Introduction

Safety at sea has been a primary driver for internationally coordinated marine observations since the foundation of WMO. Over the past two decades, demand has steadily grown for expanding marine observation systems to support other applications, such as the initialization of increasingly sophisticated and longer-range weather-forecast systems, coastal area management, optimization of commercial fishing activities, ship routeing, off-shore resource exploration and development, pollution prevention and clean-up and, most recently, climate modelling and prediction. These applications require global observational datasets and prediction products for both the ocean and the overlying atmosphere.

Such interdisciplinary requirements have necessitated the development of ever-closer working relationships between oceanographers and marine meteorologists and the development of a “systems approach” to international coordination of national implementation efforts. A global observing system by definition crosses international boundaries with the potential for both benefits and responsibilities to be shared by many nations. Recognizing these needs, WMO and the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization established, in 2001, the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). JCOMM now provides an intergovernmental framework for global system planning and coordination. As maritime nations prepare to meet again in 2009 for JCOMM-III, it is timely to reflect on progress over the last decade and the challenges that lie ahead.

Implementation plan

The ocean chapter of the Global Climate Observing System (GCOS) Implementation Plan for the Global Observing System for Climate in support of the United Nations Framework Convention on Climate Change (UNFCCC) (GCOS-92) provides the roadmap for system implementation. The ocean observing system documented in GCOS-92 is a composite system of systems, made up of sustained high-quality satellite measurements of the atmosphere and ocean surface, in situ measurements of the ocean surface and the subsurface ocean and in situ measurements of the atmosphere over the ocean.

Each component subsystem brings its unique strengths and limitations; together they build the composite system of systems. Figure 1 illustrates this initial global ocean observation system of systems. In addition to the platforms illustrated in Figure 1, two more components are essential: data and assimilation subsystems and product delivery.

Although this baseline system is designed to meet climate requirements, marine services in general will be improved by implementation of the systematic global observations called for by the GCOS-92 plan. The system will support global weather prediction, global and coastal ocean prediction, marine hazard warning, marine environmental monitoring, naval applications and many other non-climate uses.

The initial ocean observing system for climate depends on space-based global measurements of sea-surface temperature, sea-surface height, surface vector winds, ocean colour and sea ice. These satellite contributions are detailed in other international plans but continued close coordination with the in situ systems is essential for comprehensive ocean observation.

An urgent and fundamental need identified by GCOS-92—endorsed by the UNFCCC and the Global Earth Observing System of Systems (GEOSS) 10-Year Implementation Plan Reference Document—is to achieve global coverage by the in situ networks. These include moored and drifting buoys, tide gauge stations, and...
profiling floats and ship-based systems. Coordination of national contributions to the implementation of these networks is the job of the JCOMM Observations Programme Area (OPA). Within the ocean chapter of GCOS-92, JCOMM is identified as the implementing agent or contributing implementing agent for 21 of the specific actions. These elements have been adopted by the JCOMM Observations Programme Area as an implementation roadmap. This article provides a summary of the OPA work plan, including coordination with other global programmes, in support of building the global ocean component of a Global Earth Observing System of Systems.

**Achieving global coverage by the *in situ* networks**

The JCOMM Observations Programme Area includes three implementation panels—the Data Buoy Cooperation Panel (DBCP), the Ship Observations Team and the Global Sea Level Observing System Group of Experts. Since JCOMM was established in 2001, there has been a link to the international Argo programme as well. Over the past few years, OPA has also been working to coordinate globally with the international Ocean Sustained Interdisciplinary Time Series Environmental Observation System (OceanSITES) and with the International Ocean Carbon Coordination Project (IOCCP). These programmes represent the major international activities dedicated to the implementation of sustained global ocean observing systems.

The JCOMM implementation panels focus on coordinating deployment of moored and drifting buoys on the high seas, coordinating volunteer ship observations from commercial vessels transiting the world’s oceans and coordinating tide gauge station operations at a core subset of stations that have been committed by Members/Member States to help monitor global sea level in a systematic way. The Argo programme is focused on establishing and sustaining a global array of subsurface profiling floats. OceanSITES has undertaken the establishment of a sparse global network of deep ocean moored buoys and subsurface moorings for long time series monitoring of the ocean and ocean-atmosphere interactions. The IOCCP is adding carbon measurements to the ships and buoy systems to monitor the ocean’s role in the global carbon cycle. The foci of all of these major international global programmes are needed for building a comprehensive, sustained global ocean observation system and there is opportunity for significant implementation efficiencies in working together.

Substantial progress has been made in implementing the observing networks since JCOMM-I in 2001. The total composite *in situ* ocean system achieved a significant milestone in February 2005 by surpassing the 50 per cent completion mark. At the time of JCOMM-I, the system was estimated to be about 34 per cent complete, which can be compared to...
the present estimate of 59 per cent as JCOMM-III approaches. These percentages are based on the system targets identified in GCOS-92. The last eight years of progress and the plan for the next three years, as presented at JCOMM-II, are summarized graphically in Figure 2. Great progress has been made, but the job is only 60 per cent done. It is now clear that completion of the initial ocean climate observing system by 2010, as the plan in Figure 2 envisions, is not realistic. Completion will require substantial additional yearly investment by Members/Member States.

Two major milestones have been achieved so far: the Data Buoy Cooperation Panel in September 2005 reached the initial system design goal of 1 250 surface drifting buoys in sustained service; and the Argo Steering Team in October 2007 reached the initial system design goal of 3 000 active profiling floats in service. The global drifting buoy array became the first component of the initial Global Ocean Observing System (GOOS) to be completed. It took 10 years to reach this milestone from the time the international community began implementation of GOOS with the publication of the Scientific Design for the Common Module of the Global Ocean Observing System and the Global Climate Observing System by the Ocean Observing System Development Panel in 1995.

Sustainability in the long term remains an issue, since many of the national Argo and DBCP programmes are still supported through research funding. Sustainability is justified for both research and operational applications. The drifter data have long been used by climate scientists to measure global sea-surface temperature change and by operational centres to initialize climate and weather-forecast models. Argo data are increasingly being used for climate studies and for ocean and climate modelling. The value of Argo data in improving ocean forecasts has been demonstrated. Argo is now in transition from its implementation phase to its sustained maintenance phase. The latter phase will optimize the array’s design, address new challenges (e.g. extending float lifetime beyond fours years) and permit further development of the quality and usefulness of the data.

System-wide monitoring and performance reporting

Another major challenge for the JCOMM Observations Programme Area is to develop easy-to-understand performance reports that can help evaluate the effectiveness of the composite observing system and convince governments to provide the funding needed to meet global implementation targets. It will not be possible to achieve global coverage of the Earth’s oceans with existing resources. As noted above, the existing system is only 59 per cent complete. That means that 41 per cent of the global ocean remains essentially unobserved. Governments need to commit additional resources in order to achieve complete global coverage. JCOMM’s operational support centre—JCOMMOPS—has been working with OPA to develop standard base maps showing what is required against what is currently in place, to evaluate observing system status and effectiveness and to develop summary reports illustrating how advancements toward global coverage improve the effectiveness of the observational information.

A standard map projection has now been accepted by OPA for reporting system status and progress. It is an equidistant cylindrical projection, 90°N to 90°S, broken at 30°E. A standard set of colours indicating country contributions is used by JCOMMOPS. For indicating system performance, a progression of colours (red, orange, yellow, green and blue) is used: red represents poorly observed; blue represents adequately observed. For illustrating measurements: hot colours (red) are used for warm temperatures, generally high values and shallow ocean depths; varying to cool colours (blue) for cool temperatures, generally low values and deep ocean measurements. All Members/Member States are encouraged to use these conventions when mapping their observing system contributions.
Challenges to Members/Member States in completing the global system

Data Buoy Cooperation Panel

- Deploy and maintain a sustained array of 1250 surface drifting buoys (now 100 per cent completed) for measuring sea-surface temperature and surface currents
- Add barometers to all drifters (presently 500 barometer upgrades in service) to measure sea-level pressure
- Extend the Tropical Moored Buoy network across the Indian Ocean (15 of 47 sites have been deployed) to complete coverage of the equatorial regions of the Atlantic, Pacific and Indian Oceans—the heat engine of global climate and weather patterns
- Coordinate with OceanSITES for common use of platforms and logistics support

Ship Observations Team

- Improve Volunteer Observing Ship (VOS) reporting of marine weather and ocean surface conditions (of the approximately 6700 ships registered, less than 2300 report regularly)
- Implement 250 VOS Climate (VOSClim) ships (currently 218 ships) as a high-quality subset for climate analysis of the long-term records that have been kept by commercial ships
- Implement automated weather systems on volunteer ships (currently 140 ships) to improve real-time reporting for weather forecasting and climate
- Fully occupy 51 high-resolution and frequently repeated expendable bathythermograph lines that were specified by the 1999 upper-ocean thermal workshop (currently 41 lines) to measure upper-ocean temperature structure and transports
- Coordinate with the International Ocean Carbon Coordination Project to use common platforms and logistics infrastructure for both the physical and chemical measurements in the global ocean and surface atmosphere

Global Sea Level Observing System Group of Experts

- Improve station reporting (only 176 of the 290 core network stations report regularly) to provide continuous high quality measurements of tides and sea-level
- Implement the GCOS Reference Station subset of 170 globally distributed tide gauge stations with real-time reporting and geocentric location (currently 106 real-time reporting) for long-term monitoring of climate change and for real-time support of tsunami warning systems

Argo

- Maintain a global array of 3000 active floats (now in service) for measuring subsurface ocean temperature and salinity

OceanSITES

- Establish a sparse global network of moored buoys and subsurface moorings to monitor various ocean/climate regimes and measure global-scale ocean circulation (43 of 89 sites now in service)

International Ocean Carbon Coordination Project

- Conduct a complete carbon inventory of the global ocean once every 10 years, using oceanographic vessels (20 of 37 lines have now been re-surveyed), and monitor the ocean-atmosphere exchange of carbon dioxide from voluntary observing ships and moored buoys.
In addition to platform statistics calculated by JCOMMOPS, quarterly performance reports are now available for sea-surface temperature, sea-surface salinity, temperature profiles, salinity profiles, near-surface currents and heat storage of the mixed layer. The OPA is working to incorporate reports for other ocean variables that have been specified by GOOS and GCOS. Access to these reports is via JCOMMOPS at http://www.jcommops.org/network_status. An example of the type of quarterly performance reports that are available is shown for subsurface temperature profiles in Figure 3.

A consolidated progress report with contributions by countries is available at http://www.jcommops.org/network_status. It lists the 73 countries and the European Union that maintain elements of the composite ocean observing system, and the number of in situ platforms and expendables contributed by each country. This report allows tracking of progress toward implementation of the ocean system specified in GCOS-92. All JCOMM Members/Member States are invited to routinely review this report and provide corrections as needed to opa@jcommops.org. (Observing system contributions are included in this report only if they provide data to the international community in accordance with WMO and IOC data policies.)

A Web page has been developed to provide for a single entrance portal to link to all Websites being maintained by countries contributing to implementation of the global ocean observing system. This single portal is intended to illustrate the ocean system of systems that is being implemented by JCOMM and partner programmes. This portal to national centre Websites is available through the JCOMMOPS access point: http://www.jcommops.org/network_status. Members/Member States are encouraged to review the Website and provide corrections as needed to opa@jcommops.org.

The OPA has also been working to develop an Observing System Monitoring Centre (OSMC) Web tool that provides for real-time monitoring capability with a live access server and provides Web browser and data visualization for system analysis and evaluation (http://www.osmc.noaa.gov/). Real-time data and metadata are pulled from multiple sources, including the Global Telecommunication System, JCOMMOPS and Web-based data servers, and are stored on the OSMC servers for five years for display and analysis. This system complements the JCOMMOPS monitoring system, which provides for metadata collection, monthly monitoring and longer-term archiving of the observing system status and its evolution. Using both systems, system managers and other users are now able to generate their own customized reports for specific global and regional needs using this international observing system management infrastructure.

Working together

Since the Indian Ocean tsunami disaster of December 2004, implementation of a comprehensive global marine hazard warning system has become a high priority on the international ocean agenda. Opportunities for JCOMM and Ocean-SITES coordination with international marine hazard warning systems are already being advanced, including real-time reporting from GLOSS tide-gauge stations, coordinated deployment of ocean buoys and the use of common sites/platforms and logistics infrastructure for multiple observational purposes. Coordinated implementation of observational components in support of international comprehensive marine hazard warning systems is now a main driver for the JCOMM OPA work plan.

An example of coordinated system implementation is illustrated in Figure 4. It shows a Chilean tsunami warning buoy being serviced from the US research vessel Ronald H. Brown during an October 2007 climate
mission for annual maintenance of the OceanSITES moored buoy station “Stratus” in the eastern Pacific Ocean. Both the tsunami buoy and the Stratus buoy (the Stratus buoy is pictured in Figure 1, representing the global reference mooring network) were cooperatively deployed by a joint Chilean/US team using the same ship-support infrastructure. Meteorological sensors were installed on the tsunami buoy to make it into a multi-purpose platform. Also deployed during this mission were DBCP surface drifting buoys and Argo profiling floats.

Figure 4 — Chilean tsunami warning buoy being serviced from the US research vessel Ronald H. Brown by a joint Chilean/US team during a climate mission for annual maintenance of ocean reference station “Stratus”. Meteorological sensors were installed on the tsunami buoy to make it into a multi-purpose platform. Also deployed during this mission were DBCP surface drifting buoys and Argo profiling floats.

Conclusion

Bringing together the oceanographic and marine meteorological observing networks under the JCOMM umbrella has demonstrated the effectiveness of a “systems approach” to Earth observation. Looking to the future, Fifteenth World Meteorological Congress (Geneva, May 2007) initiated a process for integration of the observing components of all WMO programmes. While proposing a step-by-step approach to the development of the WMO Integrated Global Observing System (WIGOS), Congress recommended the establishment of a number of pilot activities, including the integration of the JCOMM programmes supporting implementation of the Global Ocean Observing System and the Global Climate Observing System, working with other key international organizations such as the IOC. The pilot projects will promote interoperability of ocean data systems within the WMO Information System; the comprehensive documentation and integration of standards and best practices within the meteorological and oceanographic communities; and development of appropriate quality-management systems. It is expected that the JCOMM pilot project for WIGOS will enhance accessibility of both real-time and delayed-mode data of known quality, delivered according to agreed standards, to meet the growing requirements of numerical weather prediction, ocean forecasting, climate forecasting, disaster risk reduction, marine services and Earth system research.