Improving Surface Marine Meteorological Data Using Metadata:

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1. Work Package 1: Metadata

1.1 Overview of Work Package 1

The metadata improvement element of the work plan has been extremely successful and has built on previous work funded by the Met Office (Berry et al. 2004, Kent and Taylor 2006, Kent and Challenor 2006, Kent and Kaplan 2006, Rayner et al. 2003). Although some of the resources required to achieve the work became available much later than anticipated, the funding allowed the exploitation of unforeseen opportunities to improve metadata quality and availability. Work Package 1 outputs include:

1) Improved Voluntary Observing Ship (VOS) metadata database derived from World Meteorological Organisation (WMO) Publication No. 47 (Pub. 47).
2) Contribution to digitisation process for Pub. 47, 1955 to 1972.
3) Improved information on metadata availability and strategy for exploitation of available metadata.
4) Construction of International Comprehensive Ocean-Atmosphere Dataset (ICOADS) metadata attachment for period 1973 - 2005.
5) Gridded observation height dataset for period 1970 - 2005.
6) Journal paper describing evolving contents of Pub. 47 (Kent et al. 2006b).
7) Participation in metadata-related international activities.
8) Archive of observing instructions.

1.2 Work Package 1

1.2.1 Improved Pub. 47- derived metadata database

Pub. 47 has been issued as an operational resource since 1955 and contains information on the instrumentation carried by, and characteristics of, the VOS. The metadata are submitted by the nations operating the VOS. As an operational resource the metadata have never been checked for consistency and completeness and no efforts have been made to maximise the historical information contained within Pub. 47. There are several challenges to the development of a consistent and more complete metadata database from Pub. 47. Firstly

the contents of Pub. 47 have evolved over time, documented by Kent et al. (2006b). Secondly the methods used to maintain Pub. 47 have not resulted in the highest quality dataset. For example the maintenance of Pub. 47 relies on regular updates being received to notify changes and the assumption is made that if no update is received from a particular country then the metadata for those ships operated by that country remains the same. However analysis of the metadata revealed that some countries do not make regular submissions to Pub. 47, which reduces the quality of the dataset (Kent and Berry 2006a). The process of developing the improved dataset is described in detail by Berry and Kent (2006a) and summarised by Kent and Berry (2006a). The impact of the improved metadata database on metadata availability in ICOADS is described in Kent and Berry (2006a, see for example Figures 6 & 7).

Output: Improved metadatabase, available on request on DVD or by ftp.

1.2.2 Contribution to digitisation of early Pub. 47

This work element required more involvement than was originally anticipated and the digitised metadata for 1955 to 1972 only became available in March 2006. Digitisation was carried out as part of the National Climatic Data Center (NCDC) Climate Database Modernisation Programme (CDMP). There were several iterations, for example defining the data entry formats, checking the metadata and revising the methodology accordingly, between February 2005 and March 2006 when the digitised metadata were finally accepted. The paper copies (icoads.noaa.gov/metadata/wmo47/cdmp_1955-72/) of the digitised data were reconstructed to aid checking the quality of the digitised metadata. The digitised files were then converted to NetCDF and used to generate the improved metadata database for the period 1955 to 2005.

Output: NetCDF versions and reconstructed pdf files of Pub. 47 editions between 1955 to 1972.

1.2.3 Metadata summary and exploitation strategy

The metadata summary report (Kent and Berry 2006a) describes the characteristics of the metadata available within ICOADS and Pub. 47. ICOADS metadata gives information on the platforms and data sources which can give information on the expected quality of individual observations. ICOADS only gives measurement methods for sea surface temperature (SST) and wind speed. The improvement of the new Pub. 47 metadata database

over the original Pub. 47 editions is clearly demonstrated. Breaking the content of Pub. 47 down by country illustrates those countries and periods for which updates were not received.

The metadata strategy document (Kent and Berry 2006b) illustrates how best to use the metadata described in the summary report (Kent and Berry 2006a) in order to maximise the number of reports within ICOADS with measurement method information. It is shown that using a combination of Pub. 47 matches to ICOADS, the internal metadata within ICOADS and assignments based on data source a significant improvement on previous characterisations of the metadata is achieved.

Output: Contract reports, Kent and Berry (2006a,b)

1.2.4 ICOADS metadata attachment

Following a recommendation from the Second Joint WMO/Intergovernmental Oceanographic Commission (IOC) Technical Commission for Oceanography and Marine Meteorology (JCOMM) Workshop on Advances in Marine Climatology (CLIMAR-II, icoads.noaa.gov/climar2) a format for an International Maritime Meteorological Archive (IMMA) metadata attachment to associate a subset of Pub. 47 metadata with individual ICOADS reports was defined and populated with metadata elements. It is anticipated that this will form a valuable resource for a wide range of research based on ICOADS and will allow interested researchers to conveniently access metadata elements without the need to cross-reference callsign information between ICOADS and the Pub. 47 editions.

Output: IMMA format metadata attachment for ICOADS, 1973 - 2005, available from: http://dss.ucar.edu/datasets/ds540.0/data/

1.2.5 Gridded observation height dataset

Gridded fields of observing platform height have been supplied to the Hadley Centre on monthly 5° by 5° and 1° by 1° area resolutions for the period 1970 to 2005. The platform heights are indicative of the measurement height of the air temperature (although Kent and Berry 2006a show that the platform height is probably a slight underestimate of the air temperature observation height). Due to the changing nature of the metadata in Pub. 47 (Kent et al. 2006b) the air temperature measurement height information is based on the platform height (1968 to 1995), barometer height (1995 to 2001) and thermometer height (2002 onwards) metadata. ICOADS observations have been matched to the available metadata and where the records pass a ship tracking check the associated heights averaged. The gridded

dataset will provide information required to make adjustments to the air temperatures used in the next version of the Hadley Centre night time marine air temperature dataset (HadMAT2, Hill et al. 2006).

Output: NetCDF gridded files of observation height, available on CD or ftp by request.

1.2.6 Pub. 47 journal paper

Consolidated documentation for the evolving nature of Pub. 47 has not been available and so a decision was made to publish a description of Pub. 47 in the scientific literature. For the first time the periods of availability of different metadata elements has been detailed, along with the coded values that can be entered. We have feedback that the preprint paper has already proved useful to those working with Pub. 47 and expect that this paper will be an important resource for those wishing to exploit the VOS metadata.

Output: Kent, E. C., S. D. Woodruff and D. I. Berry, 2006: WMO Publication No. 47 Metadata and an Assessment of Voluntary Observing Ships Observation Heights in ICOADS, Journal of Atmospheric and Oceanic Technology, in press.

1.2.7 International metadata-related activities

Over the past three years this project has funded participation in a range of international activities which are vital to maintaining and improving the availability of VOS metadata. These include the WMO Ship Observations Team (SOT) Metadata Task Team (TT), the second session of JCOMM (JCOMM-II), the third meeting of SOT (SOT-III) and the Water Temperature Metadata Pilot Project (META-T PP) instigated by the JCOMM Management Committee, the Data Buoy Co-operation Panel (DBCP), SOT and the US National Oceanic and Atmospheric Administration (NOAA) Office of Global Programs (OGP).

The SOT Metadata-TT was responsible for the definition of the latest format for Pub. 47, soon to be implemented (see Kent et al. 2006b for further information). Participation in SOT-3 highlighted the lack of updated information in Pub. 47 from some countries (Kent 2005a) and contributed to an increased level of activity by SOT to ensure that metadata were regularly submitted to the WMO by the VOS operators in the required formats, and made available promptly (see also Section 2.2.1). JCOMM-II was the decision-making meeting for JCOMM and approved the new format for Pub. 47 recommended by the SOT Metadata-TT. META-T PP is a new project designed to improve the availability of temperature metadata for all marine platforms.

Output: Engagement with international community on VOS metadata issues.

1.2.8 Archive of observing instructions

Although it was not possible in the time available to exploit the metadata available in national observing instructions, a valuable collection of documents has been assembled. Much of the documentation comes from the UK and the WMO, however some information from the US, Canada, Japan, Netherlands, Germany, Norway, Sweden, Greece, Poland and France has been collected. Some of these documents are candidates for digitisation by the CDMP (S. Woodruff, pers. comm.).

Output: Collection of various documents from a variety of nations detailing observing practice.

2. Work Package 2: VOSClim

2.1 Overview of Work Package 2

The primary objective of the Voluntary Observing Ship (VOS) Climate Project (VOSClim) is to provide a high-quality subset of marine meteorological data, with extensive associated metadata, to be available in both real time and delayed mode. (JCOMM 2002). Eventually, it is expected that the project will transform into a long-term, operational programme. Data from the project could be used: to input directly into air-sea flux computations, to assess coupled atmosphere-ocean climate models; to provide ground truth for calibrating satellite observations; and to provide a high-quality reference data set for possible recalibration of observations from the entire VOS fleet. Work Package 2 covers work associated with the VOSClim project including scientific analysis, attendance at VOSClim project meetings, the provision of advice to VOSClim and others on the scientific requirements for VOSClim and project promotion. Work Package 2 outputs include:

1) VOSClim combined dataset containing GTS ship reports, co-located model output, delayed mode parameters and associated metadata.
2) Contributions to SOT-II (London 2003) and SOT-III (Brest 2005).
3) VOSClim scientific analysis.
4) VOSClim project promotion.
5) VOSClim project assessment.

2.2 Work Package 2

2.2.1 The VOSClim dataset

Despite the VOSClim project having been set up in 2001 few aspects of the data flow are in place. As VOSClim has no funds all participation is on a voluntary basis and the participants are typically already over-stretched progress has been inevitably slow. Much time in the early part of the project was taken up trying to ensure that all the data and metadata for the various project elements were flowing smoothly. Problems highlighted included the non-availability of metadata and problems with both the real-time and delayed-mode data streams (Berry 2005, JCOMM 2005a, Kent and North 2004, Kent et al. 2003-2006). The current status of the data streams is described by Kent and Berry (2006c). Whilst we await the delivery of some data from the designated sources we have developed a combined data and metadata dataset for VOSClim as an interim measure. This dataset, in NetCDF format, contains all the VOSClim data streams (except project photos) including the GTS ship data, co-located model elements, delayed mode VOSClim additional parameters and associated metadata.

Output: VOSClim merged data and metadata, available on request on DVD or by ftp.

2.2.2 Contributions to SOT-II and SOT-III

The VOS and VOSClim programs are managed by the JCOMM SOT. The second session of SOT (SOT-II, London July 2003, JCOMM 2003) occurred at the official project start in August but was extremely important for VOSClim (Kent 2003b). The third session (SOT-III, Brest March 2005, JCOMM 2005a, Kent and Berry 2005b, Kent and North 2005, Kent et al. 2003-2006) highlighted problems with metadata delivery (vital for both VOS and VOSClim), and both the real-time and delayed mode data delivery. At SOT-III a decision was taken to convert VOSClim to a project under the VOS Panel and to move VOSClim from an implementation phase to an assessment phase (Kent and North 2005). At this time it was thought that the outstanding problems with the VOSClim data streams could be fixed in a fairly short time. However the real-time data is still not flowing reliably (although we are maintaining an archive of the real-time data at NOCS as a backup) and several countries have not yet implemented the new IMMT-3 format (JCOMM 2005b) required to complete the delayed mode data flow.

The positive outcome for SOT-III in terms of metadata delivery (see Section 1.2.7) was important for resolving the metadata delivery for VOSClim (Kent et al. 2003-2006, Kent 2003b). The profile of VOS, in addition to VOSClim, as a climate resource has been raised with the ship operators (Kent et al. 2005a,b).

Output: Engagement with VOS and VOSClim operators. Input to management of VOSClim.

2.2.3 VOSClim scientific analysis

Analyses of the VOSClim dataset have been made on 3 separate occasions, none with the full dataset (see Section 2.2.1). Preliminary results were presented at SOT-II (the 4th VOSClim session, Kent 2003b, Kent et al. 2003) and at SOT-III (Kent and Berry 2005b). The most recent analysis is described by Kent and Berry (2006c). This assessment was not as wide-ranging as had been hoped as time had to be spent reconstructing the dataset from a variety of non-standard sources in a range of different data formats. However data from 139 ships from 9 countries were analysed with some interesting results. The preliminary analysis showed that the VOSClim dataset will be a useful resource for understanding and comparing ship surface meteorological observations. Measurements of sea surface temperature (SST) made using buckets were shown to be relatively warm under conditions of high solar radiation; air temperature bias due to solar radiative effects was shown to be significantly reduced using the correction of Berry et al. (2004); measurements of humidity made using ventilated screens were significantly lower than those from other methods and probably of highest quality; pressures from mercury barometers were shown to be of relatively low quality and wind speed observations flagged as being derived from visual observations of the sea surface were very similar to those from anemometers prior to adjustment for height (Thomas et al., *in preparation*). The value of the delayed mode parameters was demonstrated for the case of relative wind speed.

The analysis of the VOSClim dataset has so far resulted in a journal paper (Berry and Kent 2005a). This paper showed that assessments of the air temperature sensor exposure (Kent et al 1993a,b) from the VOSClim photos could be related to the skewness of the distribution of differences between the ship-measured air temperature and co-located Numerical Weather Prediction model air temperatures. Kent et al. (1993a,b) showed that air temperature radiative heating bias was high for poorly exposed sensors. The identification of ships with poorly exposed sensors is highly desirable and is now possible.

Output: Kent and Berry (2006c); Berry, D. I. and E. C. Kent, 2005: The Effect of Instrument Exposure on Marine Air Temperatures: An assessment using VOSClim data, International Journal of Climatology, 25(7), 1007-1022, DOI: 10.1002/joc.1178.

2.2.4 VOSClim project promotion

Activities designed to raise the profile of VOSClim and to promote the project include: with the scientific community (Berry and Kent 2005, Kent et al. 2004, 2005c); with the VOS operators (Kent 2003b,d, Kent et al. 2003); with the observers (Kent 2003e); and with the GCOS panels (Kent 2003a,c, Kent and North 2004).

Output: Increased awareness of the aims and progress of VOSClim.

2.2.5 VOSClim project assessment

Assessments of the VOSClim project have been hindered by the slow progress in implementing the VOSClim dataflow. Kent and North (2005) suggested that VOSClim should move into an assessment phase in which the "added-value" of the project should be determined. There is a commitment to make this assessment by SOT-IV due to be held in spring 2007. The VOSClim analyses (e.g. Kent and Berry 2006c and Berry and Kent 2005a) show the value of the co-located model output and of the ship photographs but we are not yet in a position to make a full assessment of the project.

A brief assessment report has been written (Kent and Berry 2006d) which summarises the current status of the VOSClim project. It has not been possible at this time to make a full assessment of the "added-value" of the VOSClim project due to delays in the construction of the analysis dataset resulting from the non-availability of some data from the VOSClim DAC (see Section 2.2.1). This assessment will be made as soon as the required data are available, and in time for consideration by SOT-IV.

Output: Preliminary VOSClim assessment report (Kent and Berry 2006d).

3. Work Package 3: Application to Climatology: the ICOADS

3.1 Overview of Work Package 3

The aim of Work Package 3 was to take the improved metadata from Work Package 1 and the results of the analysis of the VOSClim dataset from Work Package 2 and to apply these to the International Comprehensive Ocean-Atmosphere Dataset (ICOADS, Woodruff et al. 1987, 1998, Worley et al. 2005). Delays in metadata delivery (see Section 1.1) and

problems with the VOSClim dataset (see Section 2.2.1) resulted in a change of focus toward the development of a new surface marine meteorological dataset suitable for the exploitation of improved metadata and data characterisation information (Kent and Berry 2006e), although progress has been made on data characterisation (Berry and Kent 2005a, Kent and Berry 2005a, 2006e, Thomas et al. *in preparation*, Kent and Kaplan 2006). Another activity that became important over the period of the contract was the need to provide advocacy for the VOS as a climate observing system in an attempt to raise its priority with the climate research community and with the observing system operators. These efforts have raised awareness of the decline in VOS data coverage, but have yet to result in an improvement in data coverage.

Work Package 3 outputs include:

1) Preliminary dataset of improved gridded meteorological and surface flux fields derived from ICOADS.
2) Improved determination of random uncertainty in ICOADS observations.
3) Improved determination of bias adjustments and uncertainty in ICOADS observations.
4) Participation in 2nd Workshop on Advances in the Use of Historical Marine Climate Data (MARCDAT-II).
5) International Activities and VOS advocacy.

3.2 Work Package 3

3.2.1 ICOADS-derived dataset

The construction of a new dataset based on ICOADS is described in Kent and Berry (2006e). Although the dataset is still under development monthly gridded fields from a preliminary version are available on request. Past ICOADS-derived datasets have typically produced monthly-mean fields on spatial grids ranging from 1° to 5°. The new dataset uses existing optimal interpolation (OI) methods but applies these to ICOADS to produce daily files with associated uncertainty estimates. The advantages of this approach include: improved distinction between data errors and natural variability; improved quantification of both measurement and sampling uncertainty; reduced bias in surface fluxes calculated from meteorological fields (see Kent and Berry 2006e for more information). The new dataset has been promoted at several meetings including: the 86th Annual Meeting of the American Meteorological Society (Berry and Kent 2006b), the 13th American Geophysical Union Ocean Sciences Meeting Hawaii (Berry and Kent 2006c), MARCDAT-II (see Section 3.2.4),

the National Centre for Ocean Forecasting development workshop (Kent and Berry 2006f), and a poster was sent to the 3rd SeaFlux Workshop (Kent and Berry 2006g).

Output: 1) Preliminary dataset of improved gridded meteorological and surface flux fields derived from ICOADS, available on request

3.2.2 Improved determination of random uncertainty in ICOADS observations.

Building on work funded by a previous contract with the Met Office (Kent and Berry 2005a, Kent and Challenor 2006) and using the enhanced metadata information from Work Package 1, estimates of uncertainty in ICOADS observations of surface wind speed, air temperature, SST, humidity and pressure have been made (Kent and Berry 2006e).

Output: 2) Improved knowledge of random uncertainty in ICOADS observations

3.2.3 Improved determination of bias in ICOADS observations.

Bias estimates developed as part of this project and under previous projects have been re-examined and, where appropriate, applied to the observations. A model of the biases in SST measurements from buckets and engine room intake observations (Kent and Kaplan 2006), developed under a previous contract with the Met Office, has been improved to account for uncertainty in the input parameters using a Bayesian analysis. When applied, the model improves the SST record, bringing the bucket and engine room intake observations into better agreement with each other and reducing the random errors in the SST observations (Kent and Berry 2006e).

The bias correction of Berry et al. (2004) has been applied to the MAT observations and has been shown to bring the diurnal cycle in the air temperature into agreement to that seen in the SST. The correction has also been shown to reduce the random errors in the MAT observations (Kent and Berry 2006e).

A new correction has been proposed for humidity observation made using thermometers housed in marine screens based on differences between psychrometer and screen humidity measurements. A preliminary version of the correction has been applied to ICOADS observations and has been shown to improve the humidity record (Kent and Berry 2006e) and be superior to a previous correction (Josey et al. 1999). The random uncertainty in the humidity observations is reduced by application of the correction.

Marine wind speeds from ICOADS show an increasing trend over recent decades. Recent work (Thomas et al., *in preparation*) has shown that this trend is reduced by

application of adjustments for measurement height and method, but that differences remain between observations made using anemometers and those from visual observations of the sea state and that those differences are increasing with time. One explanation of the difference is that observers are mis-flagging measured winds as estimated winds. An attempt has been made to determine which ships may be mis-flagging their reports based on the distributions of observations, but much more work is required.

Output: 3) Improved knowledge of bias uncertainty in ICOADS observations

3.2.4 Participation in CLIMAR-II and MARCDAT-II

Two important workshops for the marine climatology community occurred during the project, the 2nd JCOMM Workshop on Advances in Marine Climatology (CLIMAR-II, Brussels, November 2003) and the 2nd Workshop on Advances in the Use of Historical Marine Climate Data (MARCDAT-II, Exeter October 2005). Participation in MARCDAT-II was funded by this project and included: membership of the organising committee; oral and poster presentations (Berry and Kent 2005b, Kent 2005b, Kent and Berry 2005c); authorship of meeting reports (Kent et al. 2005f, Kent and Rayner 2005, Rayner et al. 2006).

These meetings are important for disseminating results, scientific networking and generating new ideas. For example, as a result of the MARCDAT-II workshop significant interest has been generated in the new surface meteorology and flux dataset under development. This should ensure the dataset is widely exploited. Both the CLIMAR-II and MARCDAT-II workshops have strengthened links between NOC and the ICOADS team, Met Office and other researchers through increased collaboration. Examples of this can be found in the exploitation of the metadata (section 1, also: Kent et al., 2006; Hill et al., 2006) and research on biases in wind speeds (Thomas et al., *in preparation*)

Output: 4) Participation in marine climatology meetings and improved visibility for ICOADS-based gridded products (WP3, Output 1).

3.2.5 International Activities and promotion of the VOS contribution to the climate observing system.

In recent years the number of ships contributing to the VOS program and the number of observations they provide has decreased, resulting in a decrease in the proportion of the ocean adequately sampled. Two different approaches have been taken to try to raise the profile of ship-based weather reports as a climate resource. Firstly the improvement in VOS-based datasets developed as part of this contract (see Section 3.2.1) are helping to demonstrate to the

scientific community that high-quality datasets can be derived from VOS data. Secondly the decline in this important component of the Global Climate Observing System has been highlighted within JCOMM and the ship operators (Kent et al. 2005a,b,d,e), within the World Climate Research Programme (WCRP, Kent 2003a, Kent 2004a,b) and more widely (Kent 2005b, Kent and Berry 2005c, Kent et al. 2006a). Although progress is slow there is evidence that the need to focus on VOS as a valuable source of climate data is becoming acknowledged (for example the Met Office are funding research to improve their monitoring of surface marine data including VOS; the WCRP Observations and Assimilation Panel (WOAP) are attempting to address the low priority given to in situ networks [http://copes.ipsl.jussieu.fr/Organization/COPESStructure/WGOA.html]; and an article was requested for CLIVAR Exchanges, Kent et al. 2006a).

Output: 5) Profile of VOS as part of the Global Climate Observing System raised and importance of monitoring surface observations for climate applications established.

4. Summary of Work Packages, Outputs and Knowledge Transfer

Work Package 1 has improved the metadata record through homogenising (see Section 1.2.1) and extending (see Section 1.2.2) the metadata record. This improved metadata will aid in the assessment of the observations and assignment of random errors in the observations (Kent and Berry, 2005). In turn, this should lead to better quality assurance and data assimilation, important for both developing climate quality datasets and weather forecasting. The improved metadata has been made available to the scientific and operational communities through a number of datasets (see Sections 1.2.1, 1.2.4 and 1.2.5). Knowledge has been transferred through interactions with the operational agencies (see Section 1.2.7), raising awareness of the importance of the metadata, and with the scientific community (see Section 1.2.6). This should result in the maintenance and wide exploitation of the metadata resource.

Work Package 2 has seen the development (see Section 2.1.1) and analysis (see Section 2.2.3) of the VOSClim dataset. The dataset will form an important resource for further quantification of uncertainties and biases in the observations (Kent and Berry 2006c). The analysis has resulted in one scientific publication (Berry and Kent 2005) and highlighted future work. Contributions have also been made to the management (see Section 2.2.2) and promotion (see Section 2.2.4) of the VOSClim project. These efforts will improve the

likelihood of the VOSClim project being a success and the dataset being fully exploited. Although it has not been possible to perform a wide-ranging assessment of the VOSClim project at this time, this assessment will be made when the VOSClim dataflow is fully operational and in time for SOT-IV in early 2007.

Work Package 3 has seen the exploitation of work funded under previous Met Office contracts together with the outputs of work packages 1 and 2. Bias corrections for the Marine Air Temperature (Berry et al., 2005) and SST (Kent and Kaplan, 2006) have been applied to VOS observations and demonstrated to improve those observations through a reduction in the random errors and a more consistent record (Section 3.2.3). The metadata from Work Package 1 has been used to improve random error estimates (Section 3.2.2) and used in the development of a new humidity correction (Section 3.2.3). The random error estimates, bias corrections and improved metadata have then been used in the generation of a new surface meteorology and flux dataset (Section 3.2.1). Results from Work Package 3 have been published in the scientific literature (Kent and Kaplan, 2006) and promoted at international conferences (Section 3.2.4). Attendance at conferences has led to new national and international collaborations (Section 3.2.4). International activities have helped to raise the profile of VOS as part of the Global Climate Observing System (Section 3.2.5).

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