MEETING SUMMARIES

Advances in the Use of Historical Marine Climate Data

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Understanding and observing climate change is a priority. While we rely on numerical models to predict changes to the climate, we gain confidence in those models through their ability to model the evolution of past climate change. Monitoring current climate change demands as long a historical perspective as possible. The study of past climate change relies critically on the availability of datasets that characterize the climate of Earth, both in instrumental and preinstrumental times. Marine climatology involves the development and analysis of such datasets and the Joint World Meteorological Organization (WMO)–Intergovernmental Oceanographic Commission (IOC) Technical Commission for Oceanography and Marine Meteorology (JCOMM) Workshop on Advances in Marine Climatology (CLIMAR)/International Workshop on Advances in the Use of Historical Marine Climate Data (MARCDAT) series of meetings brings together the community of scientists who strive to produce climate-quality datasets from a variety of sometimes unpromising data sources. Their interests range from the recovery of data from centuries-old ships' logbooks to producing consistent datasets from series of operational satellites.

SECOND INTERNATIONAL WORKSHOP ON ADVANCES IN THE USE OF HISTORICAL MARINE CLIMATE DATA

WHAT: Sixty participants—marine data users and managers of marine data and products—from eight countries met to set priorities for the future development of marine climate data and products
WHEN: 17–20 October 2005
WHERE: Met Office, Exeter, United Kingdom

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MARCDAT-II attracted more than 60 participants from Canada, Denmark, Germany, Japan, the Netherlands, Russia, the United Kingdom, and the United States for four days of oral presentations, posters, and discussion. On 21 October two related Global Climate Observing System (GCOS) Working Group meetings were held—one on SST and sea ice, and the second on surface pressure.

Invited and contributed presentations covered a wide range of topics during the first two-and-a-half days. Participants then divided into breakout groups categorized by climate variable to discuss developing gridded datasets, quantifying data and analysis uncertainties, and using marine data in climate research; database development and access was considered in plenary. This article summarizes the workshop's presentations, breakout session results, and recommendations. These and other results are being reported to the Atmospheric Observation and Ocean Observations Panels for Climate (AOPC/OOPC).

The meeting opened with a review of progress on the consolidated recommendations from past workshops. Good progress had been made in many areas since MARCDAT-I (see appendix for expansion of acronyms) in early 2002, including the incorporation of ICOADS into global analyses; data and metadata digitization and recovery; dataset development, including the quantification of uncertainty; the use of metadata to understand data bias; and improved data access and archival. A special issue of the *International Journal of Climatology* (2005, Vol. 25, No. 7; see Gulev 2005) for CLIMAR-II, for example, ensured those meeting outcomes were widely disseminated.

ABOUT THE WORKSHOP SERIES

The MARCDAT-II workshop was the latest in a series held approximately every two years since 1999. MARCDAT (in Boulder, Colorado, in 2002 and Exeter, United Kingdom, in 2005) alternates with the CLIMAR Workshops on Advances in Marine Climatology [in Vancouver, British Columbia, Canada (1999), Brussels, Belgium, (2003), and planned for the coming year (2008)].

All of these workshops have brought together a wide spectrum of marine data users and managers of marine data and products, and have included an underlying focus on the continuing evaluation, utilization, and improvement of ICOADS (Worley et al. 2005). In addition to published outcomes (including Díaz et al. 2002; WMO 2003; Parker et al. 2004), the previous workshops have produced and actively tracked a consolidated set of scientific and technical recommendations (see information online at www.marineclimatology.net) to help guide the work of this group and provide feedback for the broader research community.

HISTORICAL DATA AND DIGITIZATION. Several projects including CLIWOC, the Japan Meteorological Agency Kobe Collection Digitization, the NOAA CDMP, and the EU's EMULATE project have significantly increased the availability of marine meteorological data, going back as far as 1750 and in the very data sparse periods covering the two World Wars. For example, the EU's CLIWOC project (García-Herrera et al. 2005) produced a daily oceanic climatological database for the period from 1750 to 1854. CLIWOC contains ship logbook data from archives in Spain, the United Kingdom, Holland, and France, which needed a range of corrections and adjustments before they could be used for further research. One of the problems was that the use of Greenwich, United Kingdom, as the prime meridian was only accepted internationally in 1884. In CLIWOC, 646 different prime meridians were used. In addition, the accuracy of the ships' position information was not high, and small daily inaccuracies accumulated into large miscalculations by the end of a voyage. Resources are still required to incorporate these data into marine archives such as ICOADS (Woodruff et al. 2005).

THE MULTIVARIATE IN SITU CLIMATE RECORD. The routine meteorological observations from merchant, research, and other VOS continue to provide a critical contribution to the marine climate record. Not only do they form the longest marine in situ record, but they also provide information on a wide variety of meteorological parameters, such as SST, air temperature, humidity, winds, pressure, ocean waves, clouds, surface heat exchange, precipitation, sea ice, and subsurface ocean profiles. It has long been known that the production of climate-quality datasets from these observations is a challenge because of variable measurement methods and data quality. However, meeting participants heard of significant progress toward understanding biases and uncertainty in all of these variables. Recently produced VOS-based datasets now routinely contain estimates of both bias and sampling uncertainty, allowing rigorous estimates of long-term climate change to be made.

METADATA AND DATA BIAS. The availability of metadata describing the measurement methods used by VOS is proving vital in advancing our understanding of the marine record. Again, digitization efforts are enhancing our knowledge; VOS metadata collected by WMO between 1955 and 1972 have recently been digitized by CDMP. These, along with more recent metadata, show the evolution of the VOS program from a low-tech combination of visual observations, bucket sampling of SST, and mercury thermometers and barometers, to advanced, often high-resolution, systems using anemometers, digital aneroid barometers, and psychometric air temperature and humidity observations. The climate observing system requires both quality and consistency, so the evolving system must be monitored and understood, including the important requirement, which is as yet unmet, for a similar coordinated system of historical and contemporary metadata from buoys and other ODAS.

DATASET DEVELOPMENT. The workshop participants heard of significant progress in dataset development techniques. Improving techniques to produce gridded datasets, combined with a greater understanding of data uncertainties, has led to a diversity of gridded marine data products, especially for SST, surface pressure, and sea ice. Other important marine variables, such as clouds, humidity, and surface waves, have received less attention and more limited progress toward data products. This is disappointing because an intercomparison of products, created using independent assumptions and procedures, is a good method to understand and improve marine data fields. There is also much to be gained from multivariate analyses, for example, combining surface flux and ocean profiles, SST, and either sea ice or air temperature. A technique was also presented that used a climate model to successfully validate bias corrections applied to historical SST data. Submonthly products are now starting to be developed from in situ sources, and other new developments were presented, including the possibility of generating 100 years of daily reanalysis products with uncertainties similar to those in a modern 2–3-day forecast, new methods for the construction of surface flux datasets using probability distributions, and the effect of dataset reconstruction techniques on climate change estimates.

DATA RECOVERY AND IMPROVEMENT. The story does not end with the VOS reports. Buoys, both moored and drifting, are forming a larger and larger part of the marine climate record, together with other ODAS (e.g., near-surface ocean profile temperatures). Many ODAS provide a higher sampling resolution than do VOS, but may not report all of the variables needed to compute air–sea fluxes. There is evidence of systematic time-varying differences between ship and buoy SST data in recent decades that need much more study. This inhomogeneity has a potential impact on climate change assessments. Historically, not all humidity observations from moored buoys had been decoded, and resources to make these data available through ICOADS are needed. Many are surprised that high-quality meteorological observations from research vessels have not typically found their way into the climate record. ICOADS is working in partnership with SAMOS to subset these research vessel data and include them in the climate record with appropriate metadata. Other reports covered SAMOS work to improve the quality of research vessel meteorological data, and the JCOMM VOSClim project, which has been designed to characterize and improve the quality of the VOS reports.

THE CLIMATE RECORD FROM SATELLITES. Satellite estimates of marine parameters, while of a much shorter duration than the ship record, are now an important part of the climate record and in some cases are able to provide very high resolution fields, for example, SST. However, it should be noted that the Intergovernmental Panel on Climate Change has not yet used satellite SST records to estimate temperature changes in their core assessment products because of concerns about residual inhomogeneities. To help resolve this issue, the Pathfinder project was a 21-yr, 4-km-daily SST analysis that is undergoing careful intercomparison and validation, while the GHRSST-PP plans a "reanalysis" effort to produce climate-quality SST back to at least 1984. The satellite observing system has many of the same qualities as the in situ observing system. Estimates of the same quantity from different measurement methods must be reconciled and the records of different satellites compared and combined in a way that minimizes biases. The strengths of the different satellite measurements must be exploited: the high resolution of AVHRR, the ability to "see" through clouds of the AMSR-E, and the dual-looking self-calibrating (A)ATSR, which can adjust for the effects of aerosols.

DATA ACCESS. As data products diversify it becomes increasingly important to ensure that potential data users have easy access to the latest observational data, data products, and documentation. The world's largest collection of accessible marine data—ranging from eighteenth-century ship data, to measurements from buoys and other ODAS—

has been assembled in ICOADS (Worley et al. 2005). A new IMMA format for individual observations is now available, and is also being advanced under JCOMM. The ASCII format includes flexible capabilities for attachments, including one for the ship metadata. All of the ICOADS individual observations and data products (simple gridded monthly summaries for a selection of observed and derived variables) are freely and openly available internationally, with access via the project Web page (online at http://icoads.noaa.gov). Future plans include regular updates, focusing on GTS-based data and aiming initially for an annual extension; digitization and blending of untapped logbook data from the United Kingdom and other archives; blending of additional ship metadata (1955–72) and future availability of ODAS metadata; and the generation of climate-quality surface fields and uncertainties from ICOADS using the best knowledge for bias adjustments to variables. Temperatures from the uppermost levels of ocean profiles are also included, in keeping with JCOMM goals for the meshing of marine meteorological, ocean, and ice data. The most complete collection of sea ice data is available from the WMO Global Digital Sea Ice Data Bank, which combines older ice charts with more modern ice products, incorporating remotely sensed information.

Ready access, via standardized and other formats, to the basic ICOADS summaries and to higher-level analyses and blended products is needed both to meet diverse requirements from users and for permanent archives. Some progress has been made to develop portals (e.g., see http://icoads.noaa.gov, www.hadobs.org, and www.dss.ucar.edu online) where related data products, observations, or analyses, can be discovered, but more work in this area would help researchers quickly identify the data they need.

WIDER INTERACTIONS. The declining VOS data coverage we see in ICOADS (Kent et al. 2006) emphasizes the need for the marine-climate community to interact effectively with the operational data providers. While the availability of new types of observations and observing systems has increased dramatically over recent years, the requirement for more "traditional" observation types to maintain the climate record has not gone away. The marine climate community has started to build links to operational groups, for example, through JCOMM and its Ship Observations Team, Observations and Data Management Program Areas, and its various expert teams (especially ETMC, ETSI, and ETWS); the VOSClim project; and the NOAA Office of Climate Observation. Past interactions have had positive benefits; for example, following discussions with researchers, metadata needed to assess the effects of airflow distortion on ship-measured wind speeds are now being collected by JCOMM.

OUTSTANDING CHALLENGES. Future challenges for the marine climate data community were identified, and include the requirement that uncertainties associated with all marine datasets, especially climate datasets, be represented on all appropriate space and time scales; the need for several different groups to create given types of analyses making different decisions, which will help in understanding the structural uncertainty of the datasets; the need to test the derived datasets using a variety of techniques, using climate models where appropriate; and comparison of any observed climate change signal to the total uncertainties. It was noted that a limited start has been made on some of these issues.

SUMMARY OF DISCUSSION AND RECOMMENDATIONS. Discussions were held in breakout groups, each focusing on a range of marine variables, and the following key conclusions were drawn:

- An overarching recommendation was for continuing augmentation of ICOADS with in situ marine meteorological data and enhanced links to ocean data repositories, such as the World Ocean Database (e.g., Levitus et al. 1998). At least 25 million undigitized ship logbook reports exist, for instance, in U.K. national archives. In view of scarce resources, the need for data inventories and assessments to help identify priorities for digitization and datasets for incorporation into ICOADS was also highlighted.
- Concern was expressed that the marine observation system is in decline. Observations from VOS have decreased by more than a half since 1990, and there are now fewer than a third of the number of VOS participating in the program. As a result, the uncertainty of in situ surface products is increasing. All of the discussion groups were concerned about the diminishing data quantities, which represent a huge challenge for the future. It is essential that the marine climate community makes assessments both of its future data requirements and the adequacy of the surface marine climate observing system, and feeds this information through to the appropriate operational bodies.

- The availability of comprehensive metadata on observational methods for all observation platforms was thought to be key to the production of high-quality datasets.
- The importance of improving communication between scientists and both marine observers and operational centers was stressed.
- The production of a variety of well-documented gridded datasets for each marine variable using a range of techniques is essential to understanding biases, structural uncertainties, and the impacts of quality control and analysis procedures. A number of concrete plans to achieve this were discussed. The use of different SST analyses in programs that model climate variability and change, for example, the CLIVAR Climate of the 20th Century Project (Folland et al. 2002), was recommended.
- Particularly needed are better integrated SST and sea ice extent datasets for the next generation of reanalyses, especially where climate quality is being attempted. Here, creating homogeneous sea ice concentration data for the last few decades is still a major challenge and requires further access to in situ data, more digitization, and improved corrections to satellite data, particularly SSM/I sea ice data. The modern SST data also need much more study because there is evidence of time-varying and spatially varying biases that need correction, though these are likely to be smaller than the biases before 1942.
- The workshop participants felt that there was much to be gained from regular intercomparison of datasets produced in near–real time and from the continued use of multivariate techniques to improve marine datasets.

Although MARCDAT-II identified large efforts still needed to improve marine climatology, the progress since the first CLIMAR meeting in 1999 is impressive, and we look forward to the next in this unique series of productive meetings in early 2008.

FURTHER INFORMATION. Presentations are available online at the meeting Web site (http://icoads.noaa.gov/marcdat2/marcdat2_time.html), and progress toward meeting the recommendations from MARCDAT-II is being tracked on a "wiki" Web site (www.marineclimatology.net) for easy collaborative authoring and user updates.

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APPENDIX: LIST OF ACRONYMS.

(A)ATSR	(Advanced) Along Track Scanning Radiometer
AMSR-E	Advanced Microwave Scanning Radiometer for EOS
ASCII	American Standard Code for Information Interchange
AVHRR	Advanced Very High Resolution Radiometer
CDMP	Climate Database Modernization Program

CLIMAR	JCOMM Workshop on Advances in Marine Climatology
CLIVAR	Climate Variability and Predictability Project
CLIWOC	Climatological Database for the World's Oceans
EMULATE	European and North Atlantic Daily to Multidecadal Climate variability
EOS	Earth Observing System
ETMC	JCOMM Expert Team on Marine Climatology
ETSI	JCOMM Expert Team on Sea Ice
ETWS	JCOMM Expert Team on Wind Waves and Storm Surges
EU	European Union
GHRSST-PP	GODAE High Resolution SST Pilot Project
GODAE	Global Data Assimilation Experiment
GTS	Global Telecommunication System
ICOADS	International Comprehensive Ocean–Atmosphere Data Set
IOC	Intergovernmental Oceanographic Commission
IMMA	International Maritime Meteorological Archive
JCOMM	Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology
MARCDAT	International Workshop on Advances in the Use of Historical Marine Climate Data
NOAA	National Oceanic and Atmospheric Administration
ODAS	Ocean Data Acquisition Systems
SAMOS	Shipboard Automated Meteorological and Oceanographic System Initiative
SSM/I	Special Sensor Microwave/Imager
VOS	Voluntary Observing Ships
VOSClim	JCOMM VOS Climate Project
WMO	World Meteorological Organization