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JOINT WMO/IOC TECHNICAL COMMISSION FOR OCEANOGRAPHY AND MARINE METEOROLOGY (JCOMM)
SHIP OBSERVATIONS TEAM (SOT)

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REQUIREMENTS FOR SHIP-BASED OBSERVATIONS (RRR AND OOPC)

(Submitted by the Secretariat)

Summary and purpose of the document

This document provides information on the GOOS activities during the intersessional period in view of its contribution to meet the GOOS goals ad objectives, and provides a review of the requirements expressed by the GOOS / GCOS Ocean Observing Panel for Climate (OOPC), as required. The document also includes information on the WMO Rolling Review of Requirements and how non-climate requirements can be addressed by the Team.

ACTION PROPOSED

The Team will review the information contained in this report, and comment and make decisions or recommendations as appropriate. See part A for the details of recommended actions.

Appendices:
- **A.** Ocean Applications Statement of Guidance
- **B.** Excerpts of interest to the SOT from the Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP)
- **C.** Recommendation 3.1(1)/3 (CBS-Ext.(2014)) – Support of Members to the Implementation of the Marine Meteorological and Oceanographic Observing System in support of NWP

References:
- **A.** SOT-8 Doc 3.2, Report by the JCOMM Observations Programme Area Coordinator
- **B.** WMO Statements of Guidance as part of the WMO Rolling Review of Requirements: http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html#SOG
- **C.** Summary and conclusions from the fifth WMO Workshop on the Impact of Various Observing Systems on NWP (Sedona, Arizona (USA), 22 -25 May 2012). http://www.wmo.int/pages/prog/www/OSY/Meetings/NWP5_Sedona2012/Final_Report.pdf
- **D.** Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP): http://www.wmo.int/pages/prog/www/OSY/Publications/EGOS-IP-2025/EGOS-IP-2025-en.pdf
- **E.** Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC (2010 update), GCOS-138, GOOS-184, http://www.wmo.int/pages/ prog/gcos/Publications/gcos-138.pdf

- A - DRAFT TEXT FOR INCLUSION IN THE FINAL REPORT

5.1 GCOS / GOOS / WCRP Ocean Observations for Physics and Climate (OOPC)

5.1.1 The requirements for observations requested of the SOT remain the GCOS Implementation Plan goals reflected in the 2010 updated of the GCOS Implementation Plan (GCOS-138). These reflect a mild evolution of previous recommendations, expanding the number of Essential Climate Variables for the ocean and emphasizing integration. Of note for the Ship Observations Team were the following requested GCOS-138 actions:

- [GCOS Action O3] Improve the number and quality of climate-relevant marine surface observations from the VOS [for both marine meteorological and oceanographic Essential Climate Variables]. Improve metadata acquisition and management for as many VOS as possible through VOSClim, togther with improved measurement systems. Performance indicator: increased quantity and quality of VOS reports
- [Action O11] Implement a programme to observe sea-surface salinity to include Argo profiling floats, surface drifting buoys, SOOP ships, tropical moorings, reference moorings, and research ships. Performance indicator: data availability at International Data Centres.
- [Action O21] Establish plan for, and implement, global Continuous Plankton Recorder surveys [towed from commercial vessels]. Performance indicators: publication of internationally-agreed plans; establishment of agreements/frameworks for coordination of sustained global Continuous Plankton Recorder surveys; implementation according to plan.
- [Action O25] Sustain the Ship of Opportunity XBT/XCTD transoceanic network of about 40 sections. Performance indicator: data submitted to archive. Percentage coverage of the sections.

5.1.2 The GCOS Status Report is currently being drafted, and the progress against these actions reported against. The Team invited its members to respond to requests for information with respect to progress of GCOS-IP actions for the GCOS Status Report (***action; SOT members; May 2015***).

5.1.3 The Team noted that the 2016 Implementation Plan will be developed during 2015-2016, and this will provide an opportunity to update implementation targets. In consultation with OOPC/JCOMM OCG.

5.1.3 The Seventeenth Session of the GCOS/GOOS/WCRP Ocean Observations for Physics and Climate (OOPC), met 21 - 23 July 2014, in Barcelona, Spain, just prior to the Third Meeting of the GOOS Steering Committee, July 24-26 July, 2014. The OOPC embraces the GOOS and GCOS framework for an Essential Ocean Variables approach to defining requirements and of ongoing evaluation and assessment of observing systems. The Team reviewed evaluations of new initiatives, including Upper Ocean Thermal Review, TPOS, Boundary Current and Inter-basin flows, and the Deep Ocean Observing Strategy. The Team noted the following:

- Responding to the erosion of readiness of the Tropical Pacific Observation System, the TPOS 2020 Workshop (27-30 Jan. 2014, La Jolla, United States) an OOPC expert group, has emphasized the need to improve resilience and integration of observing systems and articulated the strengths of a multiplatform approach. The OOPC has suggested that a framework for risk assessment is needed which will include the evaluation of system “readiness”. This is a cross cutting activity which should be embraced by the JCOMM panels, such as GO-SHIP and the SOT.
- The OOPC recommends that SOT participate in the ‘Strategic Mapping of GOOS, and the development of Network Specification Sheets which articulate the role of SOT activities in the observing system, to meet requirements articulated in ‘Variable Specifications’ (see website[1]).

1 http://lists-ioc-goos.org/goos-strategic-mapping-graphic/

- The OOPC recommends that evaluation of initiatives should be accompanied by a small set of performance indicators (metrics) that capture the technical performance and uptake/impact of the system data and information, particularly in terms of the ultimate socio-economic impact.

5.1.3 The SOT agreed with the following:

- The Team requested the SOT Technical Coordinator to coordinate with the SOT, VOSP, SOOPIP, and the OCG Chairs and develop the 'Network Specification(s) for SOT activities (***action; M. Kramp; asap***). This will also form the basis of input to the GCOS Implementation Plan, 2016.
- To participate in OOPC studies of the feasibility of metrics for systems evaluation. The Team tasked [TBD] to represent the Team in such activity, and to contribute and liaise with the JCOMM OCG (***action; [TBD]; OCG-6, OOPC-18, SOT-9***).

5.1.4 The GOOS Steering Committee at its Third Session (GOOS-SC-3, Barcelona, Spain, 24 – 26 July, 2014) continued to define the structure of GOOS, which now comprises the three ocean subject Panels: Physics (OOPC); Biogeochemistry (IOCCP) and; Biology and Ecosystems. The Committee recognized that evaluating Essential Ocean Variables for "readiness" also includes an evaluation of the potential risks to continuity of extant observing systems, including funding aspects. The GOOS SC, therefore, requests that JCOMM panels develop risk and vulnerabilities information for their systems and communicate to the appropriate GOOS panel. In addition the GOOS SC elaborated a communication and outreach plan, which includes communication to the JCOMM panels of the GOOS Framework for Ocean Observing, and the new focus of GOOS on Essential Ocean Variables. The Team agreed with the following:

- [TBD] to develop risk and vulnerabilities information for the ship-based observing systems on behalf of the Team, and communicate to JCOMM OCG as needed (***action; [TBD]; GOOS-SC 4, SOT-9***).

5.2 WMO Rolling Review of Requirements update

5.2.2 The Team noted that the impact of sea level pressure data on NWP and other WMO Application Areas has been discussed at the first meeting of the CBS Inter Programme Expert Team on Observing System Design and Evolution (IPET-OSDE-1, Geneva, Switzerland, 31 March – 3 April 2014), and at the eighth Session of the CBS Implementation Coordination Team on the Integrated Observing System (ICT-IOS-8, Geneva, Switzerland, 7-10 April 2014). In particular, the Team noted the following with appreciation:

- ICT-IOS-8 agreed that the impact of marine meteorological and oceanographic data on NWP should be taken into account in the list of science questions to be addressed by the CBS, and the International Workshop in the Impact of Various Observational Systems on NWP.
- ICT-IOS-8 stressed that support of NMHSs to marine meteorological and oceanographic observations should be enhanced, noting that NMHSs don't necessarily have to contribute infrastructure, but can contribute resources to such programmes. This should be highlighted in the reporting to WMO Executive Council and Congress.
- ICT-IOS-8 noted that (a) the influence of buoy surface pressure observations is particularly large on a per-observation basis and their Observing System Experiment (OSE) impact extends from the surface throughout the troposphere in mid-latitudes (see final report of the 5th NWP Obs. Impact workshop[2]), and (b) the higher impact per cost of such data compared with other observing systems, including space- and surface-based observing

2 http://www.wmo.int/pages/prog/www/OSY/Meetings/NWP5_Sedona2012/Final_Report.pdf

systems, per the UK study presented by the Chair of IPET-OSDE at the IPET-OSDE-1 meeting (see website[3]).

- ICT-IOS-8 agreed that it was important to raise awareness of Members with regard to the profile of ocean observations to address WMO applications observational user requirements, and to the issues outlined by JCOMM. It also agreed that the impact of drifters on NWP, and its cost-effectiveness should be brought to the attention of CBS, and decided to submit a formal Recommendation to CBS Ext.(2014) on Support of Members to the implementation of marine meteorological and oceanographic observing systems in support of NWP. CBS Ext.(2014) adopted that Recommendation, which is provided in Appendix C.

- B - BACKGROUND INFORMATION

1 GCOS / GOOS / WCRP Ocean Observations for Physics and Climate (OOPC)

1.1 The Ocean Observations for Physics and Climate has the role of providing scientific recommendations and reviewing the implementation of the ocean observations required for climate in support of its 3 sponsors, the Global Ocean Observing System (GOOS), the Global Climate Observing System (GCOS), and the World Climate Research Programme (WCRP). Traditionally, OOPC has focused on open ocean and physical variables. For climate relevant biogeochemical and biological variables, OOPC will liaise with the GOOS Biogeochemistry (coordinated by the International Ocean Carbon Coordination Project, IOCCP) and GOOS Biology Panels.

1.2. The Global Climate Observing System will be developing a new 2016 Implementation Plan, through 2015-2016. This will involve an update of the section and actions for the ocean domain, taking into consideration new requirements and observing system developments. OOPC will conduct a thorough review of the ocean section of 2010 Implementation Plan and Ocean actions through late 2015/early 2016, to determine where updates are needed.

1.3. To enable OOPC to contribute to both GCOS and GOOS planning and reporting, OOPC is developing variable and network specification sheets. Network specification sheets will be drawn on in developing actions for the next GCOS IP.

1.4 At its 17th meeting (21 - 23 July 2014, in Barcelona, Spain http://www.ioc-goos.org/oopc17) the OOPC reviewed input to the reporting processes for GOOS and GCOS on systems based development and evaluations of:

- Systems based Evaluations
- Developing approaches for assessing scales and accuracy requirements of observations
- Observations for reducing uncertainties in Air Sea Flux Estimates
- Upper Ocean Thermal Review
- Tropical Pacific Observing System Workshop
- Deep Ocean Observing System
- Boundary Currents and Inter-basin flows
- Polar Seas
- Regional and coastal seas

2. WMO Rolling Review of Requirements (RRR)

2.1. WMO, as part its Rolling Review of Requirements[4] (RRR) is addressing the following application areas:

3 http://www.wmo.int/pages/prog/www/OSY/Meetings/IPET-OSDE1/documents/IPET-OSDE1-Doc-8.4-Cost-benefit-studies.pdf
4: http://www.wmo.int/pages/prog/sat/RRR-and-SOG.html

1. Global Numerical Weather Prediction
2. High Resolution Numerical Weather Prediction
3. Synoptic Meteorology
4. Nowcasting and Very Short Range Forecasting
5. Seasonal to Inter-annual Forecasts
6. Aeronautical Meteorology
7. Forecasting Atmospheric Composition
8. Monitoring Atmospheric Composition
9. Providing Atmospheric Composition information to support services in urban and populated areas
10. Ocean Applications
11. Agricultural Meteorology
12. Hydrology
13. Climate Monitoring (GCOS)
14. Climate Applications (Other aspects, addressed by the Commission for Climatology)

2.2. The Rolling Review of Requirements basically consists of the following steps:

1) Compiling the list of requirements for each applications area and each required variable in terms of (i) horizontal resolution, (ii) vertical resolution, (iii) observing cycle, (iv) timeliness, and (v) accuracy. For each criterion, requirements are given in terms of threshold (value below which observations are worthless), breakthrough (proposed target for significant progress, and optimal cost/benefit), and goal (value beyond which improvement gives no additional value). The list of requirements is independent from the technology being used to observe the required variables (technology free).
2) Estimating the performances of the instruments for each observing system and variable in terms of (i) horizontal resolution, (ii) vertical resolution, (iii) observing cycle, (iv) timeliness, and (v) accuracy.
3) Conducting a critical review and gap analysis based on (i) critical review charts which are objectively comparing the performances of the instruments with the requirements, and (ii) results from impact studies based mainly on Observing System Experiments (OSEs) and Observing System Simulation Experiments (OSSEs).
4) The interpretation of the results from the critical review and gap analysis by experts from each of the considered application area, results in the elaboration of the Statements of Guidance[5] (SoG). The draft Statements of Guidance are then discussed, and possibly updated by the CBS Inter Programme Expert Team on Observing System Design and Evolution (IPET-OSDE) before being formally endorsed by the Team.
5) Based on the Statements of Guidance, the Vision for the Global Observing System (GOS) in 2025[6], cost-effectiveness of observing systems, and the assumed resources of WMO Members, the IPET-OSDE propose priorities, and updates the Implementation Plan for the Evolution of global observing systems (EGOS-IP[7]).
6) The EGOS-IP is used by WMO Members to plan the evolution of the observing systems nationally, and commit resources as appropriate.

2.3. The SoG for an application area provides for an assessment of the adequacy of the observations to fulfil requirements and suggests areas of progress towards improved use of satellite and in situ observing systems. Only the most significant variables in a given application area have been analysed in the SOGs. SoGs are effectively gap analysis and propose priorities in terms of requirements for observations. The following terminology has been adopted. "Marginal" indicates minimum user requirements are being met, "acceptable" indicates greater than minimum but less than maximum requirements (in the useful range) are being met, and "good" means close to maximum requirements are being met.

2.4 More information on the RRR can be found at http://www.wmo.int/egos.

5: http://www.wmo.int/pages/prog/sat/RRR-and-SOG.html#SOG
6: http://www.wmo.int/pages/prog/www/OSY/gos-vision.html
7: http://www.wmo.int/pages/prog/www/OSY/gos-vision.html#egos-ip

Appendices: 3

APPENDIX A

STATEMENT OF GUIDANCE FOR OCEAN APPLICATIONS

(Point of contact: Guimei Liu, NMEFC, China)
(Updated in March 2014 by the PoC)

This Statement of Guidance (SoG) was developed, through a process of consultation, to document observational data requirements for ocean applications and the present/planned observing capabilities. This version is based on the JCOMM User Requirement Document, which was prepared by the Chairpersons of the Expert Teams within the JCOMM Services Programme Area. It is expected that the Statement will be reviewed at appropriate intervals by the JCOMM Services Programme Area Coordination Group to ensure that it remains consistent with the current state of the relevant science and technology. This document therefore presents an analysis of the gap between user requirements and the available/planned observation capabilities to address these requirements.

1. INTRODUCTION

Marine Meteorology and Oceanography occupy a global role, serving a wide range of users, from international shipping, fishing and other met-ocean activities on the high seas, to the various activities which take place in coastal and offshore areas and on the coast itself. In preparation of analyses, synopses, forecasts and warnings, knowledge is required of the present state of the atmosphere and ocean. The three major met-ocean application areas that critically depend on highly accurate observations of met-ocean parameters are: (a) Numerical Weather Prediction (NWP); (b) Seasonal to Inter-annual Forecasts (SIA), and (c) Met-Ocean Forecasts and Services (MOFS), including marine services and ocean mesoscale forecasting.

The key met-ocean variables to be observed and forecast in support of NWP and SIA are addressed in the Numerical Weather Prediction and the Seasonal to Inter-annual Forecast Statements of Guidance. This Statement of Guidance provides a brief discussion on how well the present and planned met-ocean observing systems meet the user requirements for MOFS, concentrating on those parameters not covered by previous sections of this document, such as waves, storm surges, sea-ice, ocean currents, etc. Variables such as precipitation, air temperature, humidity and cloud cover, also required for marine services, are addressed in the global and regional NWP SoG.

The requirements for MOFS stipulated here are based on a consensus of the met-ocean modelling and forecasting communities. This statement builds on the requirements for global and regional wave modelling and forecasting, marine meteorological services, including sea-ice, and ocean mesoscale forecasting, and represents in addition those variables that are known to be important for initialising, testing and validating models and assimilation, as well as for providing services.

2. GAP ANALYSIS: DATA REQUIREMENTS AND OBSERVING CAPABILITIES

The following terminology has been adhered to as much as possible:

- *poor* (minimum user requirements are not being met),
- *marginal* (minimum user requirements are being met),
- *acceptable* (greater than minimum but less than optimum requirements are being met), and
- *good* (near optimum requirements are being met).

2.1 Wind-Wave parameters (significant wave height, dominant wave period, Wave 1D energy frequency spectrum, and Wave direction energy frequency spectrum)

Global and regional wave models are used to produce short- and medium-range wave forecasts (typically up to 7 days) of the sea state, with a horizontal resolution of typically 30-100km for global models, and down to 3-4km for regional models (with a natural progression to higher resolution expected). Marine forecasters use wave model outputs as guidance to issue forecasts and warnings of important wave variables (such as, significant wave height and dominant wave period) for their area of responsibility and interest, in support of several marine operations. Specific users usually require additional parameters that are obtained from the directional spectrum of wave energy density.

The observational requirements for global and regional wave modelling depend on the applications for which the data are required and are based on the need to provide an accurate analysis of the sea state at regular intervals (typically every 6 hours). These requirements include: (a) assimilation into wave forecast models; (b) validation of wave forecast models; (c) calibration / validation of satellite wave sensors; (d) ocean wave climate and its variability on seasonal to decadal time scales, and (e) role of waves in coupling. Additionally, wave observations are required for nowcasting (0 to 2 hours) and issuing / cancelling warnings, very-short-range forecasting (up to 12 hours) of extreme waves associated with extra-tropical and tropical storms, and freak waves (in this case, in combination with other variables such as ocean currents). Whilst nowcasting is largely based on observational data, very-short range forecasts are being generated using high-resolution regional wave models.

The key model variables for which observations are needed are: (i) significant wave height; (ii) dominant wave period; (iii) Wave 1-D energy frequency spectrum; (iv) Wave directional energy frequency spectrum, and (v) 2-D frequency-direction spectral wave energy density. Also important are collocated surface wind observations, which are advantageous for validation activities. Further additional parameters are of value for use in delayed mode validation (e.g. full time series of sea surface elevation).

The geographical coverage of *in situ* wave data is still very limited and most measurements are taken in the Northern Hemisphere (mainly off the North American and Western European coasts). The majority of these data are provided by *in situ* non-spectral and spectral buoys and ships with *acceptable* frequency and *marginal* accuracy. A limited number of *in situ* spectral buoys is available around the globe. Current *in situ* reports are not standardized resulting in impaired utility. Differences in measured waves from different platforms, sensors, processing and moorings have been identified. In particular, a systematic 10% bias has been noted between US and Canadian buoys, the two largest moored buoy networks. Standardized measurements and metadata are essential to ensure consistency between different platforms.

In situ measurements are currently too sparse in the open ocean (*poor* coverage) to be of particular value, but could potentially provide higher accuracy observations to complement and correct for biases in satellite products. For dominant wave period and significant wave height, the requirement for horizontal spacing for real-time validation and assimilation, as well as maritime safety services, ranges from 20km for regional to 60km for global models, with a minimum accuracy of 1 second and 0.25m respectively. The equivalent requirement for wave 1D energy frequency spectrum and wave direction energy frequency spectrum ranges from 100km for regional to 300km for global models with a minimum accuracy of $0.2m^2Hz^{-1}$ and $0.2m^2Hz^{-1}rad^{-1}$ respectively. The required observation cycle is 24 hours.

Satellite altimeters provide information on significant wave height with global coverage and *good* accuracy. However, horizontal/temporal coverage is *marginal*. A minimum of 20km and 60km resolution is required for use in regional and global wave models respectively. Along track spacing is likely to be adequate to meet this requirement; cross-track spacing is not. Multiple altimeters are therefore required to provide adequate cross-track sampling. Fast delivery (within 6 hours at most) is required with accuracy of 10% / 25cm for wave height, and 1 second for wave period. Long-term, stable time series of repeat observations are required for climate applications.

Information on the 2-D frequency-direction spectral wave energy density is provided by SAR instruments with *good* accuracy but *marginal* horizontal/temporal resolution. Horizontal resolution of 100km is required for use in regional models, with fast delivery required (within 6 hours). Real aperture radar capability is expected to be available within 5 years.

Coastal wave models require different observing methods to those used for the open ocean, due not only to their high resolution, but also due to limitations of the satellite data close to land. Hence for these models systems such as coastal HF radar are of particular importance. These radars provide information on significant wave height with limited coverage, *good* accuracy and *acceptable* horizontal/temporal resolution. High-resolution observations (up to 100m resolution) are required over coastal model areas.

Potential contribution from other technologies and platforms (e.g. navigation radar, other radars and shipborne sensors such as WAVEX) should be developed where they can contribute to meeting the specified requirements.

2.2 Sea Level

Traditionally, permanent sea level stations around the world have been primarily devoted to tide and mean sea level applications, neither requiring real or near-real time delivery. This has been the main objective of the Global Sea Level Observing System (GLOSS). Because of this focus, not only are wind-waves filtered out from the records by mechanical or mathematical procedures, but any oscillation between wind-waves and tides (e.g. seiches, tsunamis, storm surges, etc.) has not been considered a priority. In fact, these phenomena are not properly monitored (standard sampling time of more than 5 to 6 minutes). The main component of GLOSS is the 'Global Core Network' (GCN) of 289 sea level stations around the world for long term climate change and oceanographic sea level monitoring. Due to the increased demand for tsunami, storm surge and coastal flooding forecasting and warning systems, for assimilation of in situ sea level data into ocean circulation models, and for calibration/validation of the satellite altimeter and models, this part of the spectrum needs to be covered from now on, and should be considered when choosing a new instrument and in the design of in situ sea level stations. Additionally, there has been an emphasis on making as many GLOSS gauges as possible deliver data in real and/or near-real time, i.e., typically within an hour. An ongoing issue with these data is that sea level measurements have not been well integrated into National Meteorological and Hydrographic Services (NMHSs).

The aim of any tide gauge recording should be to operate a gauge which is accurate to better than 1cm at all times; i.e., in all conditions of tide, waves, currents, weather, etc. This requires dedicated attention to gauge maintenance and data quality control. In brief, the major requirements for *in situ* sea level stations are:

- For storm surge and tsunami forecasting a spacing of 10km is required, while for climate modelling 50km spacing will meet the threshold. This will therefore require a denser network than is available today.

- A sampling of sea level, averaged over a period long enough to avoid aliasing from waves, at intervals of typically 6 seconds or less if the instrument is to be used also for tsunami, storm surges and coastal flooding forecasting and warning.

- Gauge timing be compatible with level accuracy, which means a timing accuracy better than one minute (and in practice, to seconds or better with electronic gauges) – *marginal* accuracy.

- Measurements must be made relative to a fixed and permanent local tide gauge bench mark (TGBM). This should be connected to a number of auxiliary marks to guard against its movement or destruction. Connections between the TGBM and the gauge zero should be made to an accuracy of a few millimetres at regular intervals (e.g. annually) – *acceptable* accuracy.

- GLOSS gauges to be used for studies of long term trends, ocean circulation and satellite altimeter calibration/validation need to be equipped with GPS receivers (and monitored possible by other geodetic techniques) located as close to the gauge as possible;

- The readings of individual sea levels should be made with a target accuracy of 10mm – *acceptable* accuracy;

- Gauge sites should, if possible, be equipped for recording tsunami and storm surge signals, implying that the site be equipped with a pressure sensor capable of 15-seconds or 1-minute sampling frequency, and possibly for recording wave conditions, implying 1-second sampling frequency – *poor* accuracy; and,

- Gauge sites should also be equipped for automatic data transmission to data centres by means of satellite, Internet, etc., in addition to recording data locally on site.

Coastal sea level tide gauges are invaluable for refining tsunami warnings, but due to nearshore bathymetry, sheltering, and other localized conditions, they do not necessarily always provide a good estimate of the characteristics of a tsunami. Additionally, the first tide gauges to receive the brunt of a tsunami wave do so without advance verification that a tsunami is under way. In order to improve the capability for the early detection and real-time reporting of tsunamis in the open ocean, some countries have begun deployment of tsunameter buoys in the Pacific, Indian, and Atlantic Oceans and other tsunami-prone basins. Due to cost constraints, the number of DART buoys deployed and maintained is still limited – *marginal* geographic coverage and *good* accuracy.

The geographic coverage of the *in situ* sea level data is therefore *poor* for both studies of long-term trends and for forecasting storm surges and tsunamis. Basins prone to tsunamis and storm surges (e.g. Bay of Bengal, Gulf of Mexico and Pacific Islands) require a higher density of sea level observations. Sea level measurements should be accompanied by observations of atmospheric pressure, and if possible, winds and other environmental parameters, which are of direct relevance to the sea level data analysis.

Satellite altimeters provide information on sea surface height with global coverage and *good* accuracy, i.e. within 1cm over basin scales. However, horizontal/temporal coverage is *marginal*. The main limitation of the satellite altimeter in reproducing the non-long-term sea level changes is the spatial sampling: the repeat orbit cycle leads to an across-track spacing of about 300km at mid-latitudes. This sampling cannot resolve all spatial scales of mesoscale and coastal signals which have typical wavelengths of less than 100km at mid-latitude. The scales are even shorter at high latitudes (around 50km), but fortunately the ground track separation decreases with latitude. Thus, to cover the whole mesoscale and coastal domain it is necessary to increase the spatial sampling by merging (in an optimal way with cross-calibration) different altimetry data sets. The temporal changes in sea level are usually determined along the repeat tracks of altimetry satellites. In areas close to the coasts (less than 20km offshore) the difficulty is even larger because of the proximity of land, for which the track spacing is too coarse to resolve the short scales of the sea level changes. Thus, adaptive trackers and/or specific re-tracking of altimeter waveforms and near-shore geophysical corrections (such as coastal tide models and marine boundary layer tropospheric corrections) are needed.

2.3 Sea Surface Height Anomalies (SSHA or Sea Level Anomalies)

SSHA is a derived observation product used by all operational ocean forecasting systems. The observation products are processed by the space agencies and distributed to the forecasting centres. SSHA therefore not only involves the direct observation of the ocean topography, but also the accurate estimation of the reference mean dynamic topography, the ocean tides, sea state bias and several other atmospheric and solid earth corrections.

SSHA provides an estimate of the integrated distribution of mass within the ocean (the analogue of sea level pressure for the atmosphere) and therefore provides information of the specific volume anomalies of the water column. Combined with a data assimilation scheme to define the covariability of the temperature and salinity with SSHA, observations of SSHA have the greatest impact on ocean forecasting from the current observing system. Gradients in SSHA (or pressure) drive ocean circulation on spatial scales ranging from sub-mesoscale to gyre scale and temporal scales of hours through decades. The impact of SSHA includes nowcasting and forecasting the currents and salinity and forecasting the temperature for the upper ocean. In this case the depth scale of the upper ocean is defined by the covariability of temperature and salinity with SSHA, and varies in space and time. We also note that the nowcasting of temperature of the mixed layer is well served by remotely sensed sea surface temperature that observes the foundation temperature.

Improvements to altimetry, the cal/val process, the determination of correction terms and the verification of data assimilation statistical models will have a direct impact for ocean forecasting in the near term. The greatest improvements however will come from improvements in temporal and spatial resolution, each of which has to be traded-off against the other for any given satellite. Better temporal resolution (which comes at the cost of poorer spatial resolution) allows rapidly changing features (e.g. near fronts or major ocean currents) to be observed adequately: better spatial resolution (which comes at the cost of poorer temporal resolution) allows mesoscale features (e.g. eddies) to be resolved.

The present altimeter constellation consists of three main satellites. Two satellites, Jason-1 and Jason-2, fly in formation, allowing the same spot on the ocean to be observed relatively frequently (every 5 days) but with relatively widely-spaced ground tracks (315km at the equator). Envisat has a longer repeat cycle (currently 30 days), but tighter ground track spacing (90km at the equator).

The table below specifies the consolidated user requirements for ocean forecasting systems storm surge and tsunami forecasting.

Application	Spatial resolution (km)	Delivery timeliness (hours)		Accuracy (m)
		Target	Threshold	
Coastal Ocean forecasting	< 5	3	6	< 0.08
Open Ocean forecasting	5-10	6	24	< 0.08
Storm surge / tsunami forecasting	10	0.2	24	0.1

SSHA has been observed through a series of narrow swath instruments since 1992 (TOPEX-Poseidon, Jason-1, Jason-2, ERS, ERSII, Envisat, Geosat and GFO-1). Throughout this period, as many as four altimeters have been operational, with demonstrable improvements in higher spatial and temporal coverage. It is now commonly accepted that a minimum of two interleaved operational satellites is required to support ocean forecasting applications.

The timescale for scheduling satellite missions and the competition for budgets has threatened the continuity of altimetry over the past decade and into the future. Securing continuity of satellite altimetry is critical to national service providers delivering the reliable, quality ocean services that are required to generate the full spectrum of applications. Full integration of forecasts of SST and surface currents for NWP and wave forecasting cannot be realised until ocean prediction systems achieve homogeneous skilful performance. The future progression toward fully coupled ocean-wave-NWP systems for short-range prediction will similarly require high reliability and quality from the ocean observing system. SSHA is currently considered the most critical component of this observing system for ocean prediction systems.

SSHA is used in ocean models to provide adjustments to the sub-surface density structure of the ocean. It is also critical that a global *in situ* profiling system (e.g. Argo) be maintained to calibrate/validate these projections and further constrain the deep ocean through assimilation of density profiles. SSHA observations can also be exploited in the coastal regions. However the spatial and temporal requirements in the coastal zone place greater demands on the observing system. Wider-swath observations would add significant value in this zone as well as in the open ocean. Enhancing existing coastal tide gauges networks will also add significant value to ocean prediction systems in the shelf zone.

2.4 Sea-Ice parameters (thickness, coverage/concentration, type/form, movement)

Sea-ice charts containing information of sea-ice thickness, coverage/concentration, type/form and movement are produced in support of marine operations, validation of models and for climatological studies.

Although broad knowledge of the extent of sea-ice cover has been totally revolutionized by satellite imagery, observations from shore stations, ships and aircraft are still of great importance in establishing the “ground truth” of satellite observations. At present, observations of floating ice depend on instrumental and, to a lesser extent, on visual observations. The instrumental observations are made by conventional aircraft and coastal radar, visible and infra-red airborne and satellite imagery, and by more recent techniques, such as passive microwave sensors, laser airborne profilometers, scatterometers, side-looking (airborne) radar (SLAR / SLR) or synthetic aperture radar (SAR, satellite or airborne).

Visual observations from coastal settlements, lighthouses and ships can provide an ice report several times a day as the ice changes in response to wind and ocean currents, but the total area of ice being reported is very small (e.g., from a ship, observations can cover a radius of only 7-8km; from a coastal lighthouse, observations can cover a radius of up to 20km). In some marine areas, such as the Baltic Sea, visual observations may be present in sufficient numbers that a reasonable proportion of the ice cover can be reported each day by a surface network. In others such as the Gulf of St Lawrence, where the waterways are broad and the shores often unsettled, no shore reporting system can provide data on more than a very small percentage of the total ice cover. Although surface based reports can provide excellent detail about the ice, especially its thickness, it is generally recognized that for most areas, the surface reports are not really adequate to describe ice conditions fully.

Surface reports from shore stations, ships and drifting buoys provide accurate information on ice amount, thickness, movement and its deformation over rather small areas. When many vessels and fixed observing points are available accurate information can be provided in restricted waterways. Many areas of the Kattegat and Baltic Sea coastline fall into this category.

Reports about ice coverage taken from the air, i.e., helicopters and fixed-wing aircraft, have the advantage of a much better coverage, the platform’s flying speed allowing a great deal more of the sea-ice to be reported and problems of remoteness from airports or other suitable landing sites being overcome by using long-range aircraft. In the various stages of development of sea-ice, estimates of its amount; notes on its deformation and snow cover or stage of decay data are provided by visual estimation. Comprehensive aerial reporting has its own particular requirements beginning with an accurate navigational system when out of sight of land. Inclement weather – fog, precipitation and low cloud – will restrict or interrupt the observations and the usual problems of flying restrictions at the aircraft base may also be a factor even if the weather over the ice is adequate for observing.

Recent advances in technology are now permitting more accurate data to be obtained by aerial observations. SLAR and SAR can provide information which documents precisely the distribution and nature of the ice in one or two belts along the flight path of the aircraft for distances of up to 100km on each side. Unlike most other sensors, the radar has the capability of monitoring the ice under nearly all weather conditions.

When no fog or low clouds are present a laser airborne profilometer can be used to measure the height and frequency of ridges on the ice, and under similar conditions an infra-red airborne scanning system can provide excellent information with regard to floe thickness in the range below 30cm.

The advent of polar-orbiting meteorological satellites has added a third, and now the most important and predominant mode of observing sea ice, but again there are some restrictions. The spectral range of the sensors may be visible, infra-red, passive or active microwave or a combination of these. Satellite coverage may be broad at low resolution or cover a narrow swath at high-resolution. In the latter case, data from a particular location may be obtained only at intervals of several days.

In general, most meteorological satellites make 10–12 passes daily in the polar regions, i.e., complete broad-swath coverage once or twice a day. These satellites provide visible and infra-red imagery with resolutions of 250m–1km; and passive microwave and scatterometer data at coarser resolutions of 6–70km, i.e. *good* spatial/temporal coverage.

Visible and infra-red sensors do not have cloud-penetrating capability, while microwave data are practically cloud independent. Active microwave SAR data are characterized by improved ground resolution (approximately 10–100m) but a reduced coverage due to narrow swaths and greater revisit time between exact repeat orbits. Snow cover on the ice and puddles on the floes are other complicating factors. Interpretation of SAR images may be even more difficult due to the ambiguities associated with SAR backscatter from sea-ice features that vary by season and geographic region.

Space-borne sensors, especially radars, can provide precise data on the location and type of ice boundary, concentration and the presence or absence of leads, including their characteristics. Less accurate information can be extracted on the stages of development of the sea ice (including the First-Year/Multi-Year ratio) and its surface morphology. Flow motion over approximately 12–24-hour intervals can often be determined through the use of imagery from sequential orbits.

2.5 Sea-Surface Temperature (SST)

High-resolution sea-surface temperature (SST) observations are required for: (i) NWP (addressed in the global and regional NWP SoGs); (ii) Seasonal to Inter-annual Forecast (addressed in the SIA SoG); (iii) ocean forecasting systems (assimilation in and validation of ocean models); climate modelling; and, (iv) marine services.

Coastal and inland seas users are defined as those using SST data products for regional ocean modelling and marine services. SST in the coastal and inland regions has a large variability due to the diurnal cycle of solar radiation, which creates significant changes to the surface characteristics of the land and sea and forces land-air-sea interactions, i.e., land-sea breezes. Typically, this user group has a requirement for ultra-high resolution SST data sets (1km spatial resolution and <6 hours temporal resolution), with good accuracy (< 0.1K) and temporal coverage (hourly).

The table below specifies the consolidated user requirements for ocean forecasting systems and marine services.

Application	Spatial resolution Threshold (km)	Delivery timeliness (hours)		Accuracy (K)
		Target	Threshold	
Coastal Ocean forecasting	10	1	3	0.5

Open Ocean forecasting	25	1	3	0.5
Marine modelling	25	0.08	6	1
Maritime safety Services	10	1	3	1

Ships and moored and drifting buoys provide observations of SST of good temporal frequency and acceptable accuracy as long as required metadata are provided. For example, the depth of the measurement is essential for deriving the diurnal cycle and the foundation temperature. Coverage is marginal or poor over some areas of the global ocean. The goal for high quality SST in the open ocean is ideally 5km spatial scale with accuracy 0.5K, and fast delivery (availability within 1 hour). In coastal regions, the goal is 1km with a delivery delay of 1 hour (accuracy 1K on 10km spatial scale).

Drifting buoy and other in situ SST measurements are used for calibration/validation of satellite data, in the error estimation for observations products and in combined analysis products. They are critically important in providing bias correction of these data. Satellite biases can occur from orbit changes, satellite instrument changes and changes in physical assumptions regarding the physics of the atmosphere (e.g. through the addition of volcanic aerosols). Thus, drifting buoy and other in situ data are needed to correct for any of these changes.

Satellite measurements provide high-resolution SST data. Both infra-red and microwave satellite data are important. Microwave data have a significant coverage advantage over infra-red data because microwave data can be retrieved in cloud-covered regions while infra-red cannot. However, microwave SST is at a much lower spatial resolution than infra-red. In addition microwave SST cannot be obtained within roughly 50km of land. A combination of both infra-red and microwave data is needed because each has different coverage and error properties.

Instruments on polar-orbiting satellites provide global coverage in principle, good horizontal and temporal resolution and acceptable accuracies (once they are bias-corrected using in situ data), except in areas that are persistently cloud-covered, which includes significant areas of the tropics. High-resolution SST (1km) can be retrieved by polar-orbiting infra-red radiometers and rather degraded resolution SST (5km) from radiometers on board geostationary satellites. However, quantitative measurement of the SST diurnal cycle is still a challenging subject which currently only drifters can address. In addition, microwave radiometers cannot be used for coastal applications because of (a) rather coarse spatial resolution and (b) contamination by land signals.

2.6 Sea-Surface Salinity (SSS)

We note that the standard units for salinity have recently been changed following TEOS10 (http://www.teos-10.org/), which was adopted by the Intergovernmental Oceanographic Commission at its 25th assembly in June 2009. Practical Salinity Units (PSU) have been replaced by the SI unit Absolute Salinity SA, (g/kg).

High resolution and high quality Sea-Surface Salinity (SSS) observations are required for ocean forecasting systems (assimilation in and validation of ocean models).

Frequent SSS sampling with global coverage and sufficient accuracy will provide help constrain the temporal and spatial distribution of precipitation. The remote sensing instrumentation remains experimental and the full impact of these observations is yet to be determined. Nonetheless, there is a requirement to constrain this state variable at the surface where the variability is greatest and the mass fluxes are known to have large errors.

Coastal and inland sea users are defined (as per SST above) as those using SSS data products for regional ocean modelling and marine services. SSS in the coastal and inland regions have a larger variability due to coastal systems (e.g. upwelling/downwelling processes) and river discharge as well as enhanced evaporation in regions shallower than the optical depth or with weak circulation. Typically, this user group has a requirement for higher resolution SSS data sets

(1km-5km spatial resolution and <6 hours temporal resolution), with good accuracy (< 0.1-0.7SA) and temporal coverage (hourly). The spatial scales of variability in the open ocean are dominated by the mesoscale with a resolution of 10-25km and temporal resolution of 12-24 hours. The accuracy range represents thresholds of accuracy that will impact an analysis and depend on the region of the ocean being observed.

The table below specifies the user requirements for ocean forecasting systems and marine services.

Application	Spatial resolution (km)	Delivery timeliness (hours)		Accuracy (S_A)
		Target	Threshold	
Coastal Ocean forecasting	< 1 -5	3	6	< 0.1-0.7
Open Ocean forecasting	10-25	12	24	< 0.1-0.7

As long as the required metadata are provided (e.g. the depth of the measurement is important for deriving the freshwater lens effects), ship and moored and other in situ observations of sea-surface SSS are of good temporal frequency and acceptable accuracy. Coverage is marginal or poor over some areas of the ocean globe. There is a requirement for high quality SSS in the open ocean, ideally with accuracy < 0.1SA on a 10km spatial scale, and fast delivery (availability within 1hour). In coastal regions, higher density is required (accuracy < 0.1 SA on a 1km spatial scale).

2.7 Sub-surface Temperature, Salinity and Density

Sub-surface temperature, salinity and density observations are required for: (i) Seasonal to Inter-annual Forecasts (SIA) (addressed in the SIA SoG); (ii) testing and validation of ocean forecasting models, and (iii) marine services/modelling.

The Tropical Atmosphere Ocean (TAO) / TRITON moored buoy network provides data with *good* frequency and accuracy, and *acceptable* spatial resolution for the tropical Pacific. The TAO Tropical Moored Buoy Arrays provide data of *marginal* vertical resolution for marine services applications (~50m down to 500m), which require high vertical resolution data in the mixed layer. The tropical moored network in the Atlantic (PIRATA) is *acceptable*. The Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) is being developed but is providing only *marginal* sampling at the moment. Sustained funding for the Tropical Moored Buoy Arrays remains a matter of concern.

Ships (XBT profiles) provide temperature profile data of *acceptable* spatial resolution over many of the targeted frequently repeated and high [horizontal resolution] density lines. However, sampling of about half of the targeted lines remains *poor*. Temporal resolution is generally *marginal*, but *acceptable* in some ship-specific lines. XBTs provide data with *good* vertical resolution (typically 1m) down to 1000m depth in delayed mode, but real-time data are constrained by limitations in the traditional GTS character codes being used at the moment.

Argo profiling floats provide near-global coverage of temperature and salinity profiles to ~2000m, mostly with *acceptable* to *good* vertical (every ~5m) and spatial resolutions, but only *marginal temporal* resolution, particularly for marine services. The accuracy is *acceptable* for assimilation by ocean models and for marine services.

The existing sampling is *adequate* for ocean prediction in regions of large spatial and temporal scales. However, there are many important regions where the spatial and temporal scales are shorter and the present sampling pattern is *poor*. Targeted deployments into these regions together with adaptive cycling patterns might be considered.

2.8 Ocean chlorophyll, nitrate, silicate and phosphate concentration

Ocean chlorophyll concentration observations are required for marine services applications and for validation of ocean models. Ocean chlorophyll concentration with high-spatial resolution (250m to 1km) can be deduced from remote sensing images of biological and non-biological parameters. Ocean chlorophyll concentration data can indicate several types of marine environmental problems, e.g. environmental pollution, marine eutrophication, harmful algal blooms and the level of primary productivity. Parameter retrieval algorithms in turbid waters are not yet established, but developments of an observation system based on remotely sensed ocean chlorophyll concentration have presented promising results for a future operational observing system. *In-situ* measurements are needed to complement satellite ocean chlorophyll concentration observations. These measurements should be accompanied by real-time daily observations of ocean temperature, surface wind and nutrients (i.e. phosphate, nitrate, nitrite, ammonium, silicate).

Nitrate concentration observations are required for parameterization and validation of marine ecological models. From surface to bottom waters, ocean nitrate concentration can be measured by *in-situ* observation or common chemical test in laboratory. Moored buoys and automatic online water quality analyzers are available for *in-situ* observation. For oligotrophic ocean, nitrate concentration can only be obtained by chemical test in laboratory. Nitrate concentration data are helpful to evaluate environmental pollution, marine eutrophication, N cycle, plant growth and the state of dissolved oxygen.

Silicate concentration observations are required for parameterization and validation of marine ecological models. Ocean silicate concentration can be measured by *in-situ* observation or common chemical test in laboratory. Moored buoys and automatic online water quality analyzers are available for *in-situ* observation. Silicate is necessary for the growth of diatoms to absorb Opal (Opal, $SiO_2 \cdot 2H_2O$) to constitute cells' shells. After debris of diatoms settling down to the bottom, silicate becomes a major component of deep-sea sediments. Nitrate concentration data can indicate the growth of diatoms and the silicon state in the sediment.

Phosphate concentration observations are required for parameterization and validation of marine ecological models. Phosphorus is an essential nutrient utilized by phytoplankton for energy transport and growth and phosphate availability can be an important factor influencing phytoplankton species composition and abundance. Phosphate may be the sole source of phosphorus directly absorbed by phytoplankton. From surface to bottom waters, ocean phosphate concentration can be measured by *in-situ* observation or common chemical test in laboratory. Moored buoys and automatic online water quality analyzers are available for *in-situ* observation. For oligotrophic ocean, phosphate concentration can only be obtained by chemical test in laboratory. Phosphate concentration data are helpful to evaluate environmental pollution, marine eutrophication, P cycle and the primary productivity.

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2.9 3-D Ocean Currents

Observations of 3-D ocean currents are required for marine services applications, and for testing and validation of ocean models.

Inferred surface currents from drifting buoys are *acceptable* in terms of spatial coverage and accuracy and are *marginal* in terms of temporal resolution. Targeting deployments of drifting buoys into regions of high variability such as boundary currents and downstream geostrophic turbulence would help enhance their impact on ocean prediction systems. Moored buoys are *good* in temporal resolution and accuracy, but *marginal* or *poor* otherwise. The Acoustic Doppler Current Profiler (ADCP) provides observations of ocean currents over a range of depths, with *acceptable* accuracy. Coverage is *marginal* or *poor* over most areas of the ocean globe, with *marginal* vertical resolution for marine services applications, which require high vertical resolution data in the mixed layer.

Satellite altimetry is being used to infer the distribution of ocean currents (geostrophic velocity). Satellite altimetry provides more homogeneous space and time coverage than *in situ* observations, permits to derive the ageostrophic motion (e.g. centrifugal, Ekman, ageostrophic submesoscale) and the time-mean motion. Satellite altimetry also permits to detect geostrophic eddies. Global mean dynamic topography can be obtained by combining information on the geoid, altimeters, drifters, wind field, and hydrography. These products are *poor* in terms of timeliness required for marine services applications. HF Radars provide for *good* temporal and spatial resolution in coastal regions, with *marginal* accuracy.

2.10 Bathymetry, Coastal Topography and Shorelines

Observations of bathymetry, coastal topography and shorelines are required for ocean and coastal modelling. Very high resolution data are required due to the gradual changes of the coastline through erosion and accretion processes relating to coastal meteorological and oceanographic phenomena (e.g. waves, storm surges and sea ice). Visible and infrared imagers (i.e. Landsat, SPOT), synthetic aperture radar (SAR) and aerial photography provide good information on the coastline and coastal topography.

Many sonar techniques have been developed for bathymetry. Satellite altimeters also map deep-sea topography by detecting the subtle variations in sea level caused by the gravitational pull of undersea mountains, ridges, and other masses. These provide global coverage and *acceptable* to *good* accuracy.

2.11 Surface Wind Vector over the Ocean and Coastal Areas

High-resolution surface wind vectors over the ocean and coastal areas are required as an input field to ocean models (including wave models) for marine services, marine modelling and atmospheric modelling. The surface wind-field is a key variable for driving ocean models and to nowcast and forecast marine meteorological and oceanographic conditions. It is strongly influenced by the coastal topography and land-sea surface conditions. Traditional global and regional NWP products do not have adequate spatial resolution for marine services applications, as well as for coastal modelling.

Voluntary Observing Ships (VOS) and meteorological and oceanographic moored buoys provide observations of *acceptable* frequency and accuracy Coverage is *marginal* or *poor* over large areas of the ocean globe. The tropical moored buoy network has been a key contributor to surface wind measurements over the last decade, particularly for monitoring and verification, providing both *good* coverage and accuracy in the equatorial Pacific. Fixed and drifting buoys and VOS outside the tropical Pacific provide observations of *marginal* coverage and frequency; accuracy is *acceptable*. Wind observations from drifting buoys are *poor*.

Polar-orbiting satellites provide information on surface wind, with global coverage, *good* horizontal resolution, and *acceptable* temporal resolution and accuracy. Microwave scatterometers have *marginal* spatial resolution (25km), whereas the wide swath SAR measurement has *marginal* temporal resolution (one measurement every few days) and provides no wind direction.

2.12 Surface pressure

Ships and buoys take standard surface observations of several atmospheric variables, including surface pressure. In relatively shallow waters, oil platforms do the same, but the frequency and spatial coverage are *marginal* for marine services applications. Mean sea level pressure is vital to detect and monitor atmospheric phenomena over the oceans (e.g. tropical cyclones) that significantly constrain shipping. As stated in the SoG for Synoptic Meteorology, even very isolated stations may play an important role in synoptic forecasting, especially when they point out differences with NWP model outputs.

2.13 Surface heat flux over the ocean

High-resolution surface heat flux observations over the ocean are required as input fields to ocean models and for marine services. Surface heat flux is of critical importance to improve the skill of forecasts of sea surface temperature and entrainment of heat into the surface mixed layer. Improved performance will have impacts on NWP forecasts and sonar prediction, as well as reduce background errors in ocean data assimilation. Total heat flux is composed of downward shortwave, net longwave, latent heat and sensible heat fluxes. Accuracy strongly depends on both cloud and radiation physics parameterisations, and adequate atmospheric observing systems. NWP products are reliable and provide *adequate* products for current applications.

High quality marine meteorological stations are required to more accurately observe fluxes over the ocean and to enhance the physical parameterisations contained in the NWP products. Deployment of meteorological stations in mid- and high-latitudes will further enhance this development over the range of conditions that occur at the air-sea interface.

2.14 Visibility

Poor visibility is a major hazard to all vessels because of the increased danger of collision. Surface visibility observations are made primarily by ships, and at coastal stations (mainly at harbours, where VTS (Vessel Traffic Services) is usually available). This parameter can vary substantially over short distances. Accuracy is *acceptable* in coastal areas and *marginal* in the open ocean. Horizontal / temporal resolution is *poor* over the most of the global ocean. Typically, visibility is deduced from the output of regional atmospheric models (see regional NWP SoG).

2.15 Summary of the Statement of Guidance for Ocean Applications

The following key points summarize the SoG for Ocean Applications:

- A large part of marine and ocean observing systems is currently maintained by research funding with limited duration. This has the potential of leaving observational gaps unless ongoing funding for sustained observing networks is guaranteed. The ocean observing community should therefore ensure sustained funding for the key observing systems (e.g. tropical moorings, Argo, surface drifters with barometers, as well as altimeter, scatterometer, microwave SST and sea ice measurements from satellite missions);

- The uneven geographical coverage of the *in situ* ocean observing network is also an ongoing issue for ocean applications. Considering the regional variability in requirements as well as to ensure optimized planning for observing networks with limited resources, the need for studies on geographical variability in spatial/temporal resolution for ocean observations should be emphasised;

- Ocean observing communities should also improve geographical coverage of ocean observing systems, particularly for measuring SST, SSHA, SSS and visibility, along with higher resolution geometry and extend open-ocean and coastal wind-wave observing networks (e.g. 400 time-series reporting in open ocean), possibly developing other existing observing sites (e.g. global sea level and tsunami monitoring network) into multi-purpose stations;

The critical met-ocean variables that are not adequately measured (more accurate and frequent observations and better spatial/temporal resolution are required) by current or planned systems are:

- Sea surface height anomaly - noting the high impact of this observation on ocean forecasting systems to derive both the ocean state and circulation of the upper ocean, supporting a large number of applications, it is recommended that the requirements for this variable be given high priority and that a minimum service level target be agreed and sustained;

- Wave parameters (significant wave height, dominant wave period, Wave 1-D and wave directional energy frequency spectrum) - noting that extreme wave and wind gusts events significantly constrain shipping and other marine operations, it is recommended to collocate of wind and wave sensors;

- Sea level – noting the wide range of requirements for sea level data, depending on the application area (from early detection of tsunamis to long-term trends of sea level rise), the requirements for this variable should be carefully addressed;

- Surface pressure – noting that sea-surface pressure data from drifting and moored buoys are still limited, particularly in tropical regions where these data are vital to detect and monitor atmospheric phenomena over the oceans (e.g. tropical cyclones) that significantly constrain shipping, it is recommended to install of barometers on all deployed drifters (1250); and

- Visibility – noting that visibility data are critical for harbours operations and as these are still very limited, the NMHSs are encouraged to measure visibility.

It is therefore recommended that ocean observing communities should (i) ensure that state-of-art technologies are employed to improve accuracy for all measurements; (ii) extend collaboration among themselves at national/regional levels to enhance wave measurement networks (e.g. moored buoy networks) for validation and evaluation; (iii) install barometers on all newly deployed drifting buoys (target 1250 units), and (iv) develop visibility measurement capability over the ocean (consultation needed with JCOMM experts on how to practically achieve this).

Satellite data are the only means for providing high-resolution data in key ocean areas where *in situ* observations are sparse or absent. In general, *in situ* met-ocean data and observations are *poor* for marine services (in particular, for monitoring and warning marine-related hazards) and *marginal* for assimilation into ocean models, including wave models. Better integration of met-ocean measurements into NHMSs and their sustainability are needed.

There is a need for satellite operators to ensure (i) a combination of both infra-red and microwave measurements for better coverage of SST observations; (ii) improved observations in coastal regions (altimetry, SST); (iii) a minimum of two interleaved operational satellites providing SSHA observations to support ocean forecasting applications, and (iv) the development satellite measurements of SSS on an operational basis.

APPENDIX B

EXCERPTS OF INTEREST TO THE SOT FROM THE IMPLEMENTATION PLAN FOR THE EVOLUTION OF GLOBAL OBSERVING SYSTEMS (EGOS-IP)

5. SURFACE-BASED OBSERVING SYSTEM

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5.3 Issues specific to each observing system component

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5.3.5 Upper-air observing system over the oceans. Automated Shipboard Aerological Programme (ASAP) ships

All the Actions documented in section 5.3.1.1 related to radiosonde observations over land, except those for GRUAN (5.3.1.1.2), are relevant for ASAP. These Actions refer to:

- The importance of isolated radiosonde data for removing the biggest gaps in data coverage;
- The appropriate coding of the total radiosonde information in the vertical, followed by a rapid real-time dissemination;
- The possibility to optimize the data coverage by adapting the launching time, taking into account the ensemble of the radiosonde network, but also other observation systems providing vertical profile observations (AMDAR for example).

For the North Atlantic area (with very few islands which can provide fixed radiosonde sites), EUMETNET[8] has developed a European component of the Automated Shipboard Aerological Programme (ASAP), called E-ASAP (EUMETNET – ASAP). See information on E-ASAP by going to the home page of EUMETNET. Between 15 and 20 ships regularly operate radiosonde launches in the North Atlantic on commercial line services from Western Europe to North and Central America. These ASAP ships contribute to about 10 to 15 radiosonde observations per day on average (situation of 2012), most of these observations being made at 00 or 12 UTC (possibility to make them at a different time, in order to optimize space-time coverage). In the year 2011, the E-ASAP programme contributed about 4500 radiosonde launches over the Atlantic Ocean. Concerning the impact of ASAP ships on numerical forecasts, the Proceedings of the 2008 WMO workshop states (see reference in footnote of section 4): “Even a very limited number of radiosondes located in data sparse regions in the oceans can have a significant impact on the forecast”. The North Atlantic ASAP network has not only a direct impact on forecasts, but it helps the use of satellite data by providing in-situ reference observations with a lot of vertical details. More than 80% of the total ASAP launches in 2011 were performed in the Atlantic Ocean. Therefore, for other oceanic areas, and especially for the North Pacific and Indian Ocean, there is potential for improving very significantly the overall quality of the composite observing system through the development of a very limited number of observing stations (typically 10 or 20). Dropsondes launched from reconnaissance aircrafts are an equivalent system which is used both in the Pacific and in the Atlantic, but very irregularly, to support severe storms forecasts.

Action G49

Action: Maintain and optimize the existing ASAP network over North Atlantic, and develop similar programmes for the North Pacific and the Indian Ocean.
Who: NMSs, NMHSs, in collaboration with companies operating commercial ships, RAs, JCOMM, CBS and CAS. JCOMM to lead.
Time-frame: Continuous.

[8] http://www.eumetnet.eu/

Performance indicator: Volume of ASAP data available in real-time (usual NWP monitoring indicators).

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5.3.6 Surface observing systems over the oceans

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5.3.6.3 Voluntary Observing Ships Scheme (VOS)

The list of meteorological and marine variables which is normally observed by VOS ships is the same as the one observed by sea stations (5.3.6.2.). The main practical difference is that ships are mobile: this can be an advantage for a better space-time data coverage, but it is a drawback for climate users interested in long time series.

Many recommendations made for land surface synoptic stations are also valid for VOS ships, especially those concerning: global exchange of hourly data (**Action G30**) and coding and transmission of metadata (**Action G32**). For the atmospheric pressure measurement onboard ships, a particular attention should be given to the barometer height, its correct value, correct coding and correct transmission. Indeed atmospheric pressure (often reduced to sea level in this case) is the most important ship observation for NWP, and it is also very important for marine and aviation applications, as well as synoptic meteorology and nowcasting. The global NWP monitoring of ship data shows that some ship observations are affected by important biases in atmospheric pressure measurements, which is obviously linked to incorrect barometer heights (and/or erroneous reduction to sea level). There are also potential improvements on the quality of ship air temperature, SST and wind observations, improvements which could be obtained by more regular interactions of the observation operators with the NWP monitoring centres. See for example the UK Metoffice Website[9].

Action G51

Action: Improve the quality of ship observations by more regular interactions with the NWP monitoring centres and more regular checks on the instruments onboard.
Who: Port Meteorological Officers (PMOs), NMSs, NMHSs and other NWP monitoring centres in collaboration with companies operating commercial ships. CBS and JCOMM to lead the action.
Time-frame: Continuous.
Performance indicators: Usual NWP monitoring indicators.

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5.3.7 Sub-surface oceanic observing systems

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5.3.7.3 Ships of opportunity

With XBT instruments, ships of opportunity can provide oceanic temperature profile data with a good vertical resolution (about 1m) down to 1000m. They are used by several applications in the same way as profiling floats (see 5.3.7.1), and there is also a lot of potential to improve their real-time delivery.

Action G58

Action: For ocean and weather forecasting purposes, improve timely delivery and distribute high vertical resolution data for sub-surface temperature from Ships/XBT.
Who: NMSs, NMHSs, national oceanographic institutions, in collaboration with JCOMM, international organizations and companies operating ships of opportunity, CBS and CIMO.

[9] http://www.metoffice.gov.uk/research/monitoring/observations/marine

JCOMM to lead the action in cooperation with CBS.
Time-frame: Continuous.
Performance indicators: Volume of XBT data available in real-time (usual monitoring indicators).

The action of the GCOS-IP, aimed at improving and sustaining the existing network and coverage of the ships of opportunities should be supported.

APPENDIX C

RECOMMENDATION 3.1(1)/3 (CBS-EXT.(2014))

SUPPORT OF MEMBERS TO THE IMPLEMENTATION OF THE MARINE METEOROLOGICAL AND OCEANOGRAPHIC OBSERVING SYSTEM IN SUPPORT OF NWP

THE COMMISSION FOR BASIC SYSTEMS,

Noting:

(1) Recommendation 6 (CBS-15) – Implementation Plan for the Evolution of Global Observing Systems (EGOS-IP), and actions G52, G53, and G54 in particular,

(2) Resolution 10 (EC-65) - Report of the fifteenth session of the Commission for Basic Systems relevant to integrated observing systems,

(3) WIGOS Technical Report No. 2012-1, Final Report of the Fifth WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction,

(4) Final report of the eighth session of the OPAG-IOS the Implementation/Coordination Team on Integrated Observing Systems (ICT-IOS), Geneva, Switzerland, 7-10 May 2014,

(5) GCOS Report No. 184, Ocean Observations Panel for Climate, Tropical Pacific Observing System, 2020 Workshop (TPOS 2020, San Diego, USA, 27-30 January 2014), Volume I: Workshop Report and Recommendations,

(6) WMO-No. 1093, Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology, Fourth Session (Yeosu, Republic of Korea, 28-31 May 2012),

(7) DBCP Technical Document No. 15, Twelfth Edition 2013, Data Buoy Cooperation Panel (DBCP), Global Data Buoy Observations, a DBCP Implementation Strategy,

Considering:

(1) The importance of global observing systems to address all the requirements of WMO application areas,

(2) That marine meteorological and oceanographic observations are not only required by climate monitoring and ocean applications, but also by other WMO Applications Areas such as Numerical Weather Prediction,

Recognizing that:

(1) Sea level pressure cannot be observed adequately from space with current technology,

(2) Impact studies have shown a high impact on NWP on a per observation basis of sea level pressure from drifters,

(3) The drifter technology is cost-effective, and that provisional estimates suggest that the impact/cost of drifter data is higher than for all the other observing systems,

(4) Substantial benefits can potentially be gained by NMHSs through a collaboration with oceanographic institutes which deploy standard drifters, and are offering opportunities through the DBCP for the purchase of barometer upgrades on such drifters,

(5) The tropical moored buoys also provide valuable surface meteorological, and upper ocean observations not only for climate monitoring, but also for Numerical Weather Prediction, seasonal to inter-annual forecasting, and tropical cyclone forecasting,

(6) Pending the redesign of the Tropical Pacific Observing System by 2020, it is needed to maintain the tropical moored buoy array, and assure data availability to an acceptable level,

Noting with concern:

(1) The risks of reduced funding of the barometer drifter array,

(2) The drop in the last two years of the data availability of the Tropical Moored Buoy array due to vandalism on the data buoys, and difficulties to assure maintenance due to the cost of ship time, and piracy,

Recommends that:

(1) Members contribute to the DBCP Implementation Strategy, and commit appropriate resources to the barometer drifter, and the tropical moored buoy arrays;

(2) NMHSs collaborate with partner organizations, and use the opportunity of the DBCP barometer drifter upgrade scheme;

(3) Members take steps to return the tropical moored buoy array to at least 80% data return as soon as possible, while design and planning work is carried out for the future TPOS;

Requests that the Secretary-General bring this recommendation to the attention of Members.