SURFACE *IN SITU* DATASETS FOR MARINE CLIMATOLOGICAL APPLICATIONS

Scott D. Woodruff(1), Nicola Scott(2), David I. Berry(3), Mark A. Bourassa(4), Etienne Charpentier(5), Sergey K. Gulev(6),Heike Haar(7), Elizabeth C. Kent(3), Richard W. Reynolds(8), Gudrun Rosenhagen(9), Martin Rutherford(10), Val Swail(11), Steven J. Worley(12), Huai-Min Zhang(8), Reinhard Zöllner(13)

(1) Chair, JCOMM (Joint World Meteorological Organisation (WMO)/Intergovernmental Oceanographic Commission (IOC) Technical Commission for Oceanography and Marine Meteorology) Expert Team on Marine Climatology, NOAA/ESRL (National Oceanic and Atmospheric Administration/Earth System Research Laboratory) (R/PSD3), 325 Broadway, Boulder, CO 80305, USA, Email: Scott.D.Woodruff@noaa.gov
(2) Chair, JCOMM (Joint World Meteorological Organisation (WMO)/Intergovernmental Oceanographic Commission (IOC) Technical Commission for Oceanography and Marine Meteorology) Task Team on Delayed-Mode VOS (Voluntary Observing Ship) Data, Met Office, Saughton House, Broomhouse Drive, Edinburgh, EH11 3XQ, United Kingdom, Email: nicola.scott@metoffice.gov.uk
(3) National Oceanography Centre, Waterfront Campus, European Way, Southampton SO14 3ZH, United Kingdom, Email: dyb@noc.soton.ac.uk; eck@noc.soton.ac.uk
(4) Center for Ocean-Atmospheric Prediction Studies, Florida State University, Tallahassee, FL 32306, USA, Email: bourassa@coaps.fsu.edu
(5) WMO (World Meteorological Organization), 7bis, av. de la Paix, Case Postale 2300, 1211 Genève 2, Switzerland, Email: ECharpentier@wmo.int
(6) P.P. Shirshov Institute of Oceanology, RAS (Russian Academy of Sciences), 36 Nakhimovsky ave, 117858 Moscow Russia, Email: gul@sail.msk.ru
(7) Deutscher Wetterdienst, Bernhard-Nocht-Str. 76, 20359 Hamburg, Germany, Email: Heike.Haar@dwd.de
(8) National Climatic Data Center, Federal Building, 151 Patton Avenue, Asheville NC 28801, USA, Email: Richard.W.Reynolds@noaa.gov; Huai-min.Zhang@noaa.gov
(9) Co-Chair, JCOMM (Joint World Meteorological Organisation (WMO)/Intergovernmental Oceanographic Commission (IOC) Technical Commission for Oceanography and Marine Meteorology) Task Team on Delayed-Mode VOS Data, Deutscher Wetterdienst, Bernhard-Nocht-Str. 76, 20359 Hamburg, Germany, Email: Gudrun.Rosenhagen@dwd.de
(10) Dept. of Defence, R5-SB-42, Russell Offices, Canberra Act 2600 Australia, Email: Martin.Rutherford@defence.gov.au
(11) Chair, JCOMM (Joint World Meteorological Organisation (WMO)/Intergovernmental Oceanographic Commission (IOC) Technical Commission for Oceanography and Marine Meteorology) Expert Team on Wind Waves and Storm Surges, Environment Canada, 4905 Dufferin Street, Toronto, Ontario, Canada, M3H 5TA, Email: val.swail@ec.gc.ca
(12) NCAR (National Center for Atmospheric Research), 1850 Table Mesa Drive, Boulder, CO 80305, USA, Email: worley@ucar.edu
(13) Deutscher Wetterdienst, Bernhard-Nocht-Str. 76, 20359 Hamburg, Germany, Email: z.reinhard@t-online.de

ABSTRACT

Climatological products are required for monitoring and studying global climate change and accurately identifying secular trends over the past two centuries. These products require consistent and well-characterised observational data and metadata from the earliest ship observations and from the modern ocean observing system. Maintaining and developing long-term surface marine climatological datasets requires a different approach to data management than for operational applications.

The current management of climatological datasets is discussed and specific modernization steps recommended. The status of relevant *in situ* observing systems is reviewed in the context of available satellite data. The extent to which requirements for maintaining sampling, redundancy, and consistency are met by existing data delivery mechanisms is considered. Recommendations include: data and metadata rescue; maintaining consistency with the historical record; modernization of data flow and climatological products; for observations with added-value through improved metadata, quality control and uncertainty characterization; and improved dataset construction methods.

1. INTRODUCTION

Shipboard observations have long formed the basis of climatological charts and atlases [52], and the importance of data consistency recognized [28]. Applications have evolved from defining average conditions of marine climatology [47] to now include climate change projections, research into climate variability, atmospheric reanalyses, engineering design, military applications, and operational planning.

Owing to the need for long-term data consistency, the data and metadata requirements for marine climatology can be more demanding than those for operational applications such as Numerical Weather Prediction (NWP). These requirements must be taken into account when planning and implementing the future marine observing system. In a changing climate the need for long-term, consistent datasets is obvious, and products and processing methods must be flexible to allow the accurate representation of changing environmental conditions.

The largest freely-available repository of global *in situ* surface marine data is the International Comprehensive Ocean-Atmosphere Data Set [37], [56] and [59]. Together with historical ship data back to the late 17th century rescued from worldwide archives, ICOADS integrates data from several observing systems now coordinated by the Joint WMO (World Meteorological Organisation)-IOC (Intergovernmental Oceanographic Commission) Technical Commission for Oceanography and Marine Meteorology (JCOMM), including Voluntary Observing Ships (VOS) [24] and environmental data buoys [30]—both moored [29] and drifting [21]. Integration of such varied data into climate archives must proceed carefully.

In support of global climate studies, WMO introduced the Marine Climatological Summaries Scheme (MCSS) in 1963 to facilitate international exchange, quality control (QC), and management of delayed-mode (DM) VOS data (from paper or electronic logbooks). Today however, the MCSS only partly fulfils our marine climatology requirements. Thus two JCOMM Task Teams (TTs) will modernize the separate data management and climatological product functions of the MCSS, on Delayed-Mode VOS Data management (TT-DMVOS), and Marine-meteorological and Oceanographic Climatological Summaries (TT-MOCS).

Within JCOMM, the Expert Team on Marine Climatology (ETMC) is charged with reviewing requirements from the Global Climate and Ocean Observing Systems (GCOS and GOOS) for climatological data sets [16] and determining procedures and principles for the development and management of oceanographic and marine meteorological climatological data sets. Those responsibilities cross-cut other JCOMM programmes, including the Ship Observations Team (SOT) and the Expert Teams on Sea Ice and Wind Waves and Storm Surges (ETSI and ETWS [42] and [43]).

Priorities for marine climatology have been guided through two related series of Workshops (CLIMAR [7] and MARCDAT [23]). Updates to the "dynamic" part [53] and [17] of the WMO *Guide to the Applications of Marine Climatology* [49] represent an important outcome from the CLIMAR series, and future workshops are planned.

2. REQUIREMENTS FOR MARINE CLIMATOLOGICAL INFORMATION

2.1. Applications

Marine data management programs are typically developed to meet operational requirements. Historically these were for climatological information, thus observations extracted from ships' logbooks were used to produce wind and current charts (e.g. [28], [9], [10] and [11]; see also [27]), and meteorological atlases (e.g. [2]). The development of NWP brought the requirement for near real-time (RT) data. By the 1970s, ship reports were augmented with data from moored and drifting buoys, and satellite data in increasing quantities. Alongside evolving operational requirements, the need remains for high-quality datasets for marine climatological applications. The future challenge is to define these applications, to consider their data and metadata requirements, and to ensure that those requirements are considered alongside the operational requirements at the observing system planning stage.

An obvious requirement for long-term consistent datasets is for monitoring changes in the state of the climate system. Multi-decadal datasets are essential, and century or longer datasets extremely desirable to identify secular trends and multi-decadal variability against the background of interannual and decadal variability. Sea surface temperature (SST), sea-state and sea-ice, air temperature, humidity, sea level pressure (SLP), and winds are GCOS Essential Climate Variables (ECVs) [16]; clouds and weather also are critical for marine climatology.

The particular requirements for SST analyses [34] emphasize the need for multivariate observations to interpret and adjust the SST observations, for comprehensive platform and instrumental metadata, and for independent data from multiple platforms and instruments to allow the quantification and reduction of data biases. Long-term consistent datasets are needed to initialize and verify models for climate prediction, for climate assessments (e.g. IPCC AR4), and climate change detection and attribution (e.g. [35]). The requirements for surface fluxes are discussed in [14].

Surface marine data form only one of many data streams for global atmospheric analyses [44]. However reanalysis will continue to benefit from improvements in the quality and coverage of *in situ* marine data, both as input and for product validation. The systematic feedback into climate archives of information from reanalyses (e.g. [8]) will help in characterizing the quality of input data.

Although satellite data are increasingly reliable and extensive [4], [5] and [12], *in situ* observations are needed to detect and resolve biases in remotely sensed data. For example, most satellite-based SST products require reference to *in situ* measurements to remove large-scale biases due to varying atmospheric composition. Conversely, satellite data could serve more important QC roles for the management of *in situ* data. Satellite data can also help to improve long time-series generated from *in situ* products alone (e.g. [20] and [33]).

2.2. Data characteristics

Climate applications require data of consistent quality over long periods. In reality the observations are temporally and spatially heterogeneous, as methods, instruments, and platforms change, together with data management and archiving. Each observation must therefore be as completely characterised as possible, including a unique identifier linking to the originating platform (e.g. ship callsign or WMO buoy number) to detailed metadata about each reported measurement. Further, unique identifiers for each observation would allow more effective data management [41]. This information can then be used to characterize the observations and apply adjustments where appropriate.

Observational characteristics can also vary according to the codes and formats used to report or archive the data, the original units of the observation, any unit conversions applied, and the methods used to calculate derived parameters such as relative humidity. Archives should always retain the original observation as made, and for observations that have been converted complete metadata should be retained detailing processing and conversions applied.

2.3. Sampling requirements

Sampling requirements for marine climatology are not well defined due to the irregular spatial and temporal distribution of observations from many different platforms (Fig. 1). Data adequacy will depend on the quality of each measurement (including the availability of observing metadata and information on other environmental parameters that may affect data quality), the natural variability, the spatiotemporal correlation scales of the field and observational errors. Accuracy requirements are defined in, e.g. [32].

Several climatological gridded datasets now contain uncertainty estimates (e.g. [33, 38 and 3]) and some characterization of the relationship between observation numbers and grid box uncertainty has been made [25]. Observing System Simulation Experiments may help design an observing system to satisfy a particular requirement [62]. More analyses are required to make assessments against a range of accuracy requirements for all variables and using a variety of techniques. For most variables, the present *in situ* sampling is uneven (Fig. 1) and more optimal sampling may be achievable with complementary spatial coverage from satellites [61]. Uneven sampling affects both regional climate change estimates and may also alias signals.

Although this heterogeneity causes problems for consistency, the diversity of observing methods and platforms allows the observations from different methods to be compared and help ensure that systematic biases from a particular observation type or individual platform can be detected.

2.4. Data availability and accessibility

Marine climatological data are archived in a variety of locations, often further separated according to platform types. However, for VOS data, the WMO MCSS collates and shares data internationally. Eight countries, designated Responsible Members (RMs), gather and process the logbook receipts from Contributing Members (CMs), and publish climatological summaries. Two Global Collecting Centres (GCCs) were established in 1993 in Germany and the UK to improve data management and QC. Archives of RT ship observations (and many marine and other data types) shared on WMO’s Global Telecommunication System (GTS) are often held in National Meteorological and Hydrological Services (NMHSs), sometimes in long term archives. Data are eventually archived in World Data Centres, such as the NOAA National Climatic and Oceanographic Data Centers (NCDC and NODC).

The collection of buoy observations is overseen by the Data Buoy Cooperation Panel [30]. Many moored buoy observations are available via the NOAA National Data Buoy Center (NDBC) through international co-operation, but a complete archive of coastal and open-ocean moored buoys is not presently available from a single source. Drifting buoy data are similarly available from several sources, but Canada’s Integrated Science Data Management (ISDM) operates the Responsible National Oceanographic Data Center for Drifting Buoys (RNODC/DB, [21]) archiving many of the data. Meteorological observations associated with tide gauge measurements are managed under the Global Sea Level Observing System (GLOSS) [31]. Meteorological data from coastal and fixed ocean platforms, and island stations, appear to be largely governed by national, commercial, or terrestrial data systems.

Many of these diverse data streams have been unified into ICOADS [56]. Its VOS component builds on data exchanged under MCSS, together with bilateral exchanges of many additional data. GTS or DM data from drifting and moored buoys, research vessels (RVs), near-surface oceanographic profile measurements, and from other automated Ocean Data Acquisition Systems (ODAS) are also included for recent decades. Platform and instrumental VOS metadata regularly published by WMO ([46]; Pub. 47) are also blended [22]. ICOADS observations (http://icoads.noaa.gov/) are made available in International Maritime Meteorological Archive (IMMA) format [56]. Each individual report contains the observations of ECVs and other meteorological and oceanographic variables reported by a given platform at one time and place, together with available metadata and including metadata added by the ICOADS project to track each data source.

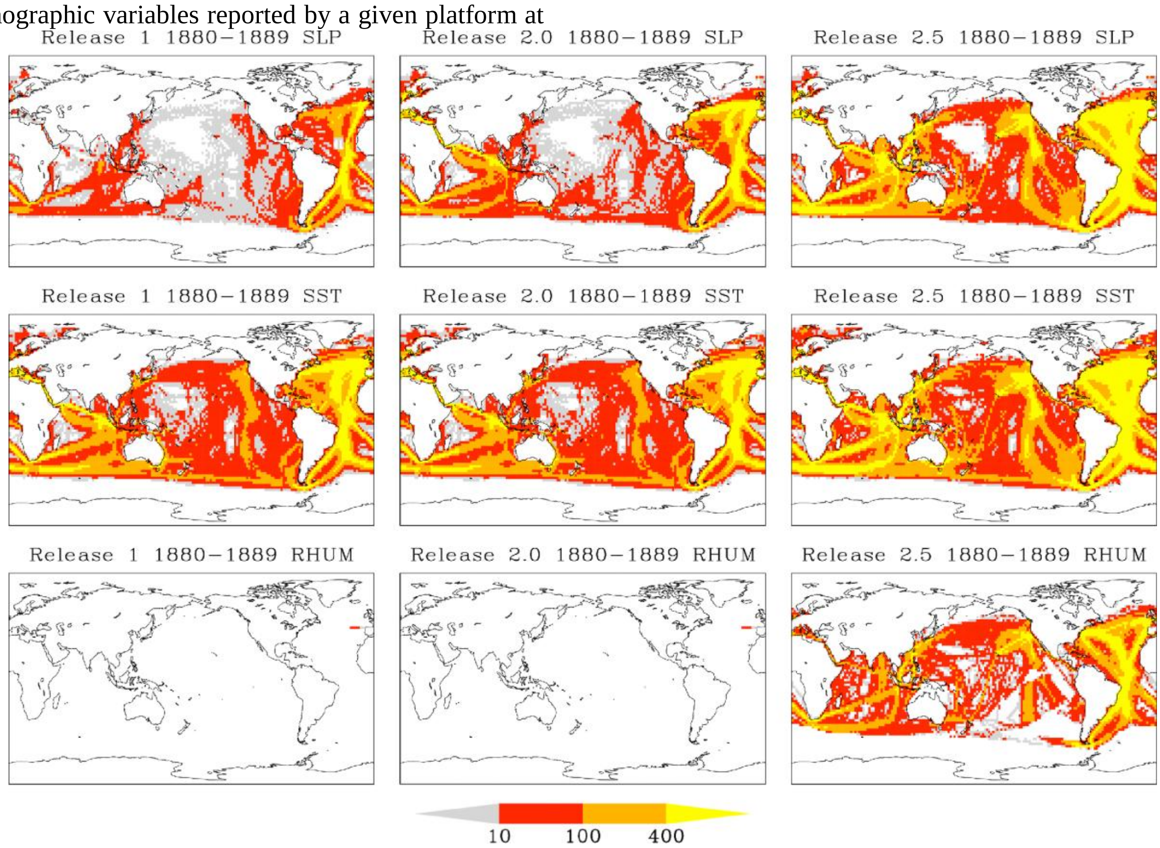

Figure 1. Upper panel: Decadal (1880-89) totals of SLP observations illustrating data additions between ICOADS Releases 1 (1985), 2.0 (2002), and Release 2.5 (2009). The colors show the number of observations in a 2° box per decade. Middle and lower panels: As for upper panel except for SST and relative humidity (RHUM). The dramatic increase in RHUM data for Release 2.5 is explained by a change in QC procedure [59].

Additional *in situ* marine data of climatological importance, but not yet regularly integrated into basic datasets such as MCSS and ICOADS, include: sea-ice data, historical and high-resolution meteorological and oceanographic data (e.g. [39]), wave data from buoys and ODAS [43], OceanSITES time series stations [36], and meteorological observations made at tide gauge locations [31]. In some cases, these data streams also are not yet well integrated into JCOMM operations. Moreover, more work is needed within JCOMM to consolidate (and rescue historically) metadata for buoys and ODAS. While improved integration of these and other more specialized data and metadata would be hugely beneficial, significant changes would be required to formats and processing systems. This may be addressed under the WMO Integrated Global Observing Systems (WIGOS) initiative.

2.5. Products

Using these extensive archives many widely-used operational, reanalysis, and climate products have been constructed. SST (with sea-ice) has received the most attention (e.g. [58] and [34]), but products are also available for SLP (e.g. [1]), visually estimated VOS wave data (e.g. [18]), surface humidity (e.g. [45]), night marine air temperature (e.g. [33]) and surface fluxes [14].

Other marine climatological products include ICOADS monthly summary statistics (e.g. Fig. 1) extending back to 1800, and MCSS chart and tabular Marine Climatological Summaries (MCS, Fig. 2). Users and requirements for marine climatological summary products such as MCS will be considered by TT-MOCS as part of its modernization, along with the potential for integrating meteorological, oceanographic and sea-ice data. Products must be readily discoverable and accessible using web service technology.

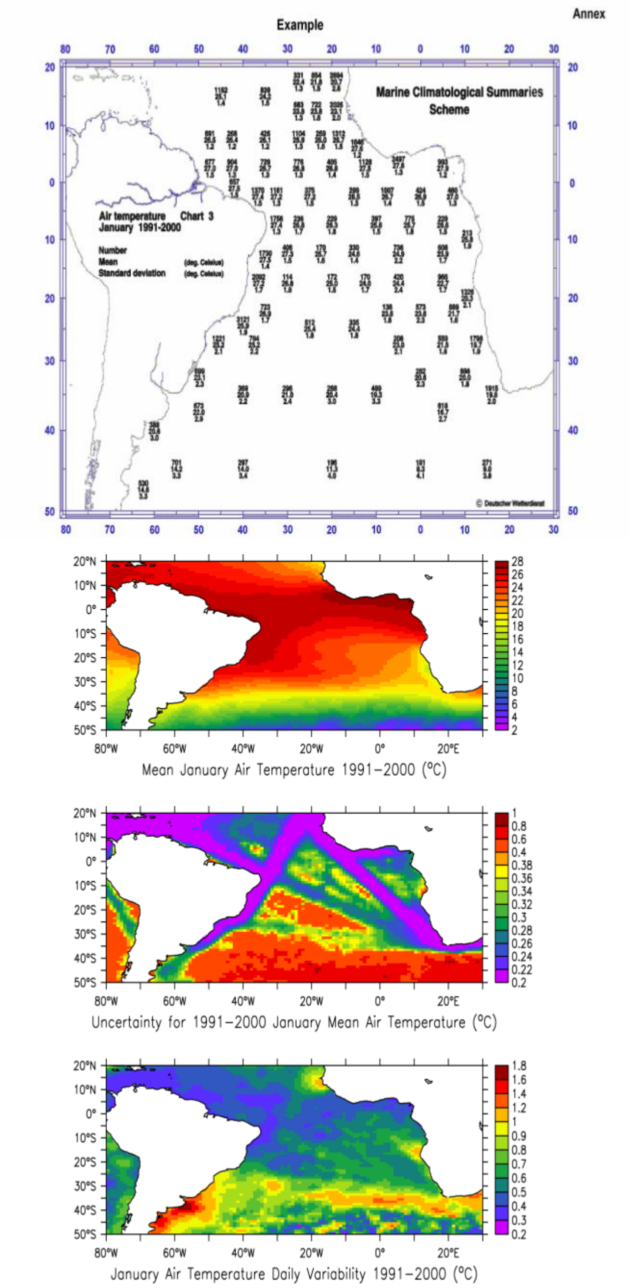

Figure 2. Upper panel: Marine Climatology Summary (MCS) example tabulation. The 10-year (1991-2000) January mean air temperature values, and accompanying statistics, have been computed for boxes that can vary in size geographically according to WMO specifications [48] (e.g., using larger boxes for data-sparse regions). Lower panel: Similar information from a bias-adjusted dataset [3].

3. DATA MANAGEMENT STATUS

3.1. Current Status

ICOADS is an important resource for the research community, including the individual observations used as input for many derived products. We therefore discuss the data management systems that feed into ICOADS for the major marine platform types. The potential for inclusion of new or underutilized data sources, and for forging more effective links with MCSS and other JCOMM/WMO programs are also considered.

The integration of DM and RT sources into climate data archives can be extremely complex (Fig. 3), with the typically more complete and higher quality DM sources prioritized over GTS receipts. Incomplete or missing ID information and time/space location errors are among the issues that can restrict the detection and elimination of duplicates between RT and DM data and among historical data.

Currently ICOADS uses GTS data primarily from the NOAA National Centers for Environmental Prediction (NCEP), processed to combine near duplicates and fragmentary receipts. The data are supplied by NCEP in the BUFR format (FM94, [51]), with the traditional alphanumeric GTS string (e.g. FM13 SHIP or FM18 BUOY, [50]) attached. This preservation of the originally reported information continues to be crucial for resolving biased or incomplete translations into BUFR, and should be adopted as best practice by WMO. Differences exist between GTS archives internationally (e.g. due to message corruption, QC processing for NWP, or different storage methods), so accessing additional sources would likely lead to a better quality product (forthcoming ETMC study).

WMO’s move to BUFR and other table-driven codes (e.g. CREX, FM95; [51]) appears to be complicated by inadequate links among WMO, JCOMM, GCOS, GOOS, and other relevant international bodies. However, JCOMM recently established a task team to coordinate and consolidate its requirements and provide a unified point of interaction with the WMO Commission on Basic Systems and in the future the WMO Information System (WIS). In view of the needs for improved observational characterization (e.g. for SST analyses), a new JCOMM Pilot Project is investigating the potential for increased RT transmission of ocean temperature metadata for a range of platforms, including VOS [41].

3.2. Ship data

Much ship data was digitized decades ago, exchanged bilaterally prior to the MCSS, and later blended into ICOADS [57]. Digitization actively continues (e.g. [13]) with a priority on filling gaps, such as the World

Wars, and extending the record earlier in time [6]. Ongoing digitization activities include RECovery of Logbooks And International Marine data (RECLAIM) (http://icoads.noaa.gov/reclaim/; [55]), Atmospheric Circulation Reconstructions over the Earth (http://www.met-acre.org/), the NOAA Climate Database Modernization Program (CDMP) [13], and Global Oceanographic Data Archaeology and Rescue (GODAR) [26]. Nevertheless rectifying omissions and biases in existing digital collections can be important scientifically, and better methods of assessing the value of digitizing data and metadata are required.

VOS DM data continue to be managed under the MCSS through the RMs and GCCs, however, further modernization is now needed. For example, not all data are promptly exchanged and some maritime countries are not participating. Benefits of participation include applied QC and feedback links to CMs regarding data quality, and availability of additional data elements in the DM reports not provided over GTS.

Together with the rapidly increasing adoption of automatic measurement systems by some VOS operators, increasing diversity of ship-to-shore transmission methods [24] may lead to changes in data availability and characteristics. Standards, guidelines, and formats for data transmission are therefore needed to avoid loss of data elements and consistency with previous data. Limited metadata on observation practices are transmitted with the observations, but a more complete characterization is possible if the VOS report can be linked to more extensive metadata in WMO Pub. 47.

Unfortunately, the association of metadata with recent VOS reports is being obstructed by RT (and to a more limited extent DM) callsign masking for commercial and security reasons [54]. Masking requires changes to data processing systems to apply QC, and bias adjustments to data may not be possible if ship identifiers are generic or absent. Solutions meeting the requirements of ship owners and operators, NMHSs and climate users are urgently being sought. One significant impact has been the complete masking since December 2007 of all ship reports in the NCEP data used as the primary GTS input to ICOADS.

3.3. Research Vessel data

Data collected by RVs do not regularly contribute to ICOADS, except where the RV is recruited to the VOS program and makes "bridge" reports usually using an instrumentation set provided by the VOS operator rather than the RV operator [40] and [24]. Subsets of high-resolution data collected by RVs using their research instrumentation, provided by the Center for Ocean-Atmospheric Prediction Studies are now available in ICOADS, but questions remain regarding the independence of bridge and high-resolution data from the same RV.

The contribution of RVs to marine climatology could be substantial, as data from their research instruments should be high quality, well-characterized with observational metadata, and often from regions poorly sampled by commercial VOS [39]. However their value as independent validation data is also high and such data must be clearly identifiable within the climate archives to allow their exclusion from data products when required.

3.4. Moored and drifting buoy data

Moored buoy data are collected in a variety of national programs, but no central repository exists. Depending on the array, GTS data can arrive either in the SHIP or BUOY code, with some BUOY data now also redundantly circulated in BUFR. Some moored buoys are presently withheld from the GTS (e.g. [36]) and transmitted to the buoy operator by satellite and retained for local or research use. Withheld data are important for NWP and other validation, however, provided such data are clearly identifiable in archives and thus excluded as desired, there are also benefits from integration.

DM tropical [29] and US coastal moored buoy data are periodically integrated into ICOADS replacing GTS receipts. Only a subset of the reports and parameters are included (e.g. omitting high-resolution wave spectra data). Other GTS sources of moored buoy observations are presently not as well identified within ICOADS, and some DM data are yet to be integrated.

ICOADS has integrated ISDM drifting buoy data from their QC'd GTS-based archive which also includes some moored buoy receipts and data from deep-drogued drifters. Although ISDM data archives are extensive, additional data are probably still available elsewhere [21].

Metadata from buoy operators are beginning to be aggregated internationally by the JCOMM in situ Observation Platform Support Centre (JCOMMOPS) and at centers such as NDBC. In addition, an ODAS metadata service (ODASMS) has been established at China's National Marine Data and Information Service (NMDIS). However, the completeness and future operational roles of these archives is unclear. Challenges remain with the rescue of historical buoy and ODAS metadata, and its integration with observations.

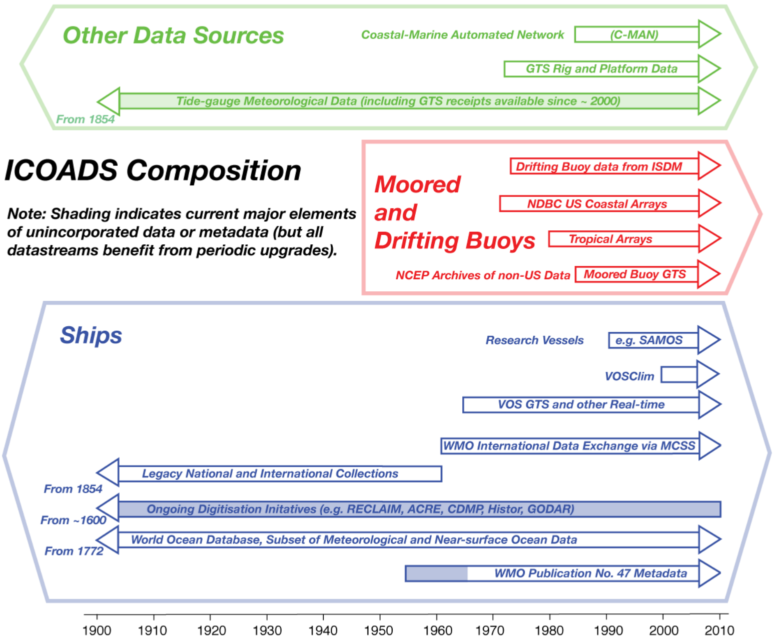

Figure 3. ICOADS data composition over time since the turn of the 20th century, grouped into three major categories of platform types (Ships, Moored and Drifting Buoys, and Other Data Sources).

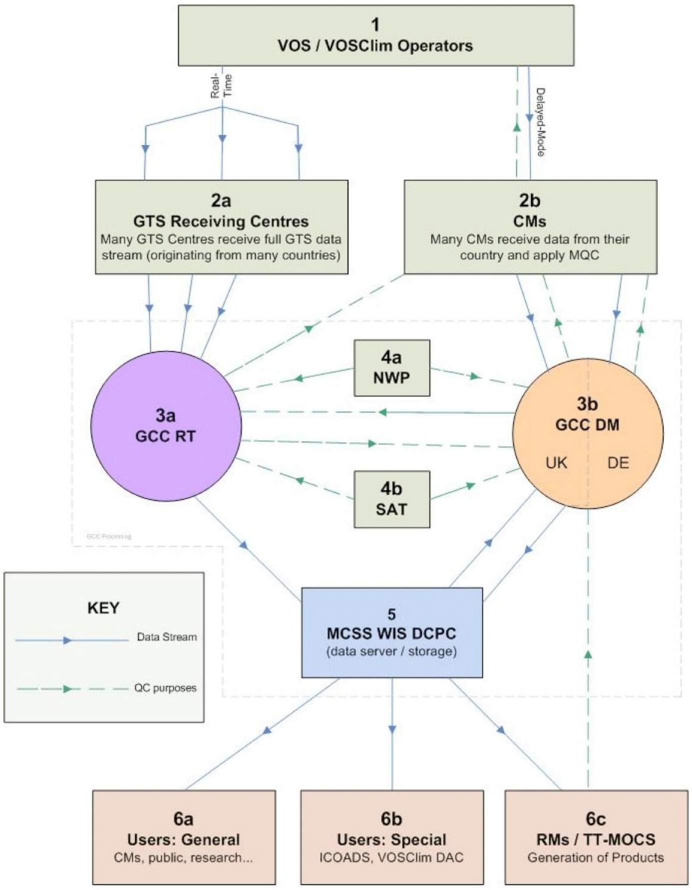

Figure 4. Proposed flow of modernized MCSS data and products, and organizational (including GCCs, TT-MOCS) and project (including ICOADS, VOSClim, and WIGOS Pilot for JCOMM) roles. The light-green boxes (1, 2 and 4) indicate components which already essentially exist in the current systems. Boxes of varying colors represent new or modified aspects to the proposed data flow.

3.5. Additional *in situ* data types

Surface values from oceanographic profiles and some accompanying surface meteorological data from the US NODC World Ocean Database (WOD) are available via ICOADS. Argo profiling floats form an important and growing contribution to WOD, and while they currently only make up a small part of the WOD temperature measurements available near the ocean surface, engineering changes are planned to incorporate more surface or near surface measurements [15]. Concurrently reported data (e.g. reference SST vs. profile "SST") would ideally be available, but are not presently via ICOADS regular fields. As for RVs, overlaps can arise between VOS bridge reports from the oceanographic ships and accompanying WOD meteorological data. A solution that preserves genuinely independent data is not yet available.

Some fixed platform (e.g. oil rig) meteorological reports are available in both RT and DM. There are unresolved difficulties with differentiating such reports from ship and buoy reports and with metadata collection. In some cases commercial interests also may complicate data and metadata availability.

4. PROPOSED DATA MANAGEMENT IMPROVEMENTS

4.1. MCSS

TT-DMVOS has proposed modernized management of DM VOS data that should improve links with GTS data collection, the WIGOS Pilot Project for JCOMM, and ICOADS. The proposed data flow is illustrated in Fig. 4 and retains important aspects of the existing scheme, including enhanced formats, QC, and strong connections to data providers, but improves linkages to the GTS, WIS, and data users including archives. Observations are made by ships participating in VOS and the VOS Climate Project (VOSClim) and managed by VOS operators. The data are ordinarily reported both in RT and DM (paper or electronic logbooks).

In the proposed RT data flow, GTS Receiving Centres retrieve VOS data from the GTS/WIS. Each GTS Receiving Centre will forward relevant marine data to the GCC RT. The GCC RT is responsible for identifying unique data among the data streams, assembling the RT dataset and applying RT QC (RQC). RQC will be based on comparisons with climatologies, co-located model NWP output, and available satellite products. RQC output will identify possible problems for notification to data collectors. Both the original and QC'd data will then be passed to the Server and exchanged with the GCC DM. This RT data handling essentially internationalizes existing national activities.

DM data are collected from the operators by NMHSs or other national services. These CMs (currently numbering 26) are responsible for applying minimum QC (MQC) to the data, and forwarding them to the GCC DM. The GCC DM is responsible for assembling the DM receipts, ensuring MQC is applied, comparing RT and DM data via the Server and managing duplicates of RT and DM data. Any problems will be notified to data collectors. A higher-level QC (HQC) is then applied before forwarding data to the Server. This represents a significant expansion of existing GCC responsibilities, including more proactive efforts to locate missing DM data, improved QC, ongoing RT/DM data comparisons, and open data availability.

Both the GCC RT and DM are planned to link to the WIS as a Data Collection or Production Centre (DCPC), using software recommended by the "International Oceanographic Data and Information Exchange" (IODE) Ocean Data Portal and the WIGOS Pilot Project for JCOMM. The WIS will hold "discovery" metadata for the data on the GCC servers. The Server then will provide appropriate access to both the discovery metadata and data, via the WIS.

Data users are explicitly recognized within the proposed structure including the public, CMs, RMs, the VOSClim Data Assembly Center (DAC), ICOADS and product developers including TT-MOCS. The RMs have indicated interest in involvement in the modernized system which may include an expanded role such as the generation of products.

One important change from the current data flow is the additional responsibility for GTS data. The combination of several GTS data sources will provide a higher quality data stream and an optimal combined GTS/DM VOS data archive. The GCCs could provide a secure environment for data processing, which may help resolve call sign masking issues. A related potential development that would likely need to be handled in a secure environment is proposed access to contemporary and/or historical "ship particulars" from Lloyd's commercial organizations, currently under discussion with the International Maritime Organization (IMO).

To supplement the current MQC, an HQC standard is also proposed, envisioned primarily as an automated system. Convergence with existing QC processing software and standards [19] will be explored, along with interoperability with ICOADS and data providers. Ultimately, the proposed QC system for DM data will include: improved position and tracking checks; and comparisons with improved climatologies, and potentially with GTS monitoring information, with archived NWP and reanalysis outputs, and with satellite data for some parameters.

4.2. ICOADS

Despite ongoing digitization and data rescue activities there remain many undigitized historical ship data, some relatively unknown outside archives and libraries. Work continues to actively catalogue, image, digitize, and ultimately convert digitized data into the IMMA format [56]. However, these are all expensive tasks, and better methods are needed for prioritizing the value of specific collections, and the scope of digitization, for different climate applications, as well as for related research disciplines, including oceanography, fisheries, and ecology [55].

Also important is the potential value of enhancing digital collections already included in ICOADS. There may be alternative data sources closer to original data than those previously used, or additional data elements such as early sea-ice observations (see [57 and 55]).

Further efforts should also be made to identify digital data holdings not yet incorporated into ICOADS. Examples include additional RV data available through activities such as SAMOS [40], and data held commercially or nationally such as that from coastal and ocean platforms, and oil rigs, such as the SIMORC data set (http://www.simorc.org). More unified and efficient access to high-resolution moored and drifting buoy data would facilitate both subsampling into ICOADS for marine climatology, and other activities based on the original data such as validation.

Improvements to QC for climate datasets are required, however more research is needed. Developing effective feedbacks with NWP and reanalyses would help. Improved QC is likely to include ship and buoy tracking to identify mispositioned reports, corrupted callsigns, and improve identification of duplicate reports. The planned incorporation of research results into data bias, uncertainty, QC methods etc. into an “advanced” version of ICOADS is described in [56].

As the number of parameters included in marine climatological reports expands to include parameters such as skin SST, salinity and precipitation there will be a need for more flexible formats. The IMMA format, proposed for wider adoption within JCOMM (including MCSS), addresses this need through optional attachments for different data types and could be extended to include a wide range of data types.

Ship data within ICOADS could be improved through the combination of information from different sources, e.g. blending of callsign information between matching DM and GTS reports. Metadata access should be improved and consideration given to the association of metadata using proxy information, such as assigning measurements methods based on VOS recruiting country, or measurement heights based on ship size or type. Flags would indicate the level of confidence in metadata assignment. Data from the VOSClim project [24] should be clearly identified within ICOADS and VOSClim additional parameters and model output incorporated into the archive.

Collection and distribution of buoy and other ODAS metadata is not yet well coordinated, although some progress has been made. The need to better incorporate metadata on hull and payload types, instruments, observation heights, data averaging and sampling into the buoy archives is recognized. The potential for inclusion of a wider range of buoy parameters in ICOADS, including from wave buoys, should also be investigated. Two Data Buoy Coordination Panel (DBCP) Pilot Projects are actively promoting the increase of wave measurements from moored and drifting buoys, investigating potential biases between different buoy platforms, and developing a comprehensive metadata archive for existing and historical buoy networks [43].

5. RECOMMENDATIONS

1) Support the continuing rescue and integration of historical ship, expeditionary, and oceanographic data and metadata, including cataloguing and improved prioritization of potential sources.

2) Support work to prioritize and reprocess existing digital sources that have been incompletely or inadequately processed, seeking to make the highest quality and broadest useful range of climate observations readily available.

3) Support the rescue of historical buoy and ODAS platform and instrumental metadata.

4) Enhance JCOMM data systems to efficiently serve integrated historical and contemporary buoy and ODAS data and metadata for both open-ocean and coastal moored buoy arrays.

5) Consider integration of surface meteorological, oceanographic, sea ice, wind wave and storm surge climatologies.

6) Ensure that migration to BUFR and other table-driven codes does not compromise the quality of climate archives by: (a) preserving all data as originally reported, (b) effective validation of new codes to ensure accurate preservation of reported data, (c) considering the requirement for continuity when developing new codes, and (d) developing standards for ship-to-shore transmission.

7) Support modernization by TT-DMVOS of the MCSS, including: (a) integration with the GTS data stream and improving data flow, completeness, rapidity of access and linkages to international data management systems; (b) development of HQC standards within MCSS; (c) developing interoperability with ICOADS.

8) Support development of modernized MCSS climatological end-user products incorporating information on data density and uncertainty, and made widely and conveniently available to users.

9) Support strategic studies seeking to develop more

optimal sampling patterns.

10) Support the continuing improvement and expansion of ICOADS with both historical and contemporary data and metadata, including the proposed international initiative for "advanced" (bias adjusted) products.

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