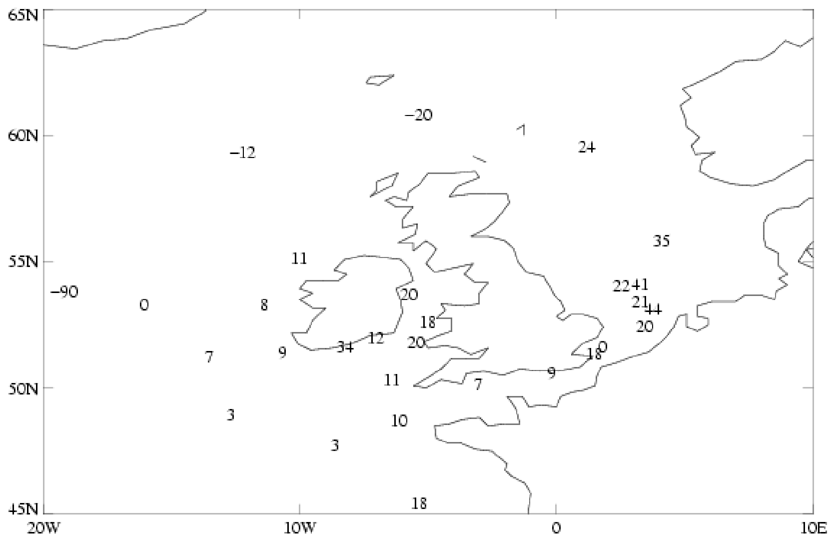

Figure 4. Speed ratios for European buoys in 2007 (where 1.20 is plotted as 20, 0.88 as -12 etc, buoy position is at the bottom right of the numerals). There are other European buoys further south but only two report in SHIP or BUOY format.

To try to quantify coastal effects a land-sea mask with a resolution of about 10 km was set up, omitting islands less than 5000 km^2 in area, and the distance from the nearest coast calculated for each sea point and interpolated to report locations. For reference the 150 km contour is shown on Figure 1. Figure 5 shows speed ratios as a function of distance from coast: 20 km bins were used out to 100 km, then 50 km bins out to 300 km with reports further from the coast all combined and plotted at 300 km. These "open ocean" reports only represented 45%, 18% and 22% of ship_manual, ship_auto and buoy_sc reports respectively (most buoy_bc reports are more than 300 km from the coast). Buoy_sc and ship winds are 5-8% stronger than background more than 300 km from the coast and 8-15% stronger than background within 100 km of the coast. (There is a small proportion of reports at OSTIA sea points but at land points according to the new mask – presumably in narrow inlets/estuaries or harbours – these are plotted at zero distance, they have much weaker winds and smaller ratios.) Ship_manual winds show a bit less variation with distance from the coast than ship_auto and buoy_bc. However larger vessel types (except passenger ships) spend more time in the open ocean than smaller vessel types and also have higher speed ratios – separate results for container ships and research vessels show more variation with distance from coast. Assuming that the reported speeds are unbiased the global background is about 12% too weak near coasts, 6% too weak in extratropical open oceans and 10% too weak in tropical open oceans (from buoy_bc results). NAE wind ratios (not shown) are approximately 3-6% lower than the global model ratios both near the coast and in open ocean.

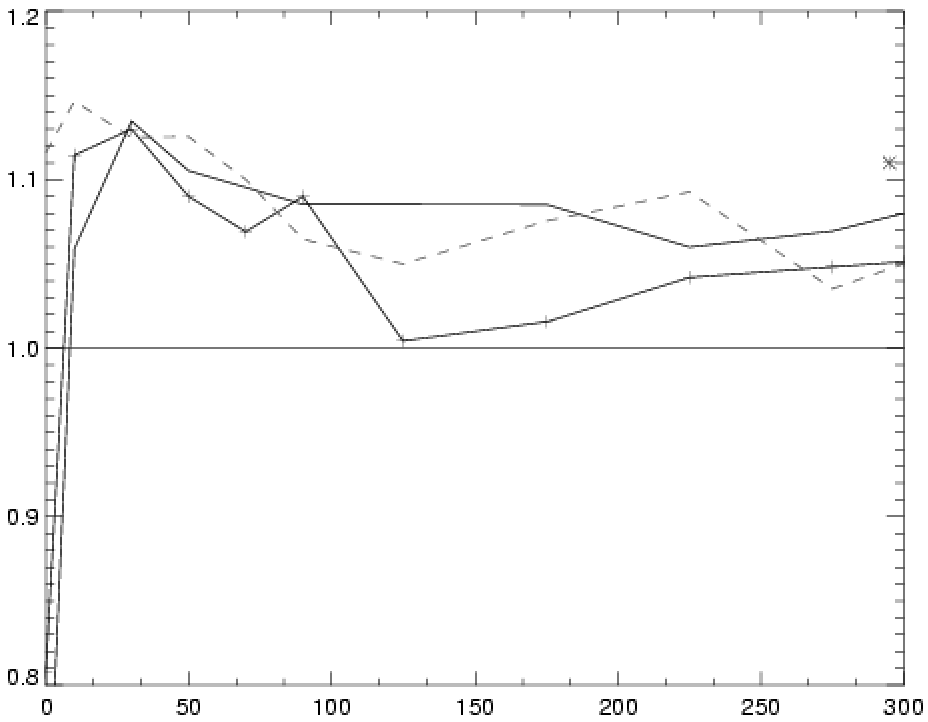

Figure 5. Speed ratios for ship_manual (solid line), ship_auto (solid line with + symbols), buoy_sc (dashed line) and buoy_bc (*) as a function of distance from coast (km): 2007 and 2008 combined. See text for further details.

Of course wind direction (onshore or offshore) is also important. Barthelmie et al (2007) estimate that in reality coastal effects extend about 20 km downwind over the sea in unstable or neutral conditions, but up to 70 km downwind in stable conditions. The results here are reasonably consistent with their findings, and with the global model spreading coastal effects up to 80 km or so on average. Higher model resolution should result in something closer to the ideal in which both the model and reported wind are subject to the same coastal effects.

4.1.5 Vector wind statistics

Vector wind statistics are presented in table 9. In the Met Office data assimilation system (and most others) ship and buoy winds are assimilated as westerly and southerly wind components (u and v respectively). Thus observation errors need to be specified for wind components – the results suggest that the estimates are too large as the rms differences should give an upper bound (section 2.3). Because averaging two vectors with the same speed but different directions gives a smaller speed, analysis wind speeds may be slightly lower than the mean of the input (observed and background) wind speeds – however this is less clear for 4D-Var than 3D-Var. Also note that reports that are weaker than background will tend to have smaller wind component rms differences than reports that are stronger than background.

		← u	→	← v	→		
N Stn	N Tot	Mn o-b	RMS o-b	Mn o-b	RMS o-b	σ_o	
2320	428984	-0.02	1.53	-0.01	1.52	2.0	ship_manual
127	136309	-0.06	1.46	-0.03	1.46	1.7	ship_auto
62	173156	-0.12	1.50	-0.10	1.42	1.7	rig
181	940844	-0.06	1.57	-0.04	1.58	1.7	buoy_sc
123	238865	-0.35	1.48	-0.08	1.56	1.7	buoy_bc
32	17938	0.20	1.64	0.01	1.80	2.5	drifter

Table 9. Mean and rms o-b differences for wind components (after adjustment of reported winds to 10 m). σ_o gives the estimate of observation error used for either u or v component.

Perhaps surprisingly the rms differences for moored buoys are slightly higher than those for ships; but note that adjustment to 10m will scale up buoy measurement errors and scale down ship measurement errors. The largest rms differences are for drifters, but as discussed in section 4.1.1 drifter winds are rather poor quality. Mostly the mean vector differences are negligible but a notable exception is that tropical moored buoys have a u bias of -0.35 m/s i.e. they are more easterly than the background (with mean u of -3.0 m/s) – most of these buoys are within 10° of the equator. These buoys are currently assimilated without adjustment to 10m and the background is in better mean agreement with their unadjusted winds. Near the equator there is much less constraint on winds from the pressure field via geostrophy and so height-adjusting the winds before assimilation may have a significant effect on analysis/background biases there.

4.2 Pressure

N Stn	N Rep	Mn o	Mn o-b	rms o-b	σ_o	
a) Results using 15 hPa tolerance:						
2469	729010	1012.99	0.02	1.74	1.3	ship_manual
147	290666	1013.61	-0.13	0.95	1.0	ship_auto
65	235120	1011.13	-0.14	0.95	0.8	rig
190	1236455	1013.08	-0.13	0.77	0.8	buoy_sc
54	123100	1010.76	0.08	0.72	0.8	buoy_bc
897	3523046	1013.23	-0.07	1.12	0.9	drifter
b) Results using 7.5 hPa tolerance						
2463	723190	1013.00	0.02	1.50	1.3	ship_manual
147	290293	1013.61	-0.13	0.87	1.0	ship_auto
65	234813	1011.13	-0.14	0.88	0.8	rig
190	1236251	1013.08	-0.13	0.76	0.8	buoy_sc
54	123047	1010.76	0.08	0.69	0.8	buoy_bc
894	3509531	1013.27	-0.07	0.91	0.9	drifter

Table 10. Pressure statistics for 2007 for reports in SHIP and BUOY code (hPa). "Mn o-b" is mean observed minus background, "rms o-b" is the root-mean-square of the differences. The σ_o values given were implemented in November 2008, prior to that 1.0 hPa was used for all surface pressure reports.

Moored buoys have very low pressure rms differences, probably reflecting both observation and background errors of 0.5 hPa or less – Table 10. Pressure gradients in the tropics are very small (so model errors there are generally small). Drifter, rig and automated ship perform well in terms of rms(o-b) – these are the sorts of accuracy one would hope for (Ingleby, 2001) – but manual ships perform relatively poorly (also noted by ECMWF, Vasiljevic et al, 2005, unpublished). Tightening the tolerance (difference from background allowed) has little effect on the best data – the moored buoys – and a significant effect on the worst data, although the additional percentage rejected is quite small. The 7.5 hPa limit is closer to that in the operational quality control system (which also includes "buddy checks" against nearby observations). Without the preliminary processing (the track, land and duplicate checks – see section 3) the statistics are worse again – especially for manual ships. The 2008 rms statistics are slightly worse overall.

Of the vessel types coastguard and research vessel perform the best and passenger ships and tankers the worst. Russian ships have relatively large errors (2.2 hPa rms) and those from US and GB are moderate (about 1.6 rms) whereas those from the other main reporting countries are less, with those from France and Canada being best – as expected from the good performance of ship_auto in Table 10. Pressure differences exhibit little dependence on distance from coast, except that ship_manual rms differences reduce close to the coast. This appears to be a sampling effect i.e. some of the best stations for measuring pressure stay close to the coast. With the exception of somewhat larger values in the southern ocean ship pressure rms is approximately independent of latitude. Drifter pressure differences are large (in mean and rms terms) near or just north of the equator. However most tropical drifters don't measure pressure, drifters dropped near tropical cyclones do which may explain the large differences.

Errors in adjusting the pressure to sea level may be significant for some ships. An error of 10m in the pressure sensor height above sea level translates to a substantial 1.1 or 1.2 hPa pressure bias. For large ships the height can vary by more than this with the ship loading – so this needs careful attention. With previous versions of the TurboWin software there were significant problems with double-correction of the pressure reading; extra reminders were added in version 3.5 (2004) and in version 4.0 (2007) there was a further clarification ("New Zealand, Australia and UK 'does the reading indicate pressure at MSL' preset to 'no'"). Some ships (only 20 according to WMO Pub47) have the barometer in a pressurised wheelhouse – observers are advised to open the door prior to taking readings (easier in some conditions than others no doubt). With manual transmission of reports there is increased risk of transmission errors (typically single digit errors, transposition of two digits, or for temperature and latitude/longitude sign errors) – also seen in slight errors in ship call sign.

In November 2008 the estimates of pressure errors were reduced for buoys and rigs and increased for manual ships (see table 10). Larger reductions were also tested, in combination with reduced estimates for automated SYNOPs, but these gave slightly worse results. The background error estimates (σ_b) for surface pressure appear to be too large, and the analysis is sensitive to the ratio of σ_o to σ_b, so σ_b would have to be updated at the same time as a reduction of σ_o to more realistic levels.

4.3 Temperature

N Stn	N Rep	Mn o	Mn o-b	RMS o-b	σ_o	
a) Results using 15°C tolerance:						
2476	730150	17.82	0.27	1.84	1.8	ship_manual
147	292338	14.18	-0.01	1.59	1.8	ship_auto
65	233958	9.56	-0.12	1.39	1.8	rig
192	1225230	14.00	-0.08	1.43	1.8	buoy_sc
125	308031	25.41	-0.25	1.08	1.8	buoy_bc
85	243762	-11.09	-0.22	4.25	2.0	drifter
b) Results using 7.5°C tolerance:						
2474	724478	17.85	0.22	1.62	1.8	ship_manual
146	290616	14.30	-0.00	1.42	1.8	ship_auto
65	233352	9.53	-0.14	1.31	1.8	rig
192	1221052	14.02	-0.09	1.32	1.8	buoy_sc
125	306726	25.45	-0.22	0.91	1.8	buoy_bc
84	220255	-10.26	-0.38	3.04	2.0	drifter
c) Results using 7.5°C tolerance and excluding model height > 50m						
2462	697570	18.01	0.18	1.55	ship_manual	
145	269322	14.50	-0.11	1.32	ship_auto	
65	233352	9.53	-0.14	1.31	rig	
180	1140331	14.28	-0.15	1.07	buoy_sc	
d) Results using 7.5°C tolerance for different ship exposure:						
500	335409	12.54	0.03	1.53	no screen	
503	313066	15.72	0.05	1.38	screen (natvent)	
948	292364	17.52	0.22	1.51	ventilated	
734	307607	16.44	0.12	1.66	unknown	

Table 11. As table 10 for temperature statistics (°C).

The temperature O-B statistics (table 11) show less variation with platform type, although manual ship reports are again worst. Results are also compared using instrument exposure from WMO Pub47: measurements from aspirated screens and sling or whirling psychrometers have been grouped together as “ventilated”. The biggest surprise is that temperatures from naturally ventilated screens (“screen (natvent)” in table 11, note that ship motion will generally provide some ventillation) have slightly lower bias and rms than ventilated measurements. One possible explanation is that screen measurements have a greater time lag and hence smoothing of high frequency variations compared to ventilated measurements. Aspirated instruments have different types of screen and in the worst case (metal screens) this may cause problems. As suggested by the mean temperatures there is a tendency for ventilated measurements to be at lower latitudes and unscreened measurements to be at higher latitudes than the screen (natvent) measurements.

Halving the tolerance to 7.5°C reduces the rms differences as expected and removes about 0.5% of the reports (this is slightly tighter than the operational QC limit). Removing reports where the interpolated model height is over 50m takes out over 5% of reports and gives larger rms reductions, especially for the buoys in SHIP code. The Batos automated reports have a very good rms of 1.24°. Statistics were also examined for the VOSClim subset: VOSClim aims to provide a high-quality subset of marine meteorological data, with extensive associated metadata, to support global climate studies (see http://www.ncdc.noaa.gov/VOSClim.html). The manual VOSClim reports (167 ships) have an rms of 1.43, compared to 1.62 for all manual reports. The Batos and VOSClim reports also perform better than average for RH, but give similar results for pressure. Buoys along the East coast of US/Canada have a larger rms of 1.25 compared to 0.97 for West coast buoys – probably due to the greater influence of land on the flow over the East coast buoys.

Statistics have also been produced as a function of stability – represented by ΔT=AirT-SST. Both temperature and humidity (and pressure to a much lesser extent) rms differences are smallest in near-neutral (ΔT≈0) conditions. This is true using ΔT from both background and reported values. Overall results are worst for ΔT>4 and ΔT<-8 and it is proposed to reject ship/rig/buoy temperatures and humidities under these conditions (although unstable conditions, negative ΔT, seem to cause less degradation for buoy statistics). The proportion rejected will be fairly small and it seems likely that large vertical gradients increasing representivity error are the main cause of the worse agreement.

Temperature differences as a function of distance from coast are shown in figure 6. Buoy_sc and ship_auto show rather higher rms differences for the 0-20 km bin (also seen for RH). The observations are slightly warmer, or the background slightly cooler, close to the coast than further away. This is a small difference in a large apparent gradient – mean temperatures near the coast are about 4°C cooler than those at 100 km for buoy_sc and ship_auto and about 8°C cooler for ship_manual (not shown). This feature appears to be due to both a tendency for more inshore reports at high latitudes and to physical effects, such as coastal upwelling and winter advection from cold continents, that tend to cool sea and air temperatures close to the coast.

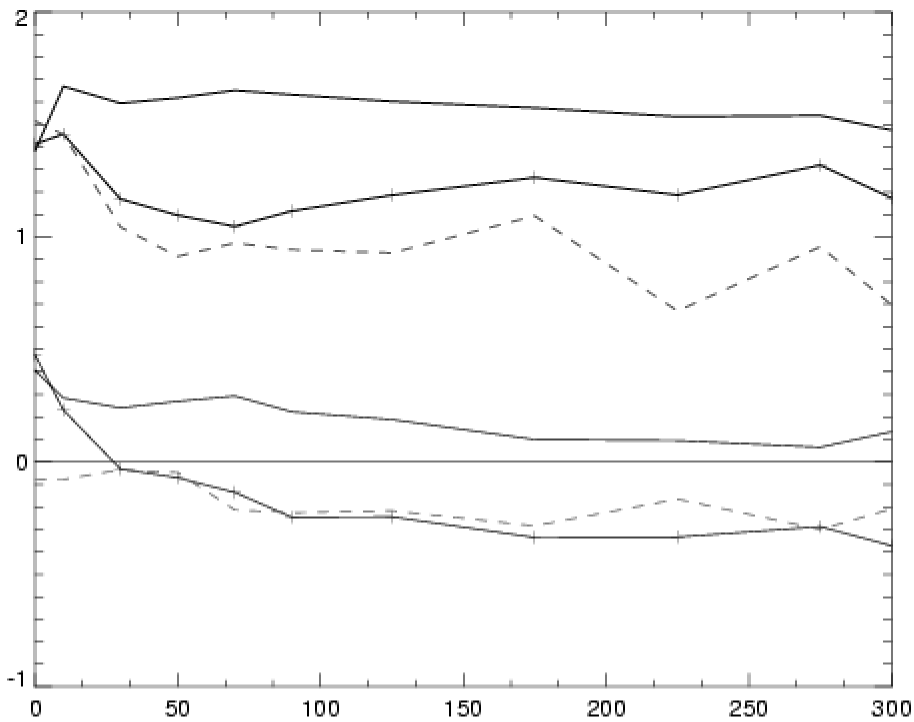

Figure 6. Rms (top) and mean (bottom) O-B air temperature differences as a function of distance from coast (km): 2007 and 2008 combined (7.5°C tolerance used and points with model height over 50m excluded). Line types as figure 5.

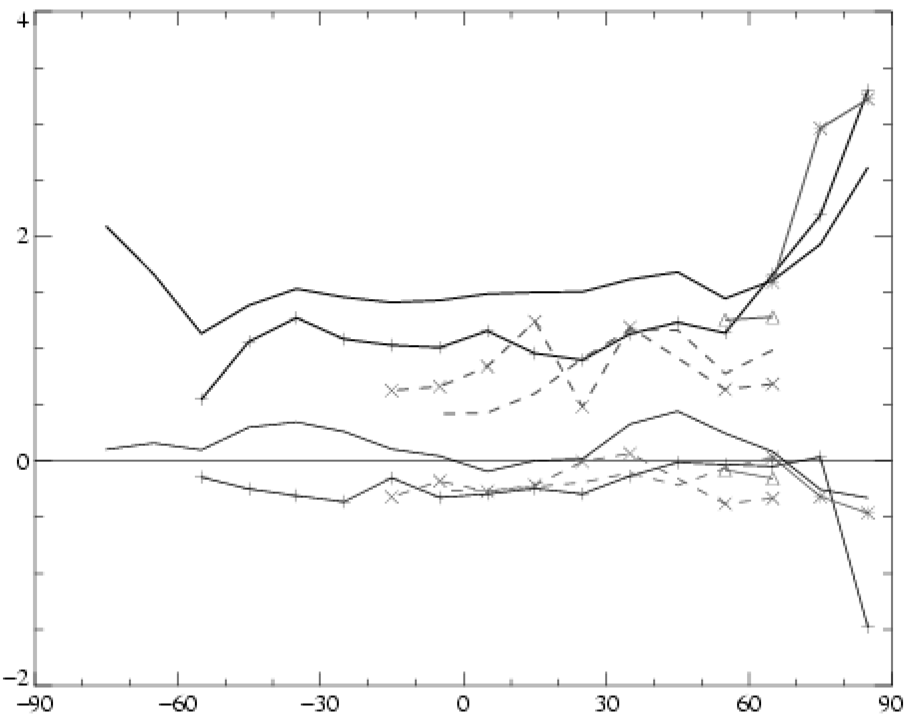

Figure 7. Temperature O-B mean (lower lines) and RMS (thicker lines) for 2007 and 2008 combined (7.5°C tolerance and model heights over 50m excluded) – values calculated in 10° latitude bands. Black solid line ships: plain – manual, '+' – auto; grey dashed line buoys: plain – buoy_sc, 'x' – buoy_bc; grey solid line: 'triangle' – rig, 'x' drifter (non-Arctic drifters excluded).

Figure 7 shows that the rms statistics are reasonably constant over most latitudes but largest at high latitudes. This may partly reflect low data density but is mainly due to the inherent difficulties in both observing and forecasting sub-zero temperatures. When this is taken into account the large rms differences of the Arctic drifters don't look unreasonable – especially as they report all year whereas Arctic ship data is summer only. (A few drifters at other latitudes report temperature, but some of them have large biases.) The larger rms difference and slightly warmer temperatures of manual vs automated ships are seen at most latitudes but there is some noise (the large bias north of 80°N comes from a single automated ship). Both sets of moored buoy statistics are reasonably consistent.

The Arctic drifters with temperature sensors are part of the International Arctic Buoy Programme (IABP) – see Rigor et al (2000) and Polyakov et al (2003). Rigor et al (2000) perform a delayed mode calibration of the temperatures – using the spring melt period to reset the 0°C value. Time-series of drifter temperatures suggest that the data are mainly of good quality although with some offsets and occasional spikes. The reported temperatures tend to have a larger diurnal range than the background (not shown). With careful quality control and appropriate observation error estimates the Arctic drifter temperatures may be usable in data assimilation.

Table 12 shows that there are significant day-night differences. Relative to background manual ship reports are notably warmer, with a larger rms difference, by day than by night (discussed further below). Rigs and ship_auto show similar features but with decreasing magnitude, while the moored buoys show less diurnal variation. Russian ships have rather large rms – independent of latitude. The US and Canada have moderately large rms, but partly due to larger differences at high latitude. On average French and Norwegian ships are relatively cooler by day than other ships. Over half of SeaKeepers reports were excluded by the model height check – without this the KS bias and rms statistics were larger. Support vessels had larger rms than other vessel types.

←	Day		→	←	Night		→	
N	Mn o	Mn o-b	RMS o-b	N	Mn o	Mn o-b	RMS o-b	
362	18.55	0.58	1.75	333	17.42	-0.26	1.30	ship_man
128	15.04	0.06	1.39	142	14.02	-0.26	1.25	ship_auto
120	10.31	0.11	1.45	114	8.71	-0.40	1.14	rig
572	14.79	-0.11	1.09	568	13.77	-0.19	1.04	buoy_sc
151	25.67	-0.11	0.91	154	25.35	-0.33	0.90	buoy_bc
99	-3.68	-0.44	2.53	83	-17.79	-0.31	3.51	drifter
121	17.71	0.42	1.54	105	15.73	-0.14	1.17	DE
91	19.24	0.76	1.96	90	18.43	-0.31	1.41	US
45	18.62	0.47	1.39	48	17.48	-0.22	1.01	GB
21	21.29	0.82	1.71	19	20.18	-0.13	1.21	NL
15	10.10	0.76	2.49	11	5.96	-0.43	2.13	RU
13	21.33	0.14	1.40	15	20.07	-0.39	1.15	AU
66	17.70	0.02	1.38	81	16.29	-0.30	1.32	FR
13	6.64	0.25	1.81	10	5.94	-0.29	1.52	CA
6	21.48	0.57	1.43	6	20.07	-0.26	1.01	NZ
13	20.94	0.38	1.51	13	20.01	-0.31	1.13	JP
12	6.87	-0.26	1.06	10	4.95	-0.59	1.06	NO
15	22.23	0.59	1.77	12	20.93	-0.44	1.40	SH
3	21.90	-0.19	1.45	3	23.63	-0.27	1.28	KS
6	15.08	0.56	1.55	5	13.39	-0.16	1.12	OT
36	16.53	0.58	1.79	32	15.36	-0.21	1.31	xx

Table 12. 2007 day/night air temperature statistics (°C) by type and country (7.5°C tolerance and model heights over 50m excluded). KS – SeaKeepers reports, call sign starts KS0. N gives number of reports in 1000s.

It is likely that warm ship and rig reports during the day are mainly due to solar heating of decks and superstructure. Direct solar heating of the instrument screen is also possible but if this were the main cause the ventilated measurements should perform better and buoy reports should have a similar diurnal range. It isn't clear why manual ships have a larger diurnal signal than automated ones, although positioning of the instruments and ship type will have some effect.

Figure 8 shows the diurnal cycle of both reported and background temperatures for 20° latitude bands for June 2007 - smoothed with a 6-hour running mean. The reported temperatures have maxima at about 3 pm local time (later at high latitudes), the background temperatures have much weaker maxima at similar times (there is no diurnal variation of SST in the model – arguably the background diurnal cycle is slightly too small). The thin lines show the diurnal cycle after the application of the Berry et al (2004) correction algorithm. (The coefficients used were x1=0.00161, x2=0.001, x3=43.00942, x4=1.0, x5=254.81161, x6=0.0, with time in units of hours. They were derived from all available ship data for 2006 using a slightly different optimisation algorithm to that in the 2004 paper, Berry, pers. comm. 2008.) For ships in the Arctic with 24-hour daylight the simpler Kent et al (1993b) algorithm - without a representation of heat storage by the ship - was used, although its effect on the statistics will be minimal. The correction almost removes the diurnal cycle in the bias, but the effect on the rms is modest (a daytime reduction from 1.86° to 1.69° for ship_manual, ship_auto rms gets worse because they start with a near-zero daytime bias). It is an average correction - in general it should vary with ship size. It uses reported cloud to estimate incoming solar radiation and relative wind speed (errors are lower at higher relative wind speeds) - both the cloudiness and relative wind are assumed to be relatively constant in the hours before the report. 27% of manual ship reports and 95% of automated reports don't contain cloud information (although the proportion is lower in daylight hours) - such reports were omitted from the uncorrected diurnal cycle in Figure 8 to aid comparison. In an NWP context it would be possible to use the modelled cloudiness/solar radiation which would be available for all reports, but it would require retuning of the algorithm. The simplest solution is to omit ship temperature reports during daylight hours.

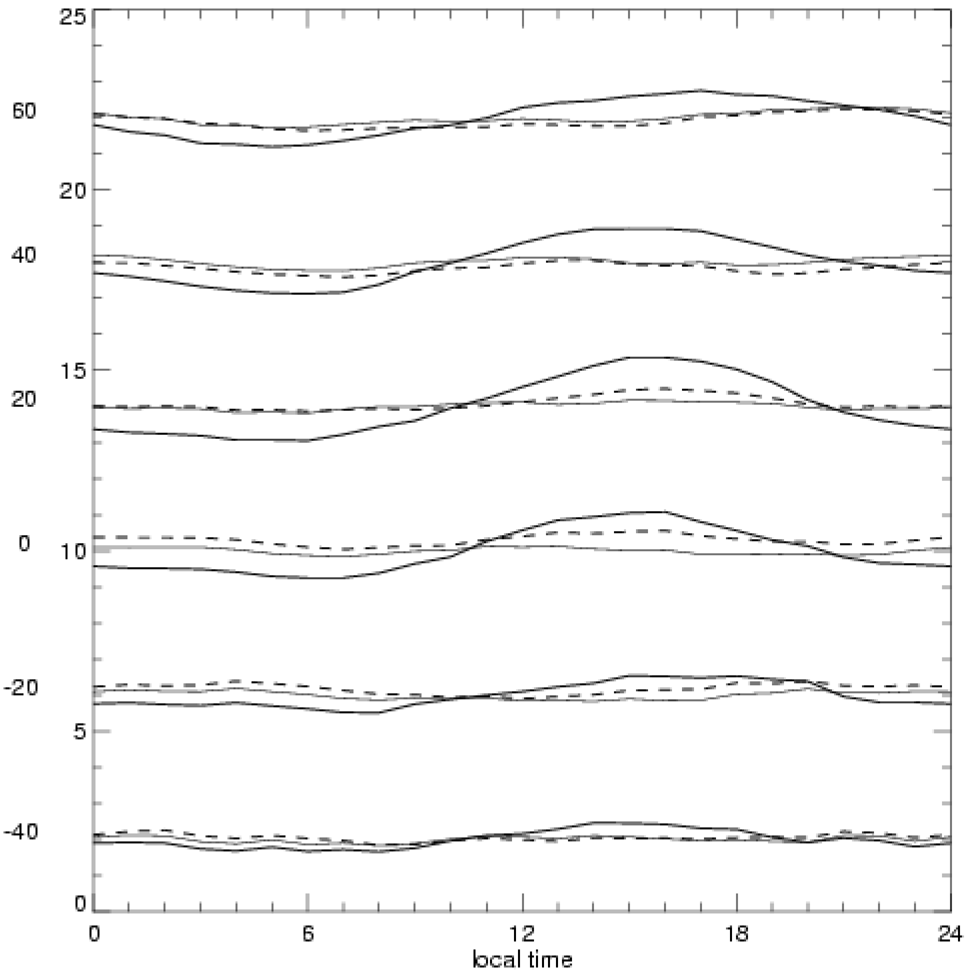

Figure 8. Diurnal cycle of reported (solid) and background (dashed) temperatures from manual ships for June 2007 with 6-hour running mean applied. Numbers at far left give the centre of the latitude bands plotted: 60 for 50-70°N, 40 for 30-50°N etc; different bands offset vertically for clarity. Thinner black lines show results with the Berry et al (2004) correction applied.

In principle there should be a correction for the height above sea level of the measurement, but this would only be about 0.03°C for a height of 50m, so this is neglected for now. (For land stations a standard lapse rate of 0.0065°/m is applied for the difference between station height and model height. On average anht is about 10m above the height of temperature and humidity readings – Kent et al, 2007.)

Anderson and Baumgartner (1998) reported direct solar heating errors on moored buoys and proposed a correction, because of the screen characteristics there can be a local minimum in the error at solar noon for high solar elevation angles. In table 12 the largely tropical buoy_bc temperatures are 0.20°C warmer by day relative to the background. This is probably not large enough to be worth correcting for DA.

4.4 Humidity

N Stn	N Rep	Mn o	Mn o-b	RMS o-b	σ_o	
1594	455322	78.85	-0.30	9.82	10	ship_manual
121	209588	78.50	-1.82	8.59	10	ship_auto
46	132190	78.55	-2.54	9.19	10	rig
100	582119	79.39	0.02	7.26	10	buoy_sc
271	169712	78.84	-1.46	10.10		no screen
472	294390	78.54	-0.90	8.83		screen (natvent)
822	261719	78.84	-0.76	9.36		ventilated
196	71279	78.56	-1.97	10.16		unknown

Table 13. As table 10 for relative humidity statistics (%) from SHIP code.

Table 13 gives differences from background for relative humidity (RH) – calculated from reported dew points. Buoys (in SHIP code) perform well with rigs and manual ship reports having the largest rms. Rigs and automated ship reports have the largest bias and are drier than the background. Looking at the exposure of the instruments unscreened humidities have a large rms and negative bias (with those of unknown exposure slightly worse). The measurements from naturally ventilated screens have slightly lower rms than the "ventilated" measurements – as for temperature and similar possible explanations apply. Berry et al (2004) suggest that poorly ventilated humidity measurements will tend to be too high – this is not apparent from the statistics here. The differences between ship exposures seem fairly small from a DA perspective. σ_o values are a bit large on average. As noted in the previous section there are larger RH and temperature differences under extremes of stability.

There are fewer humidity reports than temperature reports for all observation categories. Only about 10% of US reports have humidity, the proportion is even lower for Russian reports. Passenger ships, and other large vessels (plus yachts) tend to have above average rms. Unfortunately buoy_bc statistics are not available because of an archiving issue. About a third of tropical moored buoys report RH rather than dew point, drifters do not report humidity.

Table 14 shows day/night differences in the statistics. Daytime rms tends to be larger than at night, but the relative difference is smaller than that for temperature. Kent and Taylor (1996) suggest that specific humidity calculated from the reported air temperature and dew point temperature is largely unaffected by solar radiation effects. We might expect RH to be more affected than specific humidity but the results here do not support a blanket rejection of daytime RH. All rig humidities and daytime ship humidities without a screen or with unknown exposure have the worst results and will be rejected. Daytime humidities with interpolated model height between 1 and 50m also have large differences (9.22 rms compared to 7.76 for zero heights) and will also be rejected.

←		Day	→	←		Night	→	
N	Mn o	Mn o-b	RMS o-b	N	Mn o	Mn o-b	RMS o-b	
232	77.93	-1.09	9.88	211	79.99	0.89	9.42	ship_man
90	78.64	-1.97	8.33	104	78.55	-1.20	7.94	ship_auto
68	78.92	-3.14	9.66	64	78.14	-1.90	8.67	rig
282	79.47	-0.04	6.95	279	78.85	0.05	7.02	buoy_sc
87	78.79	-2.23	10.40	80	78.95	-0.66	9.57	no screen
130	78.38	-1.23	8.53	143	78.89	0.15	8.27	screen
138	77.86	-1.51	9.66	121	80.08	0.17	8.89	ventil.
35	78.16	-2.35	9.99	34	78.89	-1.36	9.94	unknown

Table 14. 2007 day/night relative humidity statistics (%) by type and exposure. N gives number of reports in 1000s.

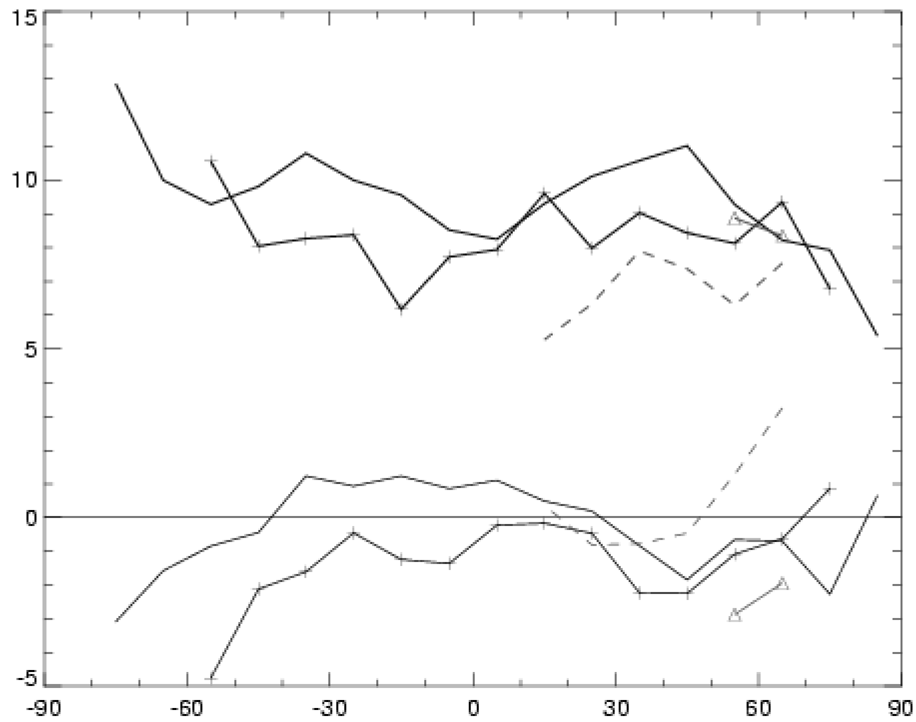

Figure 9. As figure 7 but for RH

As shown in figure 9 ship_manual O-B rms errors are largest in mid-latitudes and high southern latitudes, the bias is also most negative there, whereas in the tropics the manual observations are slightly moister than the background. The mean reported RH is slightly larger north of 50°N compared to lower latitudes.

4.4 Sea Surface Temperature (SST)

N Stn	N Rep	Mn o	Mn o-a	RMS o-a	σ_o	
2058	571074	18.70	0.13	1.24	1.2	ship_manual
96	161444	16.13	0.14	0.90	1.2	ship_auto
13	27957	10.24	0.09	0.40	1.2	rig
207	1375128	15.05	0.03	0.53	0.4	buoy_sc
132	313052	26.55	0.07	0.33	0.4	buoy_bc
2188	6476551	18.08	0.05	0.39	0.4	drifter
1381	455788	18.24	0.18	1.22		intake
145	31440	19.00	-0.08	1.15		bucket
523	207380	17.92	0.09	1.09		hull contact
105	37910	17.39	0.04	1.09		unknown

Table 15. As table 10 for SST statistics (°C).

Note that unlike the atmospheric fields (where a short-range forecast is used) the comparison here is with an SST analysis – this raises possible issues of correlation between analysis and observation errors especially for stationary platforms. The influence of in situ SST measurements is reduced by the input of large amounts of satellite data, adjusted for skin/bulk differences, although satellite pixels affected by the coast cannot be used. The OSTIA SST is a "foundation" or bulk temperature (Stark et al, 2007) so should be a good match for ship/buoy SST. SST also has higher day-to-day persistence than atmospheric fields.

The rms differences seen in table 15 show good agreement for buoy, drifter and rig, intermediate values for automated ships and worst results for manual ships. The σ_o values for rig and ship_auto are too large, those for buoy and drifter may be too small given the correlation between analysis and observation errors. The reports are slightly warmer than the analysis, especially for ships. The different measurement methods for ship have similar rms values, but a 0.18°C bias for cooling system intake and -0.08°C for the declining number of bucket measurements. Manual VOSClim reports perform slightly better than average with rms of 1.13 compared to 1.24 for all manual reports. For some reason TurboWin reports (especially German ones) perform slightly worse with rms of 1.41; for other variables TurboWin results are similar to those for all manual reports. Emery et al (2001) also reported that ship SSTs are noisier and warmer than buoy/drifter SSTs. A histogram of reported SST (not shown here but see Emery et al) is bimodal with a maximum at 27 or 28°C (and a sharp decline above this) and another maximum around 12 or 13°C. The latter appears to be mainly an artefact of preferential sampling of northern mid-latitudes whereas relatively constant SSTs over much of the tropics contribute to the former.

Relationships between variables can be important in QC and data assimilation. On a small scale there can be a significant positive correlation between SST and near-surface wind speed (Samelson et al, 2006). However on very large scales SST and wind speed are negatively correlated – this makes the relationship harder to use.

5. Discussion

5.1 Buoy-Ship-Satellite wind speed comparisons

After allowing for anemometer height ship reports have similar average speed, relative to background, to buoy winds (eg tables 3 and 8, figure 5). To compare them more directly ship-buoy pairs within 100 km of each other and at the same nominal time were determined (but if either was within 20km of the coast the pair was discarded). Collocated ship_manual and buoy_sc reports gave very similar mean speeds (7.1 m/s, also for the background) and their cumulative speed distribution (not shown) was rather similar. Ship_auto, dominated by pairs from northern Europe, gave 7.7 m/s mean – weaker than the 8.3 m/s for collocated buoys, with the background at 8.1 m/s. On the other hand tropical buoys (5.3 m/s) were weaker than collocated ships (5.9 m/s) with the background intermediate (5.6 m/s). The numbers of collocations in the tropics were relatively small and about 5% of the buoy reports there gave calms. Various authors have suggested that buoy winds are weaker than ship winds – especially at higher speeds - and a number of hypotheses to explain this have been put forward (summarised below), however the current results only support this for the tropical buoys.

As discussed in Gilhousen (2006) buoy winds could be weak due to a) buoy motion, b) wave sheltering, c) longer buoy averaging periods or d) buoy quality problems, although c) and d) were discounted. Comparisons of drifter winds with other platforms are given in Gilhousen (1993) and Large et al (1995). Large et al note that in high wind/wave conditions there is flow disturbance extending beyond the anemometer height - "wind speed decreases much faster with height in the presence of waves". So although the anemometers appear to work OK (and there are no obvious problems with wind direction), computed 10 m wind speeds are underestimated in such conditions. (The southern hemisphere results of Gilhousen (1993) are consistent with this.) Large et al suggest a speed correction above about 7 m/s - this threshold speed being dependent on the anemometer height. This would also apply to moored buoys, especially the smaller ones. Recent results from Howden et al (2008) show that with the passage of Hurricane Katrina a moored buoy, with anemometers at 5m height, was consistently tilted by 20° or more from the vertical causing an underestimate of about 10% in the wind speeds from a traditional propeller and vane anemometer compared to an experimental sonic anemometer. Note that underestimates of high winds may have only a minor effect on overall buoy statistics.

Ship superstructure and cargo can cause local distortion of the flow giving both acceleration and deceleration of the wind (Moat et al, 2006). With manual ship observations there may also be reporting issues: a possibility that gust rather than mean speed is reported, dual anemometers on a few ships – would mean or highest speed be reported? Another cause of over-strong ship winds in some cases is likely to be inadequate adjustment for the ship motion – see section 4.1.2.

Satellite sea surface wind speeds are available from scatterometers, altimeters (nadir only) and passive microwave sensors. The satellite data are presented to the assimilation as neutral 10 m winds. The algorithms are semi-empirical and often use buoy winds or NWP fields as a reference and any problems in the reference, such as an underestimate of strong winds, may also be seen in the satellite winds (Zeng and

Brown, 1998). There is a minor discrepancy in that buoy winds are absolute whereas stress-related satellite winds are relative to ocean surface currents. Within the Met Office wind speed bias corrections are applied to ERS-2 and QuikScat scatterometer winds (Keogh and Offiler, unpublished note, 2005). The uncorrected satellite winds were stronger than the background winds, and buoy winds appeared to agree better with the background. However the buoy winds were taken as valid at 10 m, whereas most are between 3 and 5 m - given this the buoy winds would agree better with the uncorrected satellite winds. More recently Windsat and ASCAT winds have been introduced operationally (ASCAT from October 2007) without any bias correction applied. Keogh (2008) found that in the extratropics ASCAT winds are about 0.4 m/s stronger than background in winter with a bias near zero in the summer. Since then the ASCAT winds, as produced by KNMI, have been retuned using ECMWF 10 m neutral wind data increasing their mean speeds by about 0.2 m/s (Keogh, pers. comm. 2008). For comparison with figure 5 background wind speeds are up to 16% weak relative to scatterometer (QuikScat and ASCAT) winds close to the coast and about 8% weak more than 400 km from the coast (J Cotton, pers. comm. 2009). This suggests that scatterometer winds are marginally stronger than buoy winds on average – however the scatterometers cannot measure winds less than 2 or 3 m/s. Over the medium term it is desirable to slightly increase background sea surface wind speeds (perhaps by modifications to the roughness length parameterisation) and to reduce the bias corrections applied to scatterometer winds.

5.2 Data assimilation issues

In principle a data assimilation system can use any observation provided a) it gives independent information about a variable of interest and b) its errors can be fairly well characterised. With the improvement of NWP systems over the years short range forecast errors are now similar to, or less than, observation errors in many cases. Good quality control is important – to exclude observations that are "worse than usual". There are essentially two levels of quality control: prior and real-time. Prior rejections can be rather sweeping (eg all drifter winds and temperatures) and are reviewed occasionally; or specific (eg reject pressure from a particular station) - these are updated monthly based on monitoring statistics. The real-time quality control is based on Bayesian probability theory assuming the observation error is either from a known normal distribution or from a flat distribution giving no useful information, i.e. the observation has a gross error (Lorenc and Hammon, 1988, Ingleby and Lorenc, 1993). The real-time QC system mainly uses the O-B increment (the background check), but also compares increments with other nearby observations (the buddy check); in general it rejects fewer values than the prior rejections. Also important are the estimated observation errors (the width of the normal distribution), used in the QC and which determine the weight given to the observations in the assimilation. For some reported values adjustments or corrections are applied. For routine monitoring and for an examination of overall distributions (as in this paper) a more lenient check on O-B is used.

Recall that background values are interpolated from the four surrounding model grid points, so that land points can have a direct effect up to one grid-length out to sea, the indirect effect will extend further downwind (both become less of a problem as model resolution improves). For this reason it makes sense to have a check on interpolated model height as well as a more realistic land check. The proportion of ship and buoy reports potentially affected by real or model coastal effects is relatively large – those worst affected have to be rejected but there has to be a balance because reports relatively close to land could be quite important for short-range forecasting.

Trialling of the following changes to the Met Office use of ship/buoy data have started, results will be reported separately. Some of the limits are rather arbitrary, but a line has to be drawn somewhere.

1. Land and track checks, similar to those described in section 3, will be applied, the speed tolerances may be relaxed slightly. The track check needs several days' data to be effective, rather than the six-hour window currently extracted.
2. Reject "stuck" values (preliminary definition is at least six consecutive identical values spanning h hours, where h is 12 for pressure, temperature and humidity, 24 for wind and 36 for SST). Ideally there would be a check for spikes as well but this would have to be variable and situation dependent.
3. Temperature, humidity and wind will not be used where the interpolated model height is over 50m (excludes about 5% of SHIP format reports), or the coast is within 20 km, daytime humidity will not be used where the model height is non-zero. Surface pressure is not so affected by proximity to land.
4. Ship and buoy winds will be processed according to their estimated anemometer heights – see next section (rig winds and estimated Dutch winds have already been adjusted to 10m).
5. Reject calm winds if the background wind speed is greater than 5 m/s?
6. Marine temperatures and humidities will not be assimilated under extremes of stability: background AirT-SST outside the range -8 to +4.
7. Reject daytime ship/rig temperatures or more targeted rejection (section 4.3)
8. Reject daytime humidities from ships without a screen or with unknown exposure and all rig humidities (section 4.4).
9. Test assimilation of Arctic drifter temperatures.
10. Monthly monitoring: additional reject based on report/background speed ratio less than 0.6 or more than 1.7 (given sufficient sample).
11. Trial the effect of modest reductions of σ_o to more 'realistic' values.
12. There are some categories of ship data which have larger than average errors (such as passenger ships and to some extent support vessels and yachts; also some countries have relatively poor results for certain variables). To some extent this is addressed by routine monitoring with feedback to data producers and rejection of one or more variables from particularly poor stations. Monthly marine surface monitoring statistics are available from http://www.metoffice.gov.uk/research/nwp/observations/monitoring/

5.3 Assimilation of ship and buoy winds

Ship winds are relatively complex to use well and they are outnumbered by better quality winds from moored buoys and satellites. On the other hand many open ocean areas are not covered by buoy winds and there are gaps in satellite wind coverage, so there is an incentive to make the best use of ship winds.

Currently in the Met Office assimilation manual ship winds are treated as valid at 20 m (the background 10 m wind is multiplied by 1.1 to adjust it to 20 m) but this treatment is not entirely consistent (the observation archive contains unadjusted winds). Buoy winds are currently treated as 10m winds. There is clearly room for improvement in using (as far as possible) the real anemometer height. The simplest option is to adjust reported winds to 10 m as done in this study. Using a surface layer formulation based on the model equations (taking account of low level stability and roughness) is also being tested. For the purpose of producing comparable statistics and checking for biases and other observational problems there are advantages to having the "observations" at the standard 10m height. Note that for assimilation the ideal is to use the reported wind at the measurement height but that this will not be done initially – it is thought that this would only give marginal benefit over the planned improvements.

6. Summary and concluding remarks

This paper documents a snap-shot of an evolving observing system and some of its strengths, weaknesses and peculiarities. There are continuing trends towards automated and unmanned reporting stations, and there has also been a trend towards larger ships. In a number of respects automated reports perform better than manual reports. Moored buoys (with minor exceptions) report good quality data. Drifter winds – only reported from a very small proportion of drifters - are very noisy and will continue to be rejected for now. Arctic drifter temperatures (currently rejected) appear be usable subject to standard monitoring and quality control procedures. There are many factors that may have some effect on ship/buoy quality, or their representivity for use in data assimilation, those that appear to be most important have been documented. Actively ventilated temperature and humidity measurements appear slightly worse than those from naturally ventilated screens – possibly because they have more high frequency "noise". Another unexpected feature is that automated ships show much less daytime warm bias of air temperatures than manual ship reports.

Reports over land and within a few kilometres of the coast were screened out. A slightly wider coastal exclusion zone, especially for hilly coasts, appears desirable for assimilation of air temperature, humidity and wind - pressure is less affected. Tightening the quality control has little effect on statistics for the best data sources but significant effects on the worst – generally manual ship reports. Proposed improvements to the processing and quality control of marine data are described in section 5.2. Preliminary results suggest that the quality control changes and the addition of Arctic buoy temperatures slightly improve forecast skill. The work reported here complements and informs the regular Met Office monitoring of surface marine data and helped with the decision not to bias correct ASCAT scatterometer winds at the Met Office.

After adjusting for anemometer height moored buoy and ship winds are about 12% stronger than the background winds in coastal areas and about 6% stronger in extratropical open oceans. Tropical open ocean moored buoys are about 11% stronger than background. In absolute terms the speed biases are larger in Winter when wind speeds are stronger. Satellite surface winds are also stronger than background (especially in Winter) and seem to be approximately comparable with the buoy and ship winds. There are persistent suggestions, and a limited amount of direct evidence, that buoys underestimate strong winds – except for tropical buoys very little evidence was found for this. Some reported ship winds do not have the ship velocity correctly removed which will increase their average reported speed. The Batos automatic ship reports (which should have the ship velocity removed correctly) are about 12% stronger than background. Other automated ship winds (mainly from coastal regions) and rig winds appear slightly weak. There is a small proportion of calm reports (some spurious?) from both ships and buoys. Rounding of ship wind speeds in manual reports adds slightly to their errors.

The existing SHIP and BUOY codes will not be developed further by WMO – rather they will be replaced by "table driven" codes with a switch over in 2012. The codes do not make clear that winds are at measurement height (except for rig reports) rather than a standard height – this has led to confusion and mistakes. The draft replacement codes include anemometer height which is a step forward. In the opinion of this author they should be extended to include: a) provision for reporting both the wind at anemometer height and the wind adjusted to 10m, b) better means of distinguishing buoy, rig and ship reports, c) buoy type, d) the wind measurement system and possibly associated quality information and e) the time of last GPS fix if different from the report time. There will be a continuing/increasing need for metadata such as vessel and instrument types and recruiting country. Any "masking" systems put in place should take account of the need of operational centres to match metadata to marine reports in real-time.

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Annex A. Observation types and anht deduced from identifier/call sign

Light vessels (15 m):
62107, 62103, 62305, 62304, 62170

List of "rigs" reporting wind adjusted to 10m, as of August 2008 (courtesy I Hendry):

62111, 62114, 62115, 62116, 62117, 62119, 62120, 62121, 62123, 62125, 62126, 62128, 62130, 62131, 62132, 62133, 62134, 62136, 62137, 62138, 62139, 62140, 62141, 62142, 62143, 62144, 62145, 62146, 62147, 62148, 62150, 62151, 62152, 62156, 62157, 62159, 62164, 62166, 62168, 63055, 63056, 63057, 63101, 63103, 63104, 63105, 63106, 63107, 63108, 63110, 63112, 63113, 63115, 63116, 63117, 63118, 63119, 64049, C6NR7, LF3F, LF3N, LF4B, LF4C, LF4H, LF5T, MQSY9, MWYG6, PJGO

Buoys:
Moored buoy WMO#s (for alphanumeric codes) all end in 000-499 and drifters end in 500-999, see http://www.wmo.int/pages/prog/amp/mmop/wmo-number-rules.html

Moored buoys reporting in BUOY code were assumed to have anht=4 m as appropriate for TAO style buoys.
Moored buoys reporting in SHIP code were assumed to have anht=5 m (as appropriate for most North American buoys) except where otherwise specified.
Heights taken from http://www.ndbc.noaa.gov/bmanht.shtml (22 Sep 2008):
10 m: 41047, 41048, 42001, 42002, 42003, 46023, 46035, 46054.
unknown (taken as 5 m): 44070, 46071, 46073, 46076, 46081, 46085, 46105, 46106, 46107, 51101
European buoys (East of 20W) were taken to have anht = 3 m

In addition call signs starting BSH were classed as moored buoys, mostly with anht=3m assumed, except for the following:
BSH50 - 8 m, Fehmarnbelt
BSH51 - 10 m, Darsser Schwelle
BSH52 - 9 m, Oderbank
BSH54 - 10 m, Arkona Becken
The names were confirmed by Henry Kleta and anemometer heights taken from http://www.bsh.de/en/Marine_data/Observations/MARNET_monitoring_network/

Ship anemometer heights were taken from WMO Publication 47, either directly or estimated from the vessel type, as described in the text.

Although care has been taken some errors in anemometer height are inevitable.