Metadata from WMO Publication No. 47 and an Assessment of Voluntary Observing Ship Observation Heights in ICOADS

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ABSTRACT

It is increasingly recognized that metadata can significantly improve the quality of scientific analyses and that the availability of metadata is particularly important for the study of climate variability. The International Comprehensive Ocean–Atmosphere Data Set (ICOADS) contains in situ observations frequently used in climate studies, and this paper describes the ship metadata that are available to complement ICOADS. This paper highlights the metadata available in World Meteorological Organization Publication No. 47 that include information on measurement methods and observation heights. Changing measurement methods and heights are known to be a cause of spurious change in the climate record. Here the authors focus on identifying measurement heights for air temperature and wind speed and also give information on SST measurement depths.

1. Introduction

The International Comprehensive Ocean–Atmosphere Data Set (ICOADS; Woodruff et al. 1998; Parker et al. 2004; Worley et al. 2005) is a compilation of surface meteorological observations from Voluntary Observing Ships (VOS), buoys, and other in situ Ocean Data Acquisition Systems (ODAS). In this study we have used only reports from VOS made between 1970 and 2004. The accuracy of individual VOS observations is not consistently high, but they remain an important source of information over the ocean. In particular, VOS reports provide information on surface air temperature, near-surface humidity, and pressure that cannot be reliably measured from satellites. Additionally, ICOADS reports can provide collocated observations of all the variables required to calculate surface fluxes of heat and momentum. Importantly, they form a long-term data source giving information stretching back over 200 yr (Woodruff et al. 2005). Obviously, the data quality will vary dramatically over this long period, and biases and random errors in the data need to be assessed so consistent estimates of long-term climate variability and change can be made. Metadata are key to understanding many possible data biases in ICOADS and estimating random errors. However, some inhomogeneities must be addressed indirectly (e.g., Peterson and Hasse 1987), because the relevant historical metadata may no longer exist.

For the modern period, it has been shown that use of metadata is vital if we are to identify artificial trends in ICOADS due to changing ship size (Cardone et al. 1990; Rayner et al. 2003) and measurement methods (Kent et al. 1993a; Kent and Taylor 1997, 2006; Kent and Kaplan 2006). Cardone et al. (1990) used a limited amount of World Meteorological Organization (WMO) Publication No. 47 (mainly WMO 1976) anemometer height metadata in a study that showed that it was necessary to account for observing method to remove spurious trends in marine wind speeds. Rayner et al. (2003)

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applied time- and space-varying measurement height adjustments, based on Publication No. 47 for a recent period, to ICOADS air temperature measurements. These adjustments were shown to improve the agreement between air temperature and sea surface temperature (SST) anomalies. Kent et al. (1993a) analyzed a subset of North Atlantic observations in the period 1988–90. They showed that there were significant differences between humidities measured using screens and those using psychrometers; and between SST measured using engine room intakes, buckets, and hull sensors; and also that adjustment of the reported anemometer-measured winds for measurement height improved the agreement between the observations and collocated numerical weather prediction output. Kent and Taylor (1997) showed that adjustment of ship anemometer-measured wind speed observations for measurement height using Publication No. 47 improved the agreement between anemometer-measured and visually estimated monthly mean marine wind speeds in the North Atlantic. Kent and Taylor (2006) showed that there were significant differences between SST measurements made using buckets and using engine intakes, which Kent and Kaplan (2006) suggested could be related to heat loss in the bucket observations and to a time-varying bias in the engine-intake observations. Further, Kent and Berry (2005) showed that application of height adjustments based on Publication No. 47 metadata reduced the magnitude of random error estimates for ICOADS air temperatures by 6% and wind speeds by 13%.

In this paper we focus primarily on the metadata collected by the WMO in support of their VOS program (section 2a). A major motivation for this paper was to gather the documentation, which is largely unpublished and difficult to locate, necessary to use these Publication No. 47 metadata. Some additional metadata (section 2b) are also reported with the individual observations, including limited information on measurement methods, or recorded when the data are added to ICOADS, such as the (originally referring to punched cards) "deck" number. We have supplemented the Publication No. 47 and ICOADS metadata with some proprietary information from Lloyd's Register (1997), giving primarily information on ship type and size (section 2c). In section 3 we describe how the Publication No. 47 metadata are merged with ICOADS, and in section 4 we present information on observation heights. Section 5 contains a summary, and the appendix includes links to sources of metadata, ICOADS data, and technical documentation.

2. Metadata sources

a. WMO Publication No. 47 metadata

Since 1955 the WMO has collected information on the ships participating in the VOS program. These metadata, although collected for operational purposes, have proved an important resource for climate research (e.g., da Silva et al. 1994; Kent and Taylor 1997, 2006; Kent et al. 1998; Josey et al. 1999 Rayner et al. 2003; Rayner et al. 2006). The metadata have been made available in the WMO *International List of Selected, Supplementary and Auxiliary Ships,* known as Publication No. 47 (e.g., WMO 1994). From 1955 to 1964 the title was *International List of Selected and Supplementary Ships*. For much of its existence Publication No. 47 (hereafter Pub. 47) has been issued annually. In the period between 1963 and 1970 the metadata were issued as a combination of major editions (1963, 1966, and 1970) and supplements (1964, 1967, and two supplements in 1968). The supplements contain additions, deletions, and changes to the last major edition or supplement. From 1998 onward, Pub. 47 metadata have been issued quarterly in digital format. The annual paper publication now only contains a subset of the information available, as extra fields are contained in digital files submitted by the participating countries. Metadata for the period 1955–72 (WMO 1955, 1956, 1957, 1958, 1959, 1960, 1961, 1962, 1963, 1964, 1966, 1967, 1968a,b, 1970, 1971, 1972) were recently digitized as part of the National Climatic Data Center (NCDC) Climate Database Modernization Program (CDMP) and are available both as images and in machine-readable form. All the full editions are available, but whether the supplements are complete is unclear. WMO (1964, 1967, 1968a,b) are all supplements, but only WMO (1964) is available as issued. WMO (1968a,b) can be identified because a copy of WMO (1966) with the WMO (1967, 1968a) supplements added and an additional copy of WMO (1966) with the WMO (1967, 1968a,b) supplements added are available. For a fuller record a further copy of WMO (1966) with only the WMO (1967) supplement added would be required but has not yet been identified. Other supplements (perhaps for 1965) may have been issued, but no copies have been identified. Pub. 47 was originally regarded as of purely operational use, so recipients were urged to keep up-to-date by applying all supplements and keeping only current information. It is therefore remarkable that the Pub. 47 metadata are almost complete.

Table 1 summarizes the metadata variables that are available from Pub. 47 since 1955. Table 2 gives more information about some of the fields and the categories

TABLE 1. Fields (and abbreviations) of Pub. 47 metadata. Dates in the column headings refer to years that the Pub. 47 format changed; nonblank entries under each year indicate the introduction (or continued availability) of a field; x indicates that the format allows space for information (in general terms) for a field, whereas a number indicates that the format allows space for information on one or multiple sensors. More information on selected fields and their codes is given in Table 2. Information in italics refers to fields in the proposed metadata format (JCOMM 2004), which are not yet available.

Field	Abbrev.	1955	1956	1957	1968	1970	1995	2002	Proposed
Pub. 47 format version	*Ver*								*x*
Name	Name	x	x	x	x	x	x	x	x
Call sign	Call	x	x	x	x	x	x	x	x
IMO No.	IMOn							x	x
Recruiting country	Rcnty	x	x	x	x	x	x	x	x
Country of registration	*Reg*								*x*
Type of VOS	VsslM	x	x	x	x	x	x	x	x
Routes	Rte	All	All	All	All	10	10	10	10
Change date	Chgd							x	x
Length	lenvsslD						x	x	x
Breadth	brdvsslD						x	x	x
Freeboard	frbvsslD						x	x	x
Draft	drfvsslD							x	x
Cargo height	chtvsslD							x	x
Distance of bridge from bow	Brdg							x	x
Vessel type	Vssl						x	x	x
Digital image	VsslP							x	x
Automation of observation	Atm							x	x
Frequency of observation	*Freq*								*x*
AWS type	*awsM*								*x*
AWS processing software	*awsP*								*x*
AWS entry/display software	*awsC*								*x*
Electronic logbook software	*loge*								*x*
Baseline check	Blc							x	x
Barometer type	Barm	All	All	All	All	2	2	2	2
Barometer model	bMS							2	2
Barometer height	brmH						2	2	2
Barometer location	brmL							2	2
Pressure units	brmU							2	2
Barometer calibration date	brmC							2	2
Thermometer type	Thrm		All	All	All	2	2	2	2
Thermometer model	thMS							2	2
Thermometer exposure	thmE		All	All	All	2	2	2	2
Thermometer location	thmL							2	2
Thermometer height	thmH							2	2
Temperature scale	Tscale							2	2
Hygrometer type	Hygr	All	All	All	All	2	2	2	2
Hygrometer exposure	hgrE		All	All	All	2	2	2	2
SST method	sstM	All	All	All	All	3	2	2	2
SST depth	sstD						2	2	2
Barograph type	Barg	All	All	All	All	2	2	2	2
Anemometer height	anHL					1	1	2	2
Anemometer height above deck	anHD							2	2
Anemometer location	anmL							2	2
Anemometer distance from bow	anDB							2	2
Anemometer distance from centerline including port/starboard indicator	anDC							2	
Anemometer distance from centerline	*anDC*								*2*
Anemometer port/starboard indicator	*anAC*								*2*
Anemometer instrument type and model	anmI							2	
Anemometer instrument type	*anmT*								*2*
Anemometer make and model	*anmM*								*2*
Wind observing practice	anmU							1	1
Anemometer calibration date	anmC							2	2
Visual wind/wave observation height	wwH							1	1
Platform height	platH				x	x			

TABLE 1. *(Continued)*

Field	Abbrev.	1955	1956	1957	1968	1970	1995	2002	Proposed
Other meteorological instruments on board	othI	All	All	All	All	7	6	6	6
Radio telephony and telegraphy	phGr						2	5	
Teleprinter and satellite	prSt						5	5	
Radio-telephony and satellite	phGr								5
Radio transmitters (frequency)			x						
Radio transmitters (coded)				x	x	x			
No. of radio operators	noRadOp		x	x	x	x			
Field abbreviation	fieldAbrev						3	10	10
Footnote ID (field number)	footed								10
Footnote ID (character)	footed						3	10	
VOS recruitment date	*vosR*								*x*
VOS derecruitment date	*vosD*								*x*
VOSClim recruitment date	*vclmR*								*x*
VOSClim derecruitment date	*vclmD*								*x*

that can be coded. From these tables we see that the content of Pub. 47 has evolved since its introduction. The first edition in 1955 contained the ship name and call sign, the recruiting country, whether the ship was a reporting as a selected or supplementary ship, and the routes that the ship normally plied. The instrumental information comprised the type of barometer, hygrometer (including some exposure information), and barograph, and the method of SST measurement. There is a column for information on "other instruments carried," which include, for example, screen thermometer, cup anemometer, maximum and minimum thermometer, sling thermometer, rain gauge, handheld anemometer, pilot balloon theodolite, sea thermometer, and sea thermograph. In 1956 fields for the type and exposure of the thermometer and the exposure of the hygrometer were added, along with information on ships' communications (see Table 2 for details). Additional instruments carried by the ship, and most other fields, were transitioned from free format to coded format. Revisions to the communications fields were made in 1957. In 1968 the height of the observing platform was added (reference level of mean water line) and in 1970 the height of the anemometer (reference level undefined). In 1995 several changes were introduced, and information on the ship type and dimensions was added, along with information on the barometer height and SST measurement depth. Unfortunately for continuity, the height of the measurement platform was dropped. The reference level for all instrument heights was redefined as the maximum load line. In 2002 major changes to the format occurred, with the addition of extra fields containing information about instrument makes, models, and locations (see Table 1 for more information). The Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) Expert Team on Marine Climatology (ETMC) in 2004 considered a recommendation from the VOS Panel of the JCOMM Ship Observations Team (SOT) and approved further changes to Pub. 47 (JCOMM 2004). These are also summarized in Table 1 but are yet to be finalized in consultation with the WMO Secretariat.

b. ICOADS metadata

Metadata reported with the ICOADS observations are more limited than Pub. 47 but more convenient to use, as the metadata are directly associated with individual observations rather than with the ships or platforms that made them. The originally reported (or ICOADS-defined) metadata include: the deck number, platform type, wind speed indicator (WI), SST measurement method indicator (SI), recruiting country code, the platform ID/call sign and its associated indicator (II), observation source, observation platform, and quality assurance trimming flags (Wolter 1997; see also Slutz et al. 1985 and Woodruff 2005). ICOADS "observation platform" information ties into Pub. 47 since it indicates, among other possibilities, whether the ship was selected, supplementary, or auxiliary. The ICOADS "observation source" gives information on whether the report is from a logbook or the Global Telecommunication System (GTS). The ICOADS deck information (Worley et al. 2005) has been shown to be an indicator of data quality, as have the country code and SI (Kent and Challenor 2006). For wind speed measurements, it is desirable to identify using WI those reports that require height adjustment and those that require Beaufort scale adjustment (Kent and Taylor 1997; Thomas et al. 2005).

Although the ICOADS metadata fields are conveniently associated with individual reports, some values

TABLE 2. Additional information on selected fields (from Table 1) of Pub. 47 metadata. More detailed field descriptions are provided in column 2, and the information that can be encoded in some of the fields is detailed in column 3. We have been unable to locate Pub. 47 documentation providing the exact meaning and specifications associated with each metadata term, but publications such as WMO (1983) or national observing instructions may be relevant. Fields and categories in italics are proposed additions and changes (JCOMM 2004).

Field	Description	Coded categories available
Pub47 format version	*Metadata format version*	*Version 0: 1955, version 1: 1956–1994, version 2: 1995–2001, version 3: from 2002, version 4: proposed*
Name	Ship name	
Call sign	Ship call sign	
IMO No.	Unique ship identification number	
Recruiting country	Country that recruited the ship to the VOS program	
Country of registration	*Country of registration (flag)*	
Type of VOS	VOS program*	Selected, supplementary, or (from approximately 1961) auxiliary
Routes	Ship's expected routes and regions of operation	Codes specific to each recruiting country
Change date	Date of last change to metadata	
Length	Length overall of the ship, ignoring bulbous bow	
Breadth	Molded breadth, the greatest breadth amidships	
Freeboard	The average height of the upper deck above the maximum summer load line (MSLL)	
Draft	The average depth of the keel below the MSLL	
Cargo height	Maximum cargo height above the MSLL	
Vessel type		Barge, bulk carrier, coast guard, container ship, dredger, passenger ferry, fishing vessel, general cargo, liquefied gas tanker, liquid tanker, light vessel, military ship, ocean weather ship, passenger ships, ro-ro ferry, ro-ro cargo, refrigerated cargo, research ship, support vessel, trawler, tug, yacht, [*cable ship, floating production/storage unit, icebreakers, livestock carrier, mobile installation, pipe layers, large sailing vessel, vehicle carrier*]
Digital image	Indicates availability of ship and instrument pictures	
Automation of observation	General observing practice	Fully automated, always supplemented by manual input, occasionally supplemented by manual input, unknown, fully manual
Frequency of observation	*Scheduled frequency of reports*	
AWS type	*Make and model of the automatic weather station (AWS)*	
AWS processing software	*Name and version of the AWS processing software*	
AWS entry/display software	*Name and version of the AWS data entry/display software*	
Electronic logbook software	*Name and version of the electronic logbook software*	
Baseline check	Baseline check of AWS operation	
Barometer type		Aneroid, ship's aneroid, mercury, digital aneroid, electronic
Barometer model	Make and model of barometer(s)	
Barometer height	Barometer height(s) above MSLL	
Barometer location		[*Unpressurized*] wheelhouse, chart room, [*pressurized wheelhouse*]
Barometer calibration Date	Last barometer calibration date(s)	
Thermometer type	Type of dry-bulb thermometer(s)	Mercury, electric resistance, or alcohol
Thermometer model	Make and model of thermometer(s)	
Thermometer exposure		Screen (not ventilated), screen (ventilated), sling psychrometer, whirling psychrometer, aspirated (Assmann) psychrometer, unscreened, ship's sling, ship's screen

TABLE 2. *(Continued)*

Field	Description	Coded categories available
Thermometer location	Location of dry-bulb thermometer(s) and hygrometer(s)	
Thermometer height	Thermometer and hygrometer height(s) above MSLL	
Temperature scale	Reporting practice for thermometer(s) and hygrometers(s)	Centigrade to tenths, half degrees centigrade, whole degrees centigrade, whole degrees Fahrenheit, Fahrenheit to tenths, dry-bulb centigrade and wet-bulb Fahrenheit, dry-bulb Fahrenheit and wet-bulb centigrade
Hygrometer type		Hair hygrometer, psychrometer, electric, capacitance, chilled mirror, torsion, hygristor
Hygrometer exposure		As thermometer exposure
SST method	Method(s) of measuring SST	Bucket and thermometer, condenser or engine intake, trailing thermistor, hull contact, through hull, radiation thermometer, bait tanks thermometer
SST depth	Depth(s) of SST sensors below MSLL	
Barograph type	Type(s) of barographs or method of determining pressure tendency	Open scale or small scale with type of clock if not 7 day (e.g., 1 day), [*tendency from electronic digital barometer*]
Anemometer height	Anemometer height(s) above MSLL	
Anemometer height above deck	Height of anemometer(s) above deck on which it is installed	
Anemometer location		Not fitted, mainmast, mainmast port yardarm, mainmast starboard yardarm, aft mast, foremast, foremast port yardarm, foremast starboard yardarm, mast on wheelhouse top, mast on wheelhouse top port yardarm, mast on wheelhouse top starboard yardarm, handheld
Anemometer instrument type	*Type(s) of anemometer*	[*Anemograph, combined cup anemometer and wind vane, separated cup anemometer and wind vane, handheld anemometer, propeller vane, sonic anemometer*]
Anemometer make and model	Makes and models of anemometer(s)	
Wind observing practice		Anemometer (true wind computed), anemometer (true wind manual), visual estimate (sea state), either visual estimate (open sea) or anemometer (near port)
Anemometer calibration date	Last calibration date for anemometer(s)	
Visual wind/wave observation height	Height above the MSLL of the visual observing platform	
Platform height	Height above the mean water line of the visual observing platform	
Other meteorological instruments on board		Bathythermometer, BT (towed), handheld anemometer, longwave radiation, max thermometer, min thermometer, pilot balloon equipment, radiosonde equipment, rain gauge, radar storm and meteorological phenomena detection, reversing thermometer, sea thermograph, shortwave radiation, temperature–salinity–depth probe, radiowind or radarwind equipment, XBT, [*fluorometer, nitrate sensor, nutrient sensor, pCO2 system, plankton recorder, photosynthetic radiation sensor, pyrogeometer, sky camera, solarimeter, sonic anemometer, turbidity sensor*]
Telecommunications	The fields for telecommunications equipment have varied over the years	

TABLE 2. *(Continued)*

Field	Description	Coded categories available
Footnotes	Footnotes allow the input of free format information and are usually associated with a particular field, e.g., giving information if "other" has been coded	

* Selected ship: A mobile ship station equipped with sufficient certified meteorological instruments for making observations and that transmits weather reports in the full SHIP code. In addition, the observations are entered into meteorological logbooks. A selected ship should have at least a barometer, a thermometer for SST, a psychrometer, a barograph, and possibly an anemometer.
Supplementary ship: A mobile ship station equipped with a limited number of certified meteorological instruments for making observations and that transmits the weather reports in an abbreviated SHIP code form. The observations are entered into meteorological logbooks (WMO 1982).
Auxiliary ship: A mobile ship station normally without certified meteorological instruments that transmits reports in a reduced code or in plain language, either as a routine or on request, in certain areas or under certain conditions (WMO 1982).
Note that, although the category of auxiliary ship only officially appeared in the title in 1966 (and then only on the cover and not the title page), some countries had added information on ships other than selected and supplementary in earlier editions, e.g., in 1956 the United Kingdom includes ships reporting in coastal waters using the shortened format "MARID" code, and the Federal Republic of Germany lists trawlers in a separate category, and also, in 1961, New Zealand started reporting auxiliary ships as a separate category.

can be missing, or may be unreliable, for individual reports or for data from particular sources or in particular periods. One example is the SI, which Kent and Taylor (2006) showed required supplementation with Pub. 47 metadata, particularly in the period before 1982. Similarly, problems and ambiguities are likely to exist in earlier wind speed indicators (e.g., Cardone et al. 1990), resulting from the way WI was historically coded in some sources: "blank" for estimated and "zero" for measured, with no allowance for a "missing" indicator. This problem has filtered down into some ambiguous or "unknown" WI values in ICOADS. Pub. 47 metadata could be used in the future to identify systematic problems with the ICOADS metadata, and possibly vice versa.

c. Lloyd's Register metadata

The freely available metadata have been supplemented with proprietary information purchased from *Lloyd's Register of Shipping* (Lloyd's Register 1997), which contains information on some ships back to 1764. Lloyd's metadata do not give any information about instruments but do give information on ship type and dimensions prior to 1995, when these fields were introduced into Pub. 47 (Table 1). Although Lloyd's has digitally stored information on every ship in service since the 1970s we have difficulty matching the Lloyd's metadata, which are indexed by International Maritime Organization (IMO) number, to ICOADS, in which reports from a particular ship are identified using the platform ID. For ships in recent years this ID is usually the radio call sign (Fig. 1), although different types of ship ID are used within ICOADS [e.g., national ship number or generic ID; see Woodruff (2005) for more information]. Lloyd's metadata include call sign as a current field but without historical information. The Lloyd's metadata have only been matched to ICOADS for the period when the current call sign is valid. This can be determined from the "flag of registry" information (which is stored by Lloyd's as a historical field), as the call sign changes when the country of registry changes. Lloyd's metadata do contain the ship name as a historical field, and it may, with some effort, in the future be possible to extend the matching using a combination of historical ship identification information in Pub. 47 (call sign and ship name), ICOADS (call sign or other ship identifier and sometimes ship name), and Lloyd's (ship name).

d. Additional historical metadata sources

Other sources we can appeal to for information on measurement methods and instrument types include

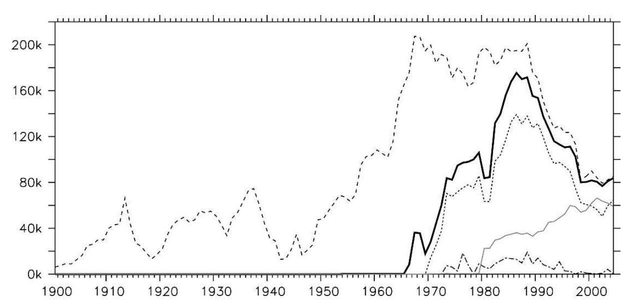

FIG. 1. Annual mean number of reports per month in ICOADS between 1900 and 2004: number of ship reports (dashed), number of ship reports with valid call sign (from ICOADS II indicator) (bold), total number of ship reports matched to WMO Publication No. 47 (dotted), number of ship reports matched to following year's edition of Pub. 47 (dot–dash), number of ship reports matched to Lloyd's metadata (gray).

the instructions to observers issued by the National Meteorological Agencies (e.g., NOAA/NWS 2004; Met Office 1977, 1995). These sources (some of which extend back prior to the twentieth century) have not been used in the present study but will be a valuable source of information for periods when it is difficult to identify individual ships in ICOADS. In the 1950s and earlier most of the ship data are associated with national deck numbers (Woodruff et al. 2005), so it may be possible to assign a likely measurement method to these reports based on surviving deck documentation and typical national practices. In addition to Lloyd's Register (1997), other published metadata on ship dimensions may exist.

3. Combining metadata with ICOADS

The ship identifier common to both ICOADS and Pub. 47 is the call sign, which is used to match individual ship reports, identified within ICOADS via the platform ID, with the published metadata. Call sign information in ICOADS first appears in the 1960s (Fig. 1), around when the GTS was being initiated, followed by steady increases in availability into the 1980s (when numbers of VOS observations begin to decline). Earlier data may contain other forms of platform ID (as discussed in section 2c), which are useful for tracking ships to identify mispositioned reports (Kent and Challenor 2006) but cannot directly be used to associate metadata with individual reports. Once call sign information is available, much of the ship data in ICOADS can be associated with the Pub. 47 metadata (Fig. 1).

There is sometimes a delay between the ship being recruited and starting to make observations and the metadata being submitted by the recruiting country to the WMO and appearing in Pub. 47. It was therefore found necessary to check Pub. 47 for the succeeding year or quarter if no call sign match were found in the concurrent year or quarter. Figure 1 shows the number of reports matched to metadata from the year following the year of the report. The number of reports unmatched in the concurrent year increases toward the end of each year as more new ships are recruited, and the metadata become progressively more out of date. However, the availability, starting in 1998, of quarterly digital updates should help (possibly influencing the matching patterns shown in Fig. 1 starting in the late 1990s). It should be possible in the future to improve both the ease of use of the metadata and their completeness by copying delayed metadata into the previous year. It will also be possible to backfill information from some fields. For example, in 1995 the ship length became available as a metadata field. This information could be inserted into previous metadata files, extending our knowledge of ships' characteristics further back in time.

Figure 2 shows examples of the information available from combining the Pub. 47 metadata with ICOADS. The most common (known) method of air temperature measurement is to use a mercury thermometer exposed in either a screen or a sling psychrometer (Figs. 2a,b). The thermometers are also exposed in ventilated screens, and in aspirated and whirling psychrometers (Fig. 2a). Alcohol thermometers are sometimes used, and electric thermometers are becoming more common (Fig. 2b). The same exposure methods are used for measuring the dewpoint temperature (Fig. 2c), but the proportion using screens is smaller than for air temperature. Psychrometric methods are typically used (Fig. 2d), but, again, electric sensors are becoming more common. Most pressure measurements are made using aneroid barometers, with digital aneroid barometers becoming more common over time (Fig. 2e). In the 1970s a few reports were made using mercury barometers.

As noted in section 2b, Kent and Taylor (2006) showed that for SST measurement method the supplementation of SI with Pub. 47 metadata enabled many more SST reports to be assigned a measurement method. Figure 2f shows the measurement method information using the ICOADS SI flag when available, or the Pub. 47 metadata in the absence of useful SI flag information. Bucket and engine-intake temperatures are the most common methods identified over the period 1970–2004. Hull sensors are becoming more common and outnumber bucket observations by the end of the period. Figure 2g shows the source of the SST metadata shown in Fig. 2f; the proportion of metadata derived from the ICOADS SI flag increases over time, and by 2000 almost all of the SST reports have an associated flag. Figure 2h shows the extent to which the SST metadata are available from only one source, or, for those reports with information from both Pub. 47 and the SI flag, it shows the extent to which the metadata disagree.

As the Pub. 47 metadata are applied to all reports for individual ships in a particular period (either year or quarter), changing measurement practice, from one observation to the next, cannot be accounted for. For example, some ships may usually make bucket reports of SST but in poor weather or busy periods may report the engine-room-intake SST. While unavailable from Pub. 47, this information on variable observing practices can be accounted for using the ICOADS SI flag. Starting around 1995 (Fig. 2h) there is an increase from around 20% to 40%–50% in the proportion of reports for

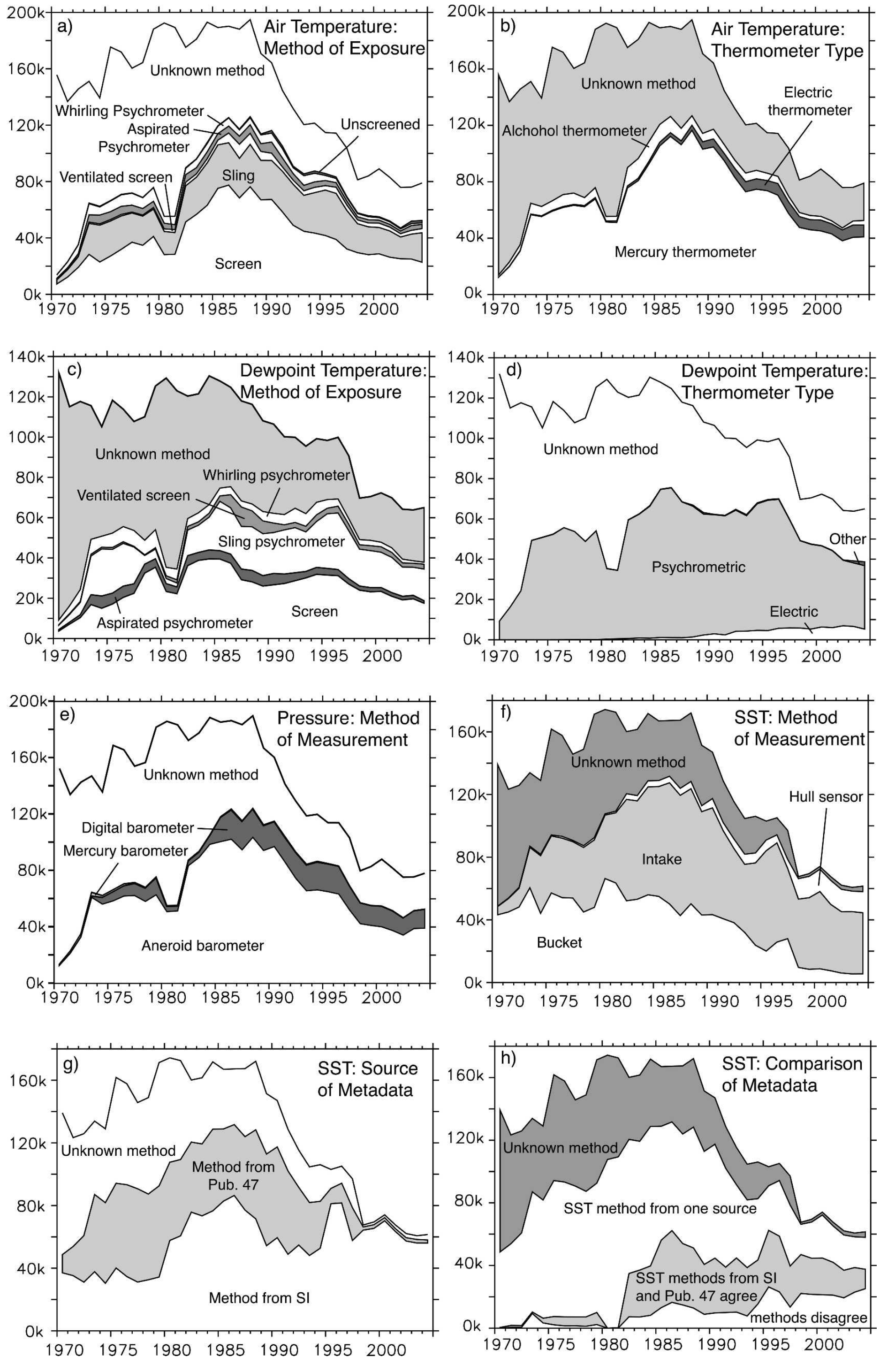

FIG. 2. Annual average numbers of observations per month in ICOADS for 1970–2004, stratified by the availability of measurement method metadata. The known methods for air and dewpoint temperatures and pressure [(a)–(e)] are all from Pub. 47, whereas those for SST [(f)–(h)] are from Pub. 47 or ICOADS.

which the metadata disagree. This coincides with the introduction in 1995 of multiple fields in Pub. 47 for SST (and other) sensors (see Table 1). As there was no instruction as to how to designate different sensors as "sensor 1" and "sensor 2," there is no guarantee that the most commonly used sensor is designated as sensor 1. This is particularly important for SST, as the sensors are usually of different types. For temperature and humidity the sensors are usually the same but located on different sides of the ship to ensure good exposure from at least one sensor. Despite these problems there is useful information in the Pub. 47 SST metadata (Kent and Taylor 2006; Kent and Kaplan 2006).

In addition to these problems with Pub. 47 metadata and with the ICOADS metadata (section 2b), it should be noted that the Lloyd's metadata can also contain errors. An example of this was the one ship in ICOADS identified as a barge using the Lloyd's metadata. The ship dimensions seemed too large for a barge, and an Internet search revealed photographs that showed that the vessel was actually a container ship. It is expected, however, that the metadata from all these sources are largely correct and when taken for ICOADS as a whole improve our understanding of the characteristics of the ships making the observations. Furthermore, overlaps between the metadata sources (e.g., between Lloyd's and Pub. 47) may allow further cross-validation in the future.

An important new development is that a subset of WMO Pub. 47 metadata has been made available blended with ICOADS individual observations, initially for the period 1973–2005. After the individual ICOADS observations were matched by ship call sign with the Pub. 47 metadata for the concurrent or following edition as described above, the selected and edited metadata were stored in a new attachment to the International Maritime Meteorological Archive (IMMA) format (Woodruff 2005). This makes readily available to other researchers both the selected Pub. 47 metadata and ICOADS observations.

4. Measurement heights

a. Air temperature

It is important to adjust air temperature observations before analysis to a standard reference height, usually 10 m (Rayner et al. 2003). (Surface pressure observations, in contrast, should have been adjusted for height before transmission or entry into the logbook.) No information on measurement height is available in ICOADS, so we rely on information in Pub. 47. The field for thermometer height was introduced in 2002; before this time it is necessary to use proxy information

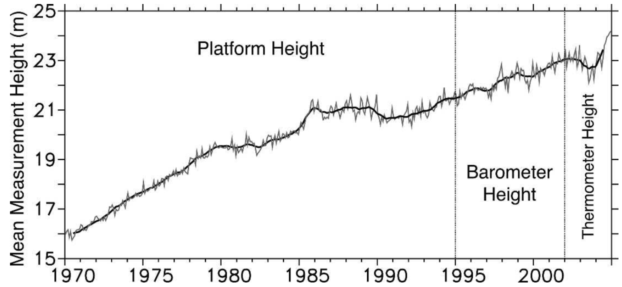

FIG. 3. Global mean of all available 2° area average observation heights (m) from a combination of ICOADS reports and Pub. 47 metadata. Gray line shows monthly averages; bold line plots the same data smoothed with a 12-month running-mean filter; vertical dotted lines indicate the dates of availability of three different measures of observing height: platform height, barometer height, and thermometer height.

to estimate the measurement height for air temperature. Table 1 shows that the first height field to be included is the "platform height," available from 1968 to 1994. In 1995 this was replaced by the "barometer height," and in 2002 the "thermometer height" was introduced.

Figure 3 shows a time series of global average ICOADS temperature measurement height using Pub. 47 metadata. The periods of availability of each of the three different estimates of temperature measurement height are indicated, and no discontinuities are apparent. If the barometer and screen or psychrometer are all in the bridge and the visual observation of sea state is made from a protruding bridge wing, then all the measurement heights should be similar. On some ships with remote readouts the air temperature sensor may be on top of the bridge (perhaps 2–3 m above a barometer located on the bridge), whereas for ships with research quality installations the sensor may be on a mast (perhaps 10 m higher than the bridge location). Remotely read sensors, and hence the ability to have sensors at a variety of different heights and away from the bridge, have become more common over time. Inspection of the Pub. 47 metadata for October–December 2004 showed that for 88% of the 746 ships reporting both barometer height and air temperature measurement height the two heights were within 1 m of each other. For 95% of these ships the heights were within 2 m. Overall, the mean difference (air temperature measurement height − barometer height) was 0.1 m, with a standard deviation of 1.4 m. The sensitivity of air temperature to measurement height is approximately 0.01°C m^{-1}, so the use of different air temperature measurement height estimates in different periods is not ideal but for most ships should not cause large biases. Global mean air temperature measurement height

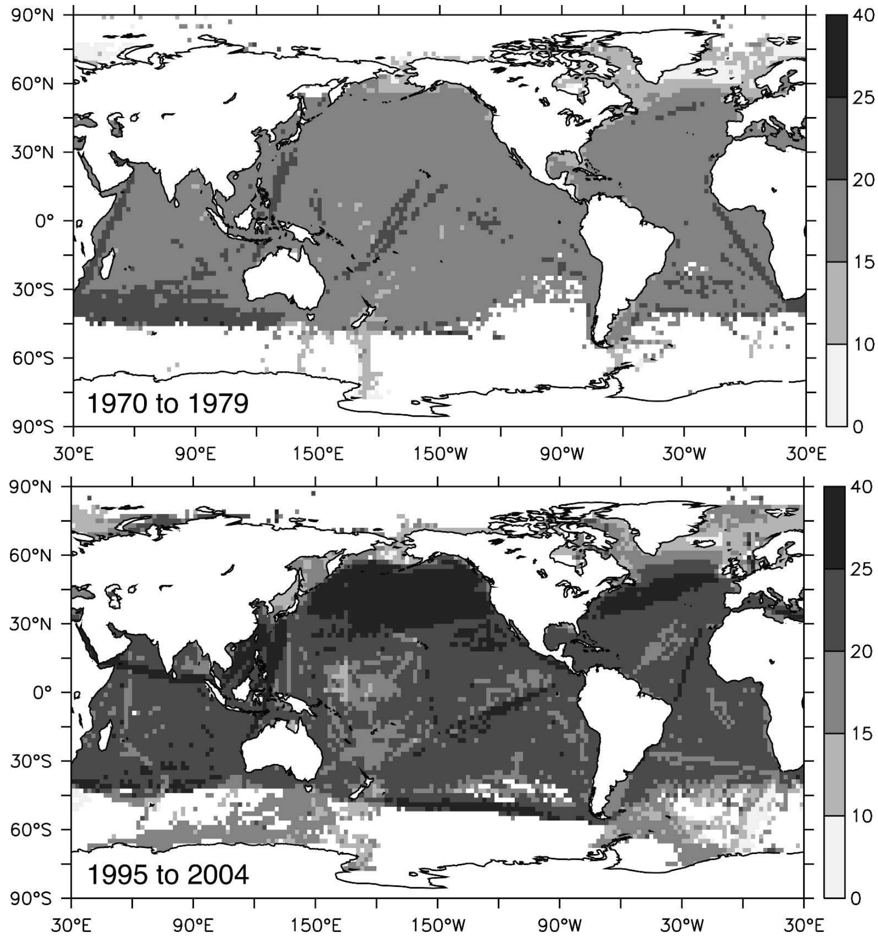

FIG. 4. The 2° area average air temperature measurement height (m) from Pub. 47 and ICOADS averaged over the periods (top) 1970–79 and (bottom) 1995–2004. Measurement height information is derived from different Pub. 47 metadata elements in different periods (platform height from 1970 to 1994, height of the barometer from 1995 to 2001, and air temperature measurement height from 2002 onward).

has increased by 7 m between 1970 and 2004. If this increase in height were not accounted for there would be a cold bias in modern air temperatures, relative to 1970 values, of about 0.07°C. Figure 4 shows 2° latitude by 2° longitude averages of measurement height for the periods 1970–79 and 1995–2004. As in Fig. 3, we see that the measurement heights have increased over the period 1970–2004, but we can also see significant spatial variations. The largest measurement heights are seen in the midoceans and major shipping lanes. High-latitude northern regions show extremely low measurement heights.

Figure 5 shows the distribution with latitude of different types of VOS in the period 2000–2002. Container ships are widely distributed and are the most common contributors of VOS reports. Also widely distributed are reports from general cargo ships, liquid/gas tankers, bulk carriers and ro-ro (roll-on, roll-off), and refrigerated ships. Research vessels make up a significant contribution to observations in the high northern latitudes and dominate south of 30°S. Fishing vessels and trawlers also make strong contributions in the high latitudes, influencing the relatively low measurement heights in these regions (Fig. 4). Ships of unknown or other (relatively uncommon) types make a significant contribution to the VOS reports at all latitudes, but particularly in the northern high latitudes (Fig. 4).

Figure 6 shows the average ship length in ICOADS derived from a combination of Lloyd's and Pub. 47 metadata over the period 1980–2004. In the major shipping lanes the mean ship length is more than 200 m. Away from the major shipping lanes the mean ship lengths tend to be smaller but are more variable. The smallest mean ship lengths are found in coastal regions

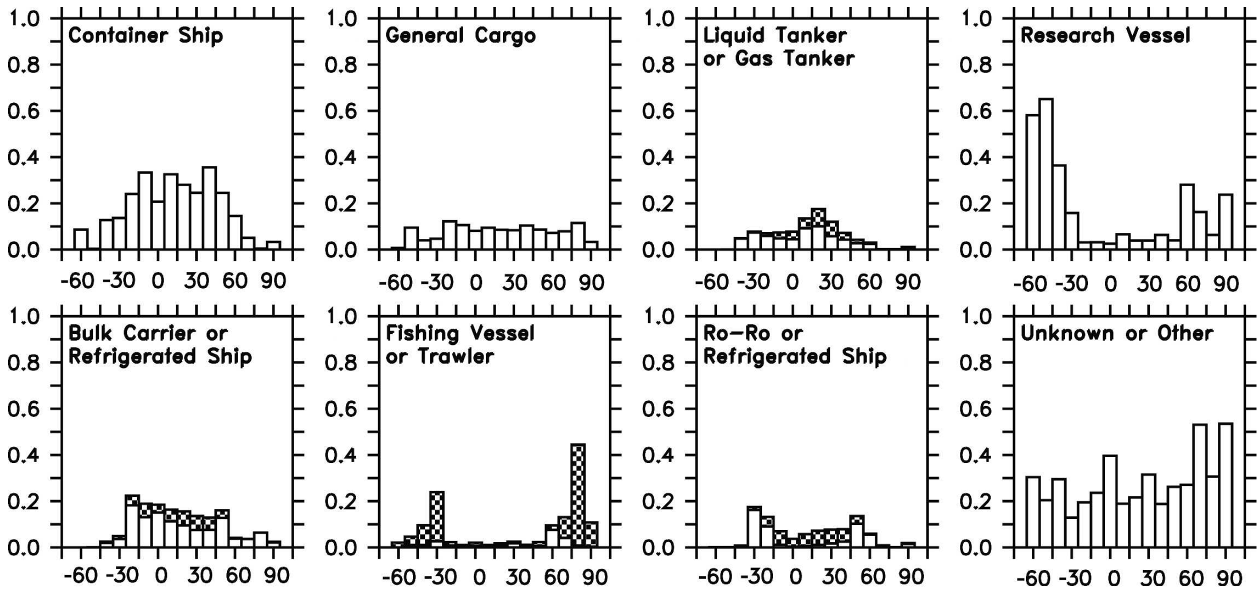

FIG. 5. The distribution with latitude of the 10 ship types most frequently contributing to ICOADS between 2000 and 2002 and of the remainder (including unknown) ship types. The contributions of gas tankers, refrigerated ships, and trawlers are indicated with checkered bars, other types with simple bars. The height of each bar represents the fraction of reports in the 10° latitude band with a particular ship type, and, for those panels where two ship types are shown, they are plotted cumulatively.

and in the northern high latitudes, where mean ship lengths are below 100 m.

Figure 7 shows the relationship between ship length and air temperature measurement height in ICOADS using Pub. 47 and Lloyd's metadata. Longer ships tend to measure air temperature at greater heights, but there is significant variation. The ships reporting in ICOADS between 1980 and 2002 that we can identify are fairly uniformly distributed in length between 50 and 300 m. Platform heights typically range from about 10 m to about 40 m, with a distribution that is more peaked than that of the ship lengths. The ellipses plotted in Fig. 7 show diagrammatically the typical variation of platform height with ship length.

Figure 8 shows the relationship between ship length and platform height separately for the most frequently reporting VOS types in ICOADS. The platform height and ship lengths vary significantly among the ship types (Table 3). Container ships, liquid tankers, bulk carriers, and gas tankers are the largest ships, typically more than 200 m long. Research vessels, fishing vessels, trawlers, tugs, support vessels, tenders, Coast Guard

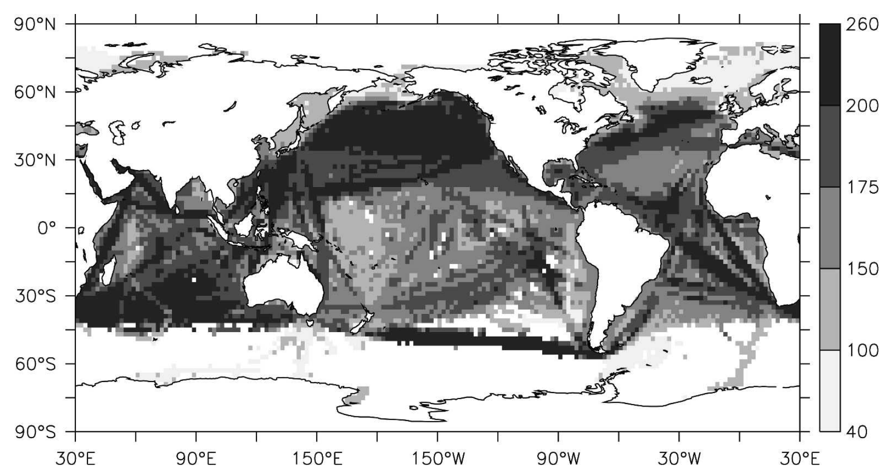

FIG. 6. The 2° area average ship length (m) from a combination of Lloyd's and Pub. 47 metadata averaged over 1995–2004.

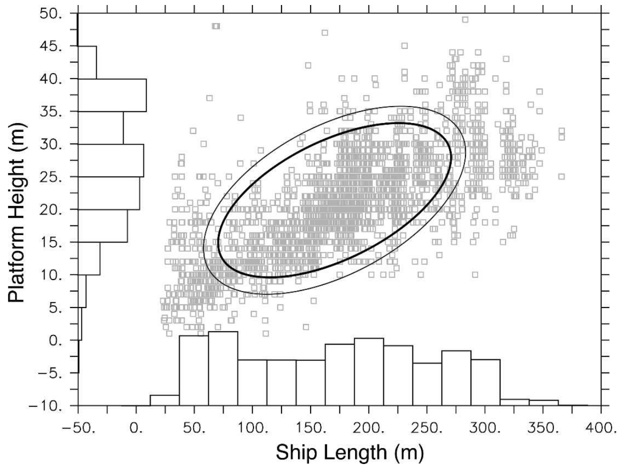

FIG. 7. The variation of measurement height (m) with ship length (m) in the period 1980–2002. Open squares show all ship length and platform height pairs identified in ICOADS from Pub. 47 and Lloyd's metadata. The histograms represent the normalized distribution of the same information. The inner ellipse has axes spanning two standard deviations (range between first and fifth sextiles), is centered on the median values, and has an orientation along the height vs ship length regression line. The outer ellipse has axes of length spanning the 10th and 90th percentiles in measurement height and ship length.

vessels, and yachts are all typically less than 100 m long. There is a reasonable correspondence between ship length and platform height, with larger ships typically measuring at greater heights. The increase over time in mean measurement height (Fig. 3) is most likely due to an increase in ship size rather than an increase in measurement height on ships of a given size (not shown). There are differences in the ship length–platform height relationship between different ship types. The smallest ships (research vessels, fishing vessels, and trawlers) tend to have the greatest relative measurement heights (Fig. 8, Table 5). Information on the ship type and size, where available from Lloyd's, should allow an improved estimate of platform height for VOS without entries in Pub. 47. Figure 9a shows the numbers of ICOADS ship reports with and without Pub. 47 measurement height information. For reports lacking the Pub. 47 information, it also shows those with ship length and type available from Lloyd's metadata. For these ships it will be possible to improve on simple default estimates of measurement height based only on platform type (e.g., as used by Josey et al. 1999) using the ship length and type and the relationships shown in Fig. 8.

Information on the height of air temperature measurement is important for removing bias in the air temperature observations, but other sources of bias remain. Air temperatures measured on board ship are known to be biased warm by solar radiative heating of the ship's environment (e.g., Folland 1971; Kent et al. 1993b), often leading to the exclusion of daytime observations from gridded datasets (e.g., Rayner et al. 2003). Recently Berry et al. (2004) developed a model to correct these biases. Berry and Kent (2005) showed that biases are larger when the air temperature screen is poorly exposed and the airflow past the sensor is restricted.

b. Wind speed

Wind speeds reported by the VOS are either measured using an anemometer or estimated from the sea state, usually according to the preference of the country recruiting the VOS [see Thomas et al. (2005) for more information on VOS wind measurement]. The WI metadata field (section 2b) within ICOADS indicates (if available) whether the wind speed is measured or visually observed. For anemometer winds the true wind speed must be calculated on board ship from the measured wind speed and direction and the ship's speed, direction, and heading. It should be noted that on board the ship instantaneous values of the ship motion parameters are used rather than the reported values of ship speed and course made good over last 3 h. There is evidence that the calculation of true wind is sometimes not performed correctly (Kent et al. 1993a; Gulev 1999; Smith et al. 1999). The anemometer wind speeds also need to be adjusted for the height of measurement to remove inhomogeneity (Cardone et al. 1990; Thomas et al. 2005). The height adjustment of VOS wind speeds has been problematic over the years. Dobson (1981), in a report commissioned by the WMO, recommended that true wind speeds [calculated from ship-relative wind speed and direction using the ship's speed, course and heading (e.g., Smith et al. 1999)] be reported or transmitted by the ship without adjustment to account for measurement height on board the ship. He also recommended that additional supplementary information should be collected to allow for adjustment for both height and flow distortion by the end user using the best estimates of biases available at the time. However, a subsequent WMO report (Shearman and Zelenko 1989) recommended a method for reducing the measured wind speed to a 10-m reference height "at the time of observation or soon after." WMO policy has apparently been that a wind speed adjusted to 10-m height should be reported by the ship; however, the status and date of introduction of the policy is unclear. The policy may have been introduced (or just recommended) in 1946: "The Committee recommends that the standard height for which the surface wind speed is given in the coded reports should be 10 meters" (International Meteorological Committee 1946). It is noted

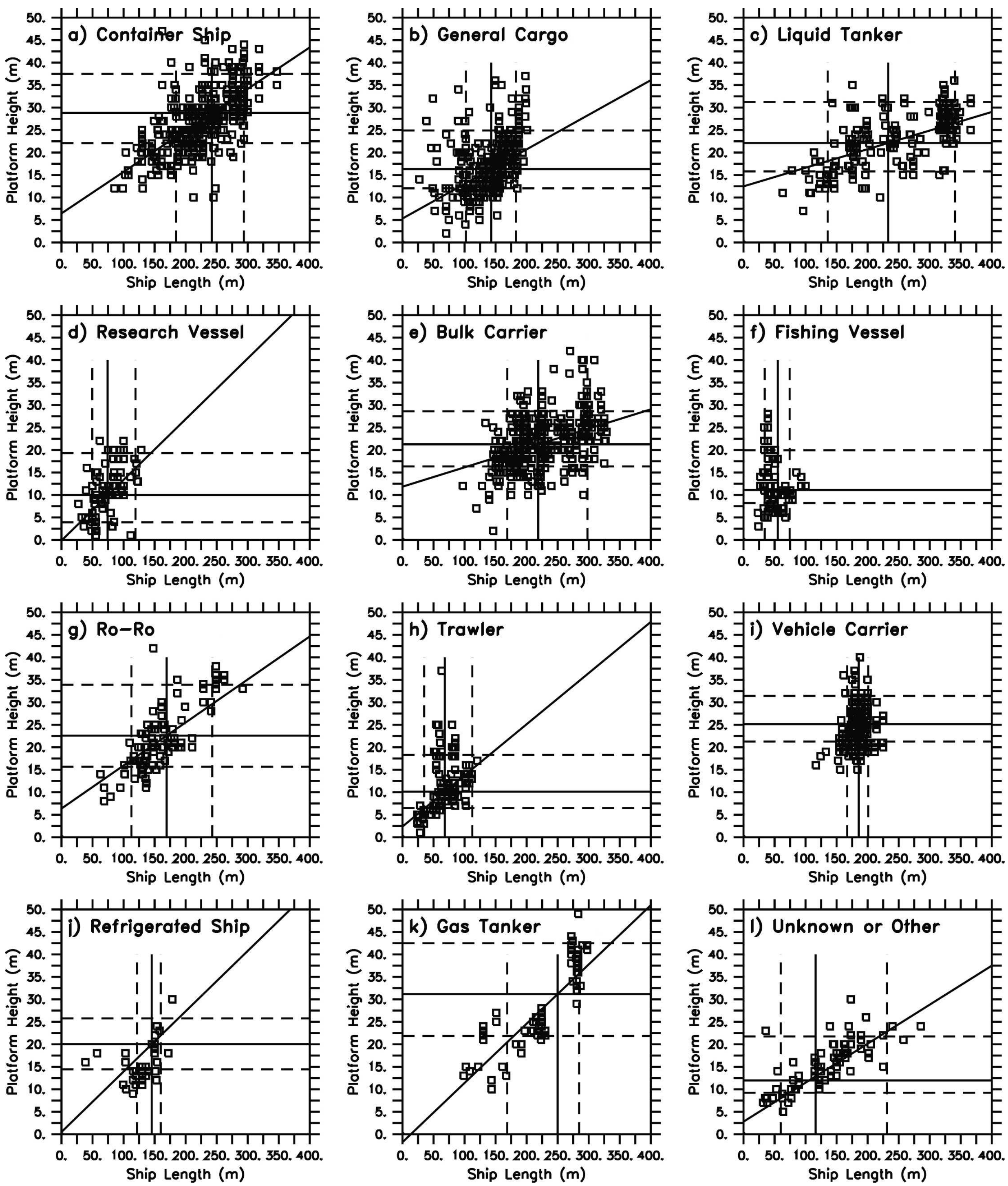

FIG. 8. Plots of platform height (m) against ship length (m) for the most commonly reporting different ship types. Horizontal and vertical solid lines indicate mean values, and dashed lines the 10th and 90th percentiles. The sloping solid lines indicate the results of linear regression.

by WMO (1983) that marine anemometers should be mounted as high as possible to avoid undue influence of the platform on the local wind structure. Further, wind measurements (V_h, at height h) should be adjusted to the equivalent at a nominal height of 10 m (V_{10}) using an acceptable profile formula. The log profile formula [$V_{10} = V_h(10/h)^x$; $x = 0.13$] was noted as having found wide acceptance. Shearman and Zelenko (1989) recom-

TABLE 3. Summary of statistics (m) for ship length, platform height, anemometer height, and the difference between platform and anemometer height for each of the most common ship types reporting in ICOADS between 1970 and 2002. Statistics are minimum (10th percentile), mean, maximum (90th percentile), and standard deviation (SD) (estimated as half the difference between the first and fifth sextiles).

	Ship length (m)				Platform height (m)				Anemometer height (m)				Difference anemometer minus platform height (m)			
Ship type	Min	Mean	Max	SD	Min	Mean	Max	SD	Min	Mean	Max	SD	Min	Mean	Max	SD
Container ship	185	242	294	43	22.1	28.8	37.5	6.1	31.0	37.4	47.0	7.1	4.5	8.6	14.6	3.6
General cargo	102	143	183	33	12.1	16.3	24.9	5.2	14.5	22.9	37.5	9.7	3.1	6.6	16.5	5.3
Liquid tanker	136	233	341	96	15.8	22.1	31.2	5.5	22.8	30.8	41.5	7.7	3.6	8.6	15.8	5.1
Research vessel	50	74	119	22	3.9	10.0	19.3	5.9	13.9	22.8	41.1	11.6	7.0	12.9	27.4	6.6
Bulk carrier	169	219	298	47	16.4	21.3	28.6	4.5	22.2	30.8	41.1	7.0	5.6	9.5	16.7	4.1
Fishing vessel	34	55	74	15	8.2	11.1	20.0	3.6	13.7	19.0	24.9	5.2	4.1	7.9	14.9	5.0
Ro-ro	113	170	243	58	15.7	22.6	33.9	6.4	22.6	30.9	40.8	7.4	2.0	8.3	15.0	4.1
Trawler	35	68	112	33	6.5	10.1	18.3	3.9	9.2	15.0	25.5	6.0	3.3	4.9	12.1	3.2
Vehicle carrier	167	186	201	12	21.3	25.1	31.4	4.2	30.6	34.3	40.3	3.8	7.0	9.2	14.0	2.7
Refrigerated ship	122	145	160	14	14.4	20.0	25.8	4.6	17.0	28.0	39.4	9.4	3.6	8.0	16.4	5.4
Gas tanker	167	250	285	43	21.9	31.2	42.5	8.2	28.6	42.4	57.0	10.7	4.3	11.2	19.2	4.9
Unknown/other	74	106	171	43	9.2	12.0	21.8	5.1	19.1	21.2	28.3	3.5	4.3	9.2	14.8	4.7
Tug	32	46	66	14	10.2	15.9	26.5	6.7	15.9	19.5	31.5	7.0	3.2	3.6	7.0	1.6
Support vessel	55	68	106	7	9.1	24.1	49.7	19.8	10.7	52.9	96.8	41.7	4.1	28.8	49.0	22.1
Military ship	121	187	232	55	13.7	22.2	33.9	7.4	23.6	33.7	56.6	9.7	7.2	11.6	18.7	4.6
Passenger ship	55	184	312	101	9.4	21.5	31.8	8.5	16.9	32.0	48.7	12.5	3.8	10.5	26.3	5.9
Buoy/lighthouse tender	59	68	77	7	9.6	11.5	15.9	2.4	19.3	22.1	27.1	3.1	5.6	10.6	14.8	4.3
Ice breaker	99	110	124	12	13.5	16.9	25.1	5.4	27.5	32.9	43.5	7.6	11.6	15.9	31.5	9.6
Livestock carrier	182	194	205	12	21.1	22.4	26.8	2.6	34.0	34.8	41.6	3.6	9.0	12.5	21.6	6.1
Coast Guard	69	87	117	24	13.2	13.4	16.8	1.7	21.2	23.2	27.8	3.1	9.2	9.8	12.9	1.7
Sailing	97	109	113	1	7.2	8.1	12.5	2.2	10.9	36.1	43.4	3.0	3.9	28.0	37.8	5.2
Yacht	26	30	45	9	3.3	4.0	6.9	1.6	28.1	27.1	29.6	0.6	23.1	23.0	27.6	2.1

mended the use of a neutral profile and provided tables of reduction factors as a function of wind speed and measurement height.

However, there is little evidence that this policy of adjustment to 10-m nominal height was widely adopted. The WMO Manual on Codes (e.g., WMO 1995) has not specified a standard of 10-m height for the wind speed (element ff) in its description of the SHIP code (currently FM 13). The U.K. (Met Office 1977, 1995) and U.S. national instructions (NOAA/NWS 2004), for example, do not contain information on height adjustment of anemometer-measured winds. Thomas et al. (2005) showed that the largest source of inhomogeneity between VOS and buoy winds in the period 1980–95 is removed by adjusting both to 10-m height, assuming that no adjustment had been made on board ship.

In recent years many ships have started to use "electronic logbook" software that automatically codes reports and makes the true wind calculation. Various versions are available; TurboWin from the Royal Netherlands Meteorological Institute (KNMI) is widely used by European VOS; the U.S. VOS Program produced a combined program for safety and meteorological observations [Automated Mutual-Assistance Vessel Rescue (AMVER)/Shipboard Environmental data Acquisition System (SEAS)]; and OBSJMA was developed by the Japan Meteorological Agency. These systems will have reduced coding errors in the VOS reports and also errors due to the miscalculation of true winds. However, TurboWin, during a software upgrade, implemented the WMO directive on height adjustment. Adjustment to 10 m was implemented in versions 2.1.2–3.0 but was removed for version 3.5. More information is given in the history section of the TurboWin Web site (http://www.knmi.nl/onderzk/applied/turbowin/turbowin.html). More recently, JCOMM (2005) endorsed a proposal from the Ship Observations Team (SOT) and Expert Team on Marine Climatology (ETMC) that, instead of the reduced wind at 10 m, the original wind data should always be reported in ship meteorological reports, including those generated by electronic logbooks.

Figure 10 shows global distribution of the heights of ship anemometers identified in ICOADS in the periods 1970–79 and 1995–2004 (as in Fig. 4 for platform height). As for platform heights, the greatest measurement heights are in the midoceans on the major shipping routes. Figure 11 shows how the anemometer height varies with ship length for the most frequently reporting VOS types in ICOADS (as in Fig. 8 for platform height). The relationships are similar to those between ship length and platform height. Typically the measurement heights for wind speed and for air temperature are better correlated with each other than with the ship length (Table 4). Figure 9b shows the numbers of ICOADS ship wind speed reports with and without Pub. 47 anemometer height information. For those reports without anemometer height the availability of other sources of information is indicated, thus illustrating the extent to which unknown measurement heights can be estimated using either the platform height or the ship type and ship length.

Information on ship type should also be important for flow distortion estimates for VOS (Moat et al. 2005, 2006a,b). Even anemometers that are sited with care on research vessels can show significant biases (Yelland et al. 2002). Comparisons of wind speeds measured on VOS and moored buoys showed biases that varied with ship type (Thomas et al. 2005), but more work is needed to quantify these effects.

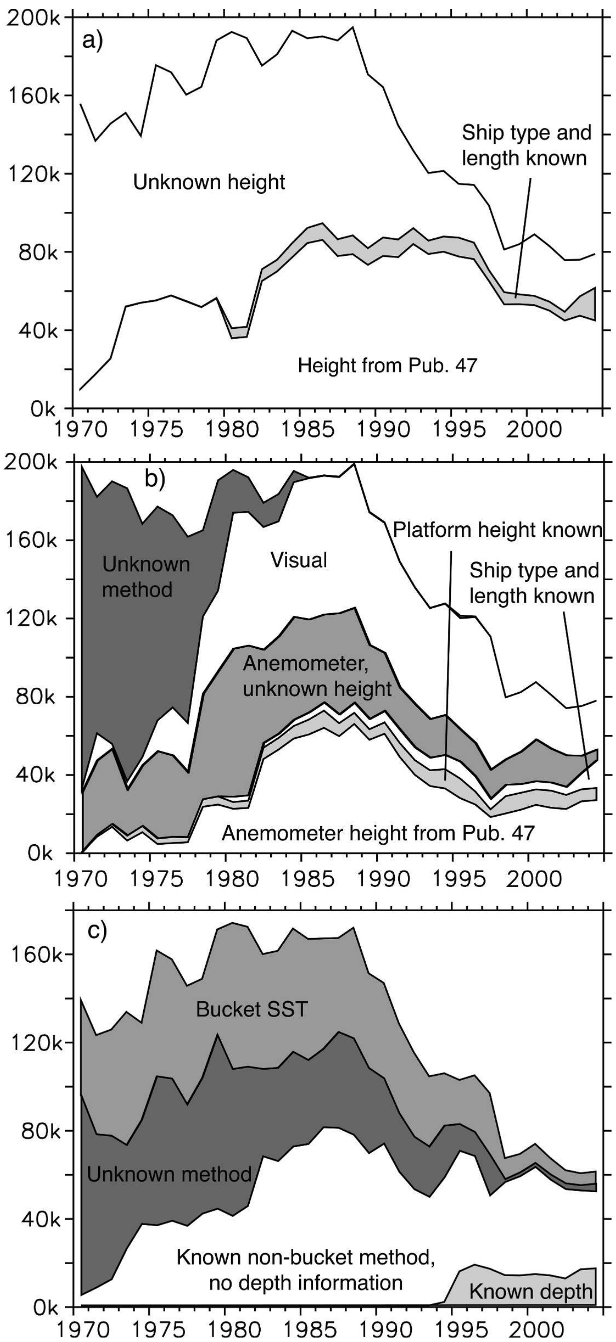

FIG. 9. Annual average numbers of observations per month in ICOADS for 1970–2004, stratified by metadata availability for (a) air temperature measurement height, (b) wind speed observation method and height, and (c) SST depth information. (a) Air temperature: observations with known measurement height (either platform height, barometer height, or thermometer height) from Pub. 47. The shaded region shows the number of observations without information from Pub. 47 but for which ship type and length are available from Lloyd's metadata. (b) Wind speed: observations showing the split between visual estimates, anemometer measurements, and observations of unknown method using information derived from the ICOADS WI indicator. For anemometer measurements only, different shadings indicate that height is unknown, or the sources of measurement height information (in order of preference): anemometer height from Pub. 47, estimated from platform height from Pub. 47, or estimated from ship type and length from Lloyd's metadata. (c) SST: observations with known measurement depth (light shading), or known to be made using buckets (medium shading) (Pub. 47 measurement depth metadata are not applicable to bucket measurements), or of unknown measurement method (dark shading). The unshaded region indicates observations for which depth information is known to be needed but is unavailable.

c. Sea surface temperature

The measurement depth for SST sensors was first included as a field in 1995 (Table 1). The depth of measurement applies only to observations made using fixed sensors, such as engine room intake or hull sensors, rather than to observations made using a bucket (Kent and Taylor 2006). Average depths of SST measurement for different types of VOS are given in Table 5, and the extent to which depth metadata are available is illustrated in Fig. 9c. The depth of measurement is related to the ship size. Bulk carriers, vehicle carriers, gas tankers, and livestock carriers typically measure SST at 7-m depth or more. Research vessels, fishing vessels, trawlers, support vessels, Coast Guard, and sailing vessels all typically measure SST at 4-m depth or less. Figure 12 shows the mean SST measurement depth on a 10° area grid for all SST observations with known measurement depth. SST is typically measured at

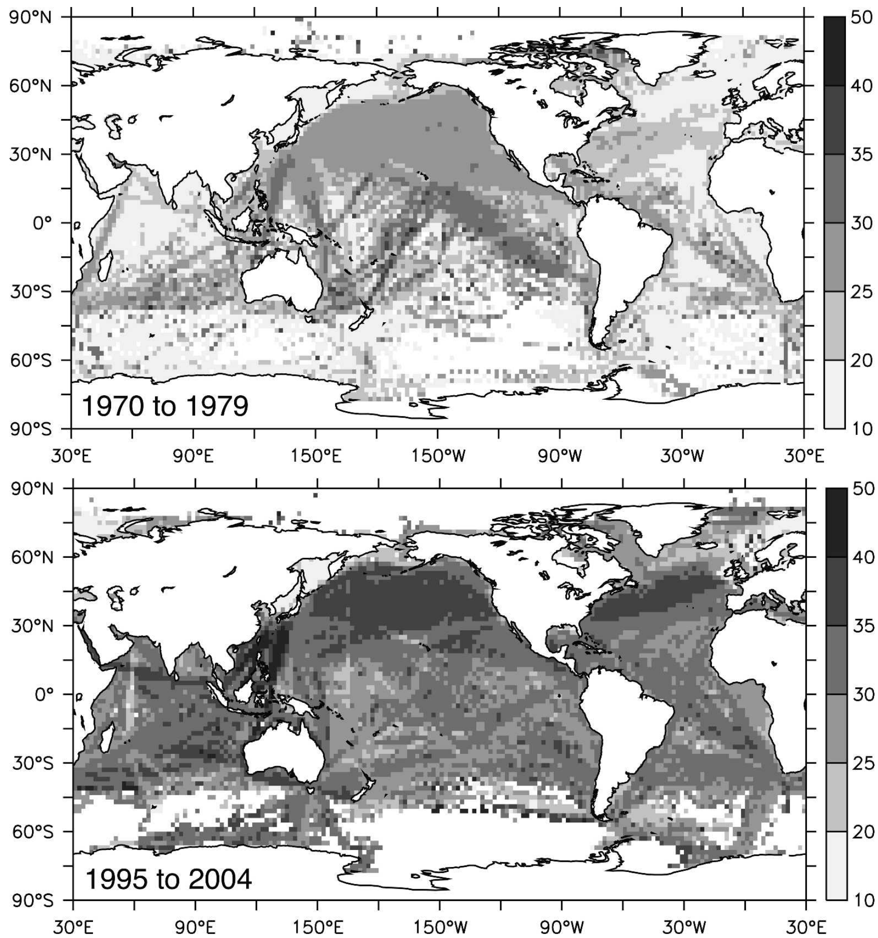

FIG. 10. As in Fig. 4, but for anemometer height (m).

greater depths in the Pacific than in the Atlantic. The effect of measurement depth on VOS SST is still unclear. James and Fox (1972) show that VOS SST observations have an increasing warm bias with increasing measurement depth, but that this is related to an increasing distance inboard of the temperature measurement location. Kent and Taylor (2006) review the literature on the causes of error in VOS SST.

5. Summary

We rely on meteorological reports from VOS for our understanding of multidecadal climate change over the ocean. The types of ship, the instruments used, and heights of measurement have changed over the years and since 1955 have been documented in WMO Pub. 47. Following a review of the past scientific usage of these metadata (section 1), we have documented the various types of information that are available in Pub. 47 over time (Tables 1 and 2), thus bringing together critical documentation that is not readily available. Major changes to Pub. 47 were made in 1995 and 2002. The height of the observing platform was first introduced in 1968, and anemometer height in 1970. The number of fields of information available has increased over the years, and since 2002 information on instrument locations has been available that may allow assessments of instrument exposure and airflow distortion (Dobson 1981; Moat et al. 2006a,b).

Pub. 47 allows the determination of measurement heights (or depths) for many of the VOS observations in ICOADS since 1970 (1995). Prior to about 1985, ability to match ICOADS VOS reports to Pub. 47 metadata becomes increasingly limited by the lack of call sign information in ICOADS. After this time the match rate is good, but the number of VOS reports declines steadily. The metadata show that the methods used by the VOS are changing over time: more air temperature observations are being made with psychrometers rather than screens; hull sensors are replacing

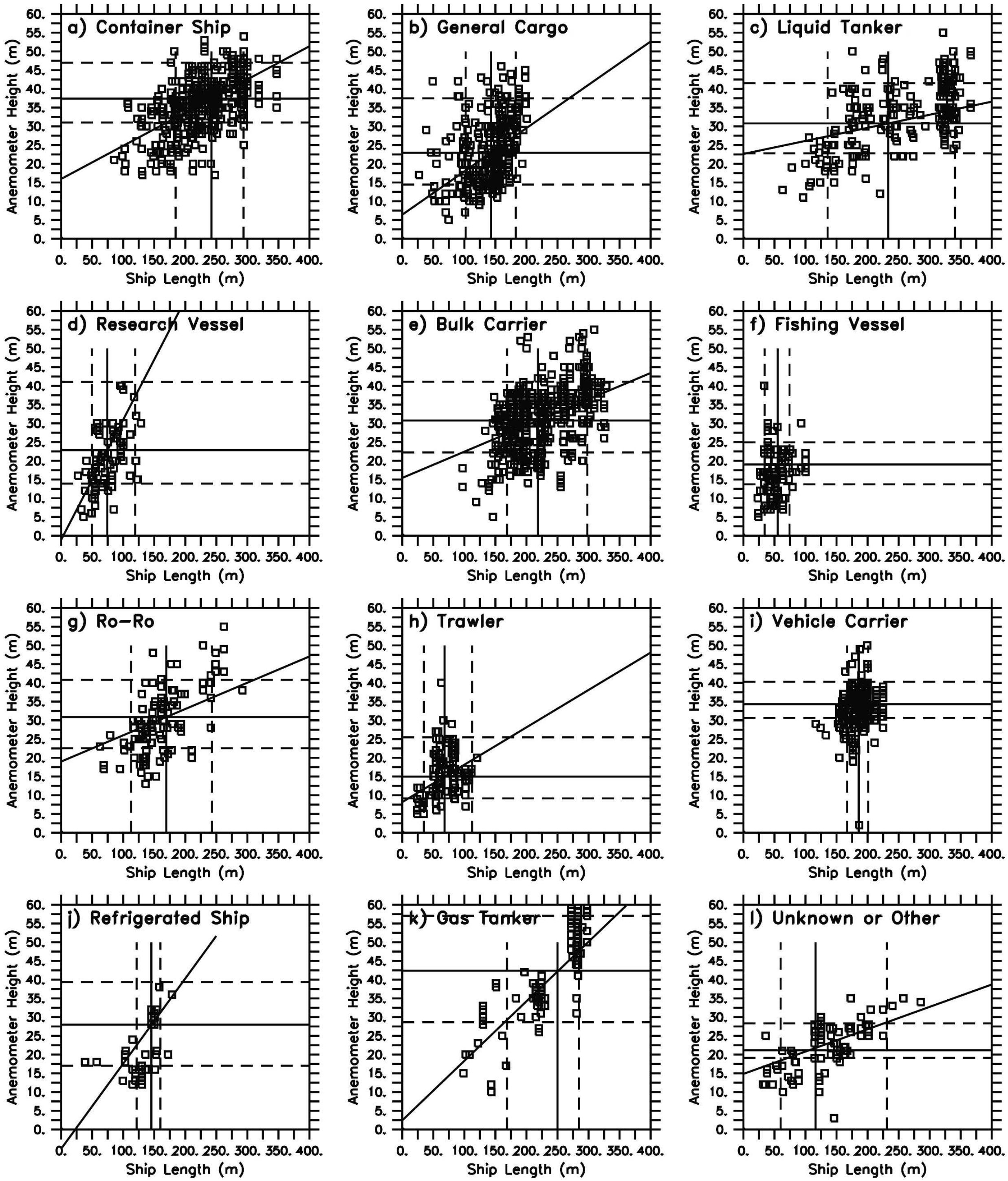

FIG. 11. As in Fig. 8, but for anemometer height (m).

buckets for the measurement of SST; digital barometers, electric thermometers, and humidity sensors are becoming more common. The heights at which air temperature and anemometer-derived wind speed are measured are increasing over time and show strong spatial variations. Air temperature observations need to be adjusted to a standard measurement height for analysis (Rayner et al. 2003). Failure to do this would introduce small but significant trends into the recent marine air temperature record. Pub. 47 metadata will allow adjust-

TABLE 4. Regression relationships among ship length, platform height, and anemometer height for the most common ship types reporting in ICOADS between 1970 and 2002 for the types for which a relationship could be determined. Regression parameters are slope, intercept, and the proportion of the variance explained by the linear fit, which is represented by R^2. Regression parameters have not been given for very poor fits with R^2 less than 0.1.

	Length vs platform height (m)			Length vs anemometer height (m)			Platform height vs anemometer height (m)		
Ship type	Slope	Intercept	R^2	Slope	Intercept	R^2	Slope	Intercept	R^2
Container ship	0.09	6.5	0.42	0.09	15.9	0.35	0.85	12.9	0.65
General cargo	0.08	5.3	0.18	0.12	6.4	0.16	1.26	2.4	0.64
Liquid tanker	0.04	12.5	0.35	0.03	22.6	0.13	1.11	6.2	0.65
Research vessel	0.14	−0.1	0.44	0.32	−1.1	0.68	1.26	10.3	0.44
Bulk carrier	0.04	11.9	0.16	0.07	15.4	0.18	1.13	6.8	0.55
Fishing vessel							1.10	6.8	0.65
Ro-ro	0.10	6.4	0.65	0.07	19.0	0.29	0.88	11.0	0.65
Trawler	0.11	2.4	0.46	0.10	8.2	0.23	0.95	5.4	0.58
Vehicle carrier							0.77	15.1	0.48
Refrigerated ship	0.13	0.5	0.42	0.23	−5.2	0.46	1.41	−0.3	0.77
Gas tanker	0.13	−1.8	0.69	0.16	2.4	0.51	1.28	2.6	0.83
Unknown/other	0.09	2.8	0.73	0.06	14.8	0.54	0.54	14.7	0.46

ment of anemometer-derived wind speeds to the standard reference level of 10 m, thereby reducing artificial trends in marine wind speeds (Cardone et al. 1990). Since 1995 we have some information on SST measurement depth. Although data volume is small there are significant spatial variations in measurement depth, and it may be possible to derive improved SST fields using this information. Information on the types of ship making observations from Pub. 47 or from Lloyd's metadata should in the future lead to improved information on airflow distortion over VOS (Thomas et al. 2005; Moat et al. 2005).

In the absence of measurement height information from Pub. 47 it is possible to make estimates of measurement heights for air temperature measurement and anemometer-derived wind speed where ship type and length information is available from Lloyd's metadata (Table 4). Knowledge of the ship type alone allows an improved estimate of either measurement height to be made (Table 3) and, where available, represents an improvement over the use of a single default value for all ships. Whether to use these approximations to measurement height, and whether to exclude observations of unknown measurement height, will depend on the particular research application.

Availability in readily usable digital form of Pub. 47 metadata back to 1955, and prospects for improved integration and cross-validation of these and other (e.g., Lloyd's proprietary) metadata with ICOADS observations, should help improve the quality and reliability of ICOADS. However, matching the earlier Pub. 47 metadata to ICOADS observations is challenging, owing to the lack of call sign information in the reported obser-

TABLE 5. Average SST depth (m) for different types of ship where metadata were available. Range quoted is one standard deviation. Note that the SST depth field is only present in the metadata from 1995 onward (Table 1).

Ship type	SST depth (m)
Container ship	7.2 ± 0.6
General cargo	5.5 ± 0.3
Liquid tanker	7.8 ± 1.1
Research vessel	2.8 ± 0.5
Bulk carrier	10.6 ± 0.6
Fishing vessel	3.8 ± 1.4
Ro-ro	4.6 ± 0.8
Trawler	1.9 ± 0.7
Vehicle carrier	7.0 ± 1.7
Refrigerated ship	4.7 ± 0.9
Gas tanker	7.6 ± 0.6
Support vessel	3.2 ± 0.4
Passenger ship	4.4 ± 1.2
Livestock carrier	14.9 ± 8.6
Coast Guard vessel	3.3 ± 1.0
Sailing vessel	1.6 ± 1.3
Unknown/other	6.3 ± 1.7

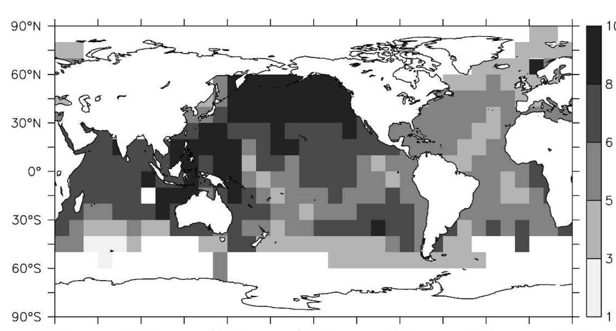

FIG. 12. The 10° area average SST measurement depth (m) from Pub. 47 and ICOADS for the period 1995–2004.

vations prior to the earliest surviving telecommunicated data (c. 1966). Efforts have also begun through JCOMM to archive metadata similar to Pub. 47 for fixed ocean platforms, buoys, and other automated ODAS. While the rescue of historical ODAS metadata appears to be a large and uncertain undertaking, all these efforts hold the potential to further improve the homogeneity of ICOADS and, as they come to fruition, benefit many avenues of climate and other research.

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APPENDIX

Online Availability of Metadata, ICOADS Data, Publications, and Technical Documentation

- Metadata files: http://icoads.noaa.gov/metadata/wmo47/
- PDFs of Pub. 47 (1955–72): http://icoads.noaa.gov/metadata/wmo47/cdmp_1955-72/
- Merged ICOADS/Pub. 47 in IMMA: http://dss.ucar.edu/datasets/ds540.0/data/
- ICOADS publications: http://icoads.noaa.gov/publications.html
- ICOADS technical documentation: http://icoads.noaa.gov/doc.html

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