WORLD METEOROLOGICAL ORGANIZATION

INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (OF UNESCO)

JOINT WMO / IOC TECHNICAL COMMISSION FOR OCEANOGRAPHY AND MARINE METEOROLOGY (JCOMM)

SHIP OBSERVATIONS TEAM

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ROLLING REVIEW OF REQUIREMENTS

(Submitted by the Secretariat)

Summary and purpose of the document

This document is proposing how to address non-climate requirements as part of the JCOMM OPA Observing System Implementation Goals. Such requirements include Global and Regional Numerical Weather Prediction, Synoptic Meteorology, and Ocean Applications as considered through the WMO CBS Rolling Review of Requirements (RRR). The goal of this document is to look at the results from the RRR and extract priority ocean variables for JCOMM to address as part of the OPA Observing System Implementation Goals.

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. Critical ocean variables according to the Rolling Review of Requirements.

References: A. WMO Statements of Guidance as part of the WMO Rolling Review of Requirements[1]

B. Summary and conclusions from the fourth WMO Workshop on the Impact of Various Observing Systems on NWP[2] (Geneva, Switzerland, 19-21 May 2008).

1: http://www.wmo.int/pages/prog/sat/RRR-and-SOG.html
2: http://www.wmo.int/pages/prog/www/OSY/Meetings/NWP-4-Geneva2008/Summary-Conclusions.pdf

- A - DRAFT TEXT FOR INCLUSION IN THE FINAL REPORT

I-3.1.3.1 The Team noted that at its third Session, Paris, 9-11 March 2009, the Observations Coordination Group has updated the JCOMM OPA Observing System Implementation Goals (previously known as OPA strategic workplan) to better take into account non-climate requirements. The document is mainly focusing on climate requirements but those for Numerical Weather Prediction, marine services, and synoptic meteorology have been included, taking into account the results from the WMO Rolling Review of Requirements, including the JCOMM Statement of Guidance for Ocean Applications. This resulted in the following requirements being expressed for critical variables where deficiencies have been noted:

- Sea level: For ocean applications, *In situ* observations are used for assimilation in ocean circulation models, and for calibration / validation of the satellite altimeter and models. The sea level observing network needs enhancing so that any tide gauge makes measurements with the following minimal requirements: 1cm accuracy, 6 to 15 min high frequency data with accurate timing (1 min.). Measurements must be made relative to a fixed and permanent local tide gauge benchmark (TGBM).
- Precipitation: Precipitation should be reported in a more systematic way to meet the requirements for global and regional NWP, as well as synoptic meteorology.
- Visibility: Horizontal visibility should be reported in a more systematic way to meet the requirements for Ocean Applications (for maritime safety essentially).
- Waves: making *in situ* wave measurements in a more systematic way would permit to address the requirements for ocean applications (model and satellite product validation). Wave observations must be regarded as a key variable to be derived from satellite observations using polar altimeters for significant wave height, and SAR.
- Snow: Snow observations are required in support of global NWP mainly.
- Atmospheric profiles: ASAP units are required in support of global NWP and synoptic meteorology. ASAP are providing aerological profiles that complement AMDAR reports over remote ocean areas where only horizontal AMDAR reports (or no such report) are available. More information is needed in order to derive a realistic target for the programme (e.g., E-ASAP is deploying about 5000 radiosondes per year in the North Atlantic Ocean).

The Meeting made the following recommendations:

I-3.1.3.2 Team Members are invited to address user requirements and particular observing systems deficiencies as expressed in:

(i) the JCOMM OPA Implementation Goals, and

(ii) the JCOMM Statement of Guidance for Ocean Applications; special efforts should be made towards observing [*list of variables to be decided by the meeting*], from VOS, [*list of variables to be decided by the meeting*] from Ship of Opportunity, and enhancing ASAP soundings (***Action: Team members, ongoing***).

Appendices: 2

APPENDIX A

**CRITICAL OCEAN VARIABLES
ACCORDING TO THE ROLLING REVIEW OF REQUIREMENTS**

1. Introduction

1.1. The JCOMM OPA Observing System Implementation Goals for Building a Sustained Global Ocean Observing System in Support of the Global Earth Observation System of Systems mainly focuses on climate requirements as expressed in the GCOS Implementation Plan for the Global Observing System for Climate in support of the UNFCCC (GCOS-92), supporting research, forecasting, and monitoring of climate change and variability, including seasonal-to-inter-annual forecasting.

1.2. Although, this baseline system is designed to meet the climate requirements, it also serves other applications of WMO and IOC requiring ocean data in ocean applications and meteorological forecasting, which are detailed in section 3.1 below.

1.3. In addressing the climate requirements, JCOMM is also de-facto addressing much of the requirements of the applications listed above; there are specific variables and priorities, which need to be addressed for these applications in a more systematic way by JCOMM. The goal of this document is to look at the results from the WMO Rolling Review of Requirements and extract priority ocean variables for JCOMM to address as part of the OPA Observing System Implementation Goals.

2. Background: the WMO Rolling Review of Requirements (RRR)

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

- Seasonal to Inter-annual Forecasts
- Ocean Applications
- Global Numerical Weather Prediction
- Regional Numerical Weather Prediction
- Synoptic Meteorology
- Aeronautical Meteorology
- Atmospheric Chemistry
- Nowcasting and Very Short Range Forecasting
- Agricultural Meteorology
- Hydrology

2.2. The Rolling Review of Requirements 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) Critical review and gap analysis using critical review charts which are objectively comparing the

performances of the instruments with the requirements.

4) The interpretation of the results from the critical review charts by experts from each of the considered application area, results in the elaboration of the Statements of Guidance (SoG). The draft Statements of Guidance are then discussed, and possibly updated by the CBS Expert Team on the Evolution of the Global Observing System (ET-EGOS) before being formally endorsed by the Team.
5) Based on the Statements of Guidance, the ET-EGOS updates its implementation plan and proposes priorities.

2.3. The SoG for each of the application areas provide 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 analyzed 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.

3. Implications for JCOMM of the RRR, by application area

3.1. JCOMM proposes only to address the following application areas, taking into consideration ocean variables, requirements for Aeronautical Meteorology, Atmospheric Chemistry, Nowcasting and Very Short Range Forecasting, Agricultural Meteorology, and Hydrology would then be addressed to a sufficient extent:

- Seasonal to Inter-annual Forecasts
- Ocean Applications
- Global Numerical Weather Prediction
- Regional Numerical Weather Prediction
- Synoptic Meteorology

3.2. Based on the different Statements of Guidance, and consultation with the ET-EGOS experts, Appendix A summarizes how specific applications are being addressed by measuring specific marine and oceanographic variables either in situ or through remote sensing for the five application areas above. **Critical variables that are not adequately measured at present are detailed below. Other variables not listed below may also be important for those applications, but it is considered that the requirements for these are (i) either properly being addressed in the existing JCOMM OPA workplan through the climate requirements, or (ii) the observational requirements for those variables and the considered applications are currently being met adequately.**

Seasonal to Inter-annual forecasts

3.3. These requirements are already being addressed properly within the JCOMM OPA Observing System Implementation Goals.

Ocean Applications

3.4. Ocean Applications refer to Met-Ocean Forecasts and Services (MOFS), including marine services, marine hazards warning, and ocean mesoscale forecasting, serving the needs of maritime transportation (e.g. safety, routing), fishing, and coastal and offshore areas activities. The need for the following variables for ocean applications is particularly critical considering the requirements and the current performances of the observing systems:

- Waves: Requirements for wave observations include (i) assimilation into wave forecast models;

(ii) validation of wave forecast models; (iii) calibration / validation of satellite wave sensors; (iv) ocean wave climate and its variability on seasonal to decadal time scales; and, (v) role of waves in coupling. 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 direction) for their area of responsibility and interest, in support of several marine operations. Satellite altimeters provide information on significant wave height with global coverage and good accuracy but marginal horizontal / temporal coverage. SAR instruments provide information on the 2-D frequency-direction spectral wave energy density with good accuracy but marginal horizontal / temporal resolution. HF radars are also being used for costal models. *In situ* observations are used for the validation of models and satellite products with requirements of 1000km spacing requiring a network of around 400 buoys with minimum 10% / 25cm accuracy for wave height and 1 second for wave period.

- <u>Sea level</u>: Sea level observations are needed for tsunamis, storm surges and coastal flooding forecasting and warning systems, as well as for tide and mean sea level applications. While altimeters are primarily being used for sea level and provide for good global coverage and accuracy, the horizontal / temporal coverage is marginal. *In situ* observations are used for assimilation in ocean circulation models, and for calibration / validation of the satellite altimeter and models. The aim of any tide gauge recording should be to operate a gauge which is accurate and better than 1cm at all times. For example, in all conditions of tide, waves, currents, weather; provide for high frequency data (6 to 15 min) with accurate timing (1 min.); measurements must be made relative to a fixed and permanent local tide gauge benchmark (TGBM).
- <u>Visibility</u>: 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 the coastal stations (mainly at harbours, where the VTS (Vessel Track System is usually available)). This parameter can vary substantially over short distances. Accuracy is acceptable in coastal areas and marginal in open ocean. Horizontal / temporal resolution is poor over the most of the global ocean. Visibility is deduced from the output of regional atmospheric models (see regional NWP SoG).

Global Numerical Weather Prediction (NWP)

3.5. Observational requirements for global NWP have recently been addressed at the fourth WMO Workshop on the Impact of Various Observing Systems on NWP (Geneva, Switzerland, 19-21 May 2008). The need for the following variables for global NWP is particularly critical considering the requirements and the current performances of the observing systems:

- <u>3D wind, temperature, and humidity fields</u>: Vertical profiles are used for assimilation in global NWP models. Satellite observations are being used and their requirements as expressed by CBS considered in the scope of CGMS, and CEOS. Profiles are available from radiosondes, including ASAP over the oceans, and from aircraft (ascent / descent profiles) and wind profilers over some areas. Over most of the Earth - ocean and sparsely inhabited land - coverage is marginal or absent. Profile data are supplemented by single-level data from aircraft (wind, T) along main air routes only, and by single-level satellite winds over low and mid-latitudes. In these areas, horizontal and temporal resolution is acceptable or good, but vertical coverage is marginal (wind). Extension of AMDAR technology (principally for ascent / descent profiles but also for flight level information) offers the best short-term opportunity for increasing observations of wind, although large areas of the world would remain uncovered. Very few aircrafts currently provide humidity measurements, and these data are not generally available, but technical advances in this area are anticipated in the next decade. The Geneva “impact” workshop agreed that remote radiosonde stations are still of exceptional value (as shown with isolated islands, ASAP observations and AMMA radiosonde observations). They are essential and should not be closed although they are the most expensive.

- Surface pressure: Surface pressure is used for assimilation in global NWP models. Surface pressure observations are important to anchor the model surface pressure. Surface pressure is not observed by present or planned satellite systems, with the exception of some contribution from radio occultation data (which has been demonstrated theoretically and merits further study). Over ocean, ships and buoys provide observations of acceptable frequency. Accuracy is good for pressure and acceptable / marginal for wind. Coverage is marginal or absent over large areas of the Earth. The May 2008 "impact" workshop in Geneva agreed that the current contribution of buoys to the large-scale forecast skill at short and medium-range is of a few hours in the Northern Hemisphere, and a few hours to six hours in the Southern Hemisphere. The need for high temporal resolution data (1 hour) is critical.
- Precipitation: Surface stations measure accumulated precipitation with a temporal resolution and accuracy that is acceptable but a horizontal resolution that is marginal in some areas and missing over most of the Earth. Ground-based radars measure instantaneous precipitation with good horizontal and temporal resolution and acceptable accuracy, but over a few land areas only. Microwave imagers and sounders offer information on precipitation of marginal horizontal and temporal resolution, and acceptable / marginal accuracy (though validation is difficult). Geostationary infra-red imagers offer some information at much higher temporal resolution through the correlation of surface precipitation with properties of the cloud top, but accuracy is marginal due to the indirect nature of this relationship. Satellite-borne rain radars, together with plans for constellations of microwave imagers, offer the potential for improved observations.
- Snow: Over land, surface stations measure snow cover with good temporal resolution but marginal horizontal resolution and accuracy (primarily because of spatial sampling problems). Visible / near infrared satellite imagery provides information of good horizontal and temporal resolution and accuracy on snow cover (but not on its equivalent water content) in the daytime in cloud-free areas. Microwave imagery offers the potential of more information on snow water content (at lower but still good resolution) but data interpretation is difficult. Snow cover over sea-ice also presents data interpretation problems.

Regional Numerical Weather Prediction

3.6. The need for the following variables for regional NWP is particularly critical considering the requirements and the current performances of the observing systems:

- 3D wind, temperature, and humidity fields: RAOBs, AMDAR, profilers and Doppler radars all provide useful wind information for regional NWP. In addition, satellite derived wind information is particularly useful where other sources of wind information are lacking. From the standpoint of mesoscale numerical weather prediction, the humidity field is marginally sampled practically everywhere in the world. Like clouds and precipitation, the humidity field has strong variability on scales of tens to hundreds of kilometres in the horizontal and, as Raman lidar observations show, on scales of hundreds of metres in the vertical. Any improvement in the density, coverage, or vertical resolution of humidity observations is likely to be helpful for mesoscale prediction. The RAOB supplies temperature and wind soundings at good vertical resolution, but the density and frequency of observations is marginal, especially in sparsely populated areas, from the standpoint of mesoscale numerical prediction. The AMDAR systems provide good accuracy temperature measurements. Spatial and temporal coverage at altitude is good over the United States of America and Europe and along a few heavily travelled oceanic routes. ASAP profiles complement horizontal AMDAR observations over remote ocean areas where no aircraft ascent/descent is available.
- Precipitation: Satellite estimates of short-term precipitation are marginal at best, but satellites are virtually the only source of precipitation information over the oceans.

Synoptic Meteorology

3.7. Surface data are quite essential in synoptic meteorology. Their horizontal coverage is generally good over populated land, and marginal to poor over oceanic or desert areas, although oceanic buoys are being deployed in large numbers and improving the situation there. Measurement frequency and data accuracy are good. Over the oceans, fewer parameters are available. The need for the following variables for synoptic meteorology is particularly critical considering the requirements and the current performances of the observing systems:

- 3D wind, temperature, and humidity fields: Radiosondes remain the reference observing system for determination of detailed vertical structure in the atmosphere. This is due to their excellent vertical resolution and second to the simultaneous presence of temperature, wind, moisture and pressure measurements (moisture with marginal accuracy, all other parameters with good accuracy). Vertical stability analyses, seeking details, which are not necessarily captured by the NWP models, are based mostly on the radiosondes. The NWP model assessment made by the forecasters relies largely on them. Thus, despite the poor temporal resolution and uneven geographical coverage, radiosondes are of primary importance in synoptic meteorology. The increasing availability of display software for ADMAR data, particularly for ascent / descent profiles is making these data a highly useful tool for forecasters, particularly in data sparse regions of developing countries. Data quality is generally good, and quality control measures are being put in place to ensure adequate data integrity. ASAP profiles complement horizontal AMDAR observations over remote ocean areas where no aircraft ascent/descent is available.
- Surface pressure: Mean sea-level pressure, measured on ships, buoys, and islands is a key tracer of synoptic activity. Even very isolated stations may play an important role in synoptic forecasting, especially when they point out differences with NWP model output.
- Precipitation: Weather radars are essential for the detection of precipitation in real-time at high-spatial resolution. In areas where radar networks are installed, the horizontal and temporal resolution are excellent, and the accuracy of the quantitative estimation of precipitation is acceptable to good except for complex topography, where obscuration of low-lying areas hidden by higher topography is a limiting factor.

4. Summary of critical ocean variables

4.1. Below is a summary of critical ocean variables (i.e. for which a gap has been noted) based on the results from the Rolling Review of requirements for Ocean Applications, Global Numerical Weather Prediction, Regional Numerical Weather Prediction, and Synoptic Meteorology.

- Sea level: For ocean applications, *In situ* observations are used for assimilation in ocean circulation models, and for calibration / validation of the satellite altimeter and models, and the sea level observing network needs to be enhanced so that any tide gauge make measurements with the following minimal requirements: 1cm accuracy, 6 to 15 min high frequency data with accurate timing (1 min.). Measurements must be made relative to a fixed and permanent local tide gauge benchmark (TGBM).
- Precipitation: Precipitation should be reported in a more systematic way to meet the requirements for global and regional NWP, as well as synoptic meteorology.
- Visibility: Horizontal visibility should be reported in a more systematic way to meet the requirements for Ocean Applications (for maritime safety essentially).
- Waves: making *in situ* wave measurements in a more systematic way would permit to address the requirements for ocean applications (model and satellite product validation). Wave observations must be regarded as a key variable to be derived from satellite observations using polar altimeters for significant wave height, and SAR.
- Snow: Snow observations are required in support of global NWP mainly.
- Atmospheric profiles: ASAP units are required in support of global NWP and synoptic meteorology. ASAP are providing aerological profiles that complement AMDAR reports over

remote ocean areas where only horizontal AMDAR reports (or no such report) are available. More information is needed in order to derive a realistic target for the programme (e.g., E-ASAP is deploying about 5000 radiosondes per year in the North Atlantic Ocean).

This should result in changes in the JCOMM Observing System Implementation Goals and imply changes to observing networks coordinated under the JCOMM OPA. This may in turn have implications in cost, in platform lifetime and deployment strategy, and in needed research and pilots for new technology. The members of the OPA Coordination Group should flag these implications to be raised at JCOMM-III and other appropriate venues.

ANNEX

Summary3 of how specific applications are being addressed by measuring specific marine and oceanographic variables either in situ or through remote sensing

Note 1: Priority for improvement based on statements of guidance.
Note 2: Variables required for seasonal to inter-annual forecasting are already being addressed by the JCOMM OPA Observing System Implementation Goals

Variables	Observing systems		Applications				
	In situ	Remote sensing	Seasonal to Inter-annual Forecasting	Ocean Applications4	Global NWP	Regional NWP	Synoptic Meteorology
SST5	Drifters Moorings Ships	Polar satellites: IR imagers, passive MW imagers. Geo satellites : IR imagers.	Analysis/Assimilation In situ complement satellite Validation	In situ complement satellite Assimilation, validation and calibration of ocean models Marine Service (pollution, search & rescue, MSI)	Analysis/ assimilation. In situ complement satellite. Validation.	Analysis/Assimilation In situ complement satellite Validation	
Surface salinity[3]	Moorings Ships	Polar satellites: low-frequency passive MW (experimental).		Assimilation and validation of ocean models Marine services (pollution)	Analysis (for 7-15 day forecast).		
Waves/sea state[3]	Moorings	Polar satellites: altimeters		In situ for satellite & model validation	In situ for satellite & model validation.	In situ for satellite & model validation.	

3 Information deduced from the WMO Rolling Review of Requirements as documented in the Statements of Guidance for the considered applications (http://www.wmo.int/pages/prog/sat/RRR-and-SOG.html).

4 Ocean applications relate to Met-Ocean Forecasts and Services (MOFS), including marine services (marine pollution, search and rescue, Maritime Safety Information - MSI), and ocean mesoscale forecasting. The Statement of Guidance (SOG) for ocean applications was developed through a process of consultation to document the observational data requirements to support ocean applications. It was based originally on the JCOMM Users Requirement Document, which was prepared by the Chairpersons of the Expert Teams under the JCOMM Services Programme Area.

5 Essential Climate Variable (ECV)

Variables	Observing systems		Applications				
	In situ	**Remote sensing**	**Seasonal to Inter-annual Forecasting**	**Ocean Applications4**	**Global NWP**	**Regional NWP**	**Synoptic Meteorology**
		(significant wave height), SAR. Coastal radars Other technologies: (e.g. Navigation radar, Other radar, Shipborne sensors such as WAVEX)		and calibration In situ also for satellite bias correction Altimeter, SAR and coastal radars for assimilation and validation of wave models Marine services	In situ also for satellite bias correction.	In situ also for satellite bias correction.	
Currents[3]	Drifters Moorings (ADCP) Ships	Polar satellites: altimeters. Ground-based: HF radars.	In situ for testing and validation	In situ for testing and validation of ocean models, and as complement to satellite to derive the mean dynamic topography Marine Services (pollution, search & rescue, MSI)	Correction of scatterometer wind measurements.	Correction of scatterometer wind measurements.	
Sea level, ocean topography[3]	Tide gauges (with GPS) Tsunameters	Polar satellites: altimeters (for sea surface height anomaly).	Testing models and validating altimetry	Assimilation in ocean models and calibration/validatio n of satellite altimeter and models Marine Services (MSI)			
Ocean colour[3]	Ships	Polar satellites: VIS/NIR imagers.	Estimating transparency and determining where radiation is absorbed	Validation of ocean models Marine services In situ to complement satellite			

Variables	Observing systems		Applications				
	In situ	**Remote sensing**	**Seasonal to Inter-annual Forecasting**	**Ocean Applications4**	**Global NWP**	**Regional NWP**	**Synoptic Meteorology**
				observations			
Sub surface Temp[3]	Argo SOOP (XBTs) Trop. moorings Drifters (strings)		Assimilation	Analysis/Assimilatio n, testing and validation of ocean models	Assimilation for 7-15 forecasts.		
Sub surface salinity[3]	Argo Trop. moorings		Assimilation	Analysis/Assimilatio n, testing and validation of ocean models	Assimilation for 7-15 forecasts.		
Sea-ice[3]	Shore stations Aircrafts Ships Ice buoys	Polar satellites: passive MW and VIS imagers, scatterometers, SAR, SLAR/SLR. Airborne: laser profilometer. Ground-based: coastal radars.	Sea-ice cover Ice thickness for fluxes and for initialization	Marine Services (MSI), Validation of models and marine climatological studies In situ for satellite Validation	Analysis / assimilation. In situ for satellite validation.	Analysis / assimilation. In situ for satellite validation.	
Surface heat and fresh water fluxes	Moorings Reference stations (OceanSITES) Ships Hydrological stations (for fresh water run off)		Validation Assimilation from NWP products (derived from analysis from short range forecast)	Assimilation from NWP products (derived from analysis from short range forecast) into ocean models Marine services (MSI)	Derived from NWP models through assimilation of observations of other variables. In situ observations useful for model validation	Derived from NWP models through assimilation of observations of other variables. In situ observations useful for model validation	
Surface pressure[3]	Drifters Moorings Ships			Assimilation (isolated stations may play important role) Marine Services (MSI)	Assimilation.	Assimilation	Assimilation (isolated stations may play important role)
Surface wind[3]	Moorings	Polar satellites:	Assimilation	Assimilation	Assimilation.	Assimilation	Used by forecasters

Variables	Observing systems		Applications				
	In situ	Remote sensing	Seasonal to Inter-annual Forecasting	Ocean Applications4	Global NWP	Regional NWP	Synoptic Meteorology
	Ships	scatterometers (speed, direction), passive MW imagers (speed).		In situ for monitoring, verification In situ also complement satellite			
Surface air temp^{3}, humidiy^{3}	Moorings Ships			Marine Services (pollution, search & rescue, MSI)	Assimilation.	Assimilation	
Precipitation^{3}	Moorings Ships	Polar satellites: passive MW imagers and sounders, MW radar. Geo satellites: IR imagers. Ground-based: weather radars.	Verification	Marine Services (MSI)	Assimilation and validation.	Assimilation and validation	Used by forecasters
Visibility	Ships Coastal stations	Polar satellites: VIS/NIR imagers (via aerosol). Radars (VTS)		Marine Services (MSI, search & rescue) Deduced from output of regional atmospheric models	Assimilation (experimental).	Assimilation (experimental).	
Snow^{3}		Polar satellites: MW imagers (snow water content), VIS/NIR imagers (snow cover).		Marine Services (MSI)	Analysis / assimilation.	Analysis / assimilation.	
Vertical aerological profiles (wind^{3}, T^{3}, U^{3})	ASAP AMDAR/TAMDA R Raobs	**Wind** Geo satellites: VIS/IR imagers and IR sounders		Used by marine forecasters (MSI)	Assimilation.	Assimilation	Used by forecasters

Variables	Observing systems		Applications				
	In situ	Remote sensing	Seasonal to Inter-annual Forecasting	Ocean Applications4	Global NWP	Regional NWP	Synoptic Meteorology
		(AMVs). Polar satellites: VIS/IR imagers (AMVs), Doppler wind lidar. Ground-based: Doppler radars, wind profilers. **Temperature** Polar satellites: IR and passive MW sounders, radio-occultation. Geo satellites: IR sounders. **Humidity** Polar satellites: IR and passive MW sounders, MW imagers, radio-occultation. Geo satellites: IR sounders. Ground-based: GPS.					