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AN INTERACTIVE INFORMATION AND PROCESSING SYSTEM FOR THE REAL-TIME QUALITY CONTROL OF MARINE METEOROLOGICAL AND OCEANOGRAPHIC DATA*

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1. INTRODUCTION

The accuracy of numerical prediction models which produce meteorological and oceanographic forecasts are dependent on; (1) the models' ability to adequately describe the physics of the atmosphere/ ocean, and (2) the quality and quantity of the data used in their analyses and initializations. Compared to land areas, the ocean observing network for providing operational measurements on a routine basis is spatially and temporally very sparse. Hence, considerable effort is made to quality control (QC) and retain those few available synoptic observations over the oceanic regions. This quality-assured data must also be delivered to the numerical prediction models in a timely manner to be useful.

National weather and oceanographic processing centers are faced with two challenges which greatly affect their marine operations; (1) the time-critical QC of the marine measurements/ observations available for ingestion into numerical atmosphere and ocean models, and (2) the timely dissemination of both the QC'ed data and the forecast guidance based on the output from numerical models (Richardson and Feit, 1990). This paper describes the QUality Improvement Performance System (QUIPS) being used by the National Oceanic and Atmospheric Administration (NOAA) Ocean Products Center (OPC) for the real-time QC of global marine surface and subsurface observations collected by conventional means (ships, buoys, etc.) and geophysical parameters derived from environmental satellite data. Also described is an expert System for Marine Analysis and Real-Time Quality Control (SMARTQC) which is to be integrated into the existing QUIPS.

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2. BACKGROUND

The NOAA OPC was formed in 1985 through the cooperative efforts of the National Ocean Service (NOS), the National Weather Service (NWS), and the National Environmental Satellite, Data, and Information Service (NESDIS) to develop new and improved marine meteorological and oceanographic guidance products, to provide real-time QC of marine measurements/observations, and to ensure the timely dissemination of these data/products to users. The operational part of the Center, which operates 24 hours/day, 7 days/week, is responsible for the collection and QC of marine data sets in real-time and the generation, preparation, and dissemination of operational marine analysis and forecast guidance products.

The OPC is collocated with the NWS National Meteorological Center (NMC) at the NOAA Science and Operations Center in Camp Springs, Maryland. This collocation allows OPC personnel to utilize NMC's data bases, output fields from large scale meteorological models, and use existing communications networks and computer interconnectability for providing products to operational and research users. In addition, the OPC cooperates with other NOAA and U.S. Navy operational centers as well as with the research and academic communities.

3. DATA COLLECTION

Our present sources of information for understanding and forecasting the ocean's structure, variability, and dynamic interaction with the atmosphere are derived geophysical parameters from satellite remote sensors and in situ observations provided from an organized global communications network. This network is a diverse composite of operational measurement systems and platforms operated by an equally varied group of agencies, including NOAA, each with different missions and objectives. Figure 1 depicts the flow of data from these systems and platforms into NMC/OPC.

Conventional surface observational data (sea-level pressure, air and sea surface temperature, winds, waves, etc.) and subsurface data (temperature and salinity) are measured by ships, moored/drifting buoys, and coastal marine stations. Data from these platforms are transmitted to NMC/OPC by radio and satellite. Marine surface data derived from satellite-borne sensors such as passive microwave (wind speed), scatterometer (wind speed and direction), and altimeter (wind speed and significant wave height) are also becoming more readily available for operational use.

In addition, NMC/OPC receives marine data via the Global Telecommunications System (GTS) and from the Navy via the Automated Weather Network (AWN). These data are used by NOAA to produce analyses and forecast guidance, to improve existing marine warning and forecast systems, to study and quantify the long-term implications of climate and global change programs, and to calibrate/validate satellite-derived measurements.

4. SURFACE DATA QC

The spatial and temporal coverage of the existing, conventional ocean network is sparse compared with equivalent measurements over land. Density ratios of marine conventional observations to those over land average 1:10 and 1:10 000 over much of the high seas area. Looking at these ratios another way, if the land areas had the same sampling densities in time and space that the ocean areas have, meteorologists would be faced with the task of initializing a forecast model for the U.S. with only 19 observations - about 1 observation for every 3 states (Richardson and Reilly, 1989)! Thus the need for more accurate marine observations becomes more apparent when these ratios are realized. As such, considerable effort is made to make every measurement count in oceanic regions.

For any measurement/observation to be operationally useful, the time, location, and accuracy of the measurement/observation must be known. In addition, the measurement/observation must be received by the processing center in a timely manner for ingestion into numerical models for the dissemination of warnings and forecast updates.

Analysts at the OPC QC global marine surface and subsurface measurements from ships, buoys, aircraft, and coastal sites continuously. Approximately 1300 reports (650 ships, 550 buoys, 100 coastal marine stations) of sea-level pressure (SLP), wind speed/direction, and air and sea surface temperatures are QC'ed daily by OPC analysts for each of the four synoptic periods (0000, 0600, 1200, 1800 UTC).

An interactive computer system which involves a network of computers and workstations makes up the real-time QC system (Figure 2). The OPC analysts, using workstations, are assisted in their QC effort by computer software known as QUIPS in the QC of surface and subsurface data. Synoptic observations/measurements, model first guess fields from NMC's Global Data Assimilation System and Aviation Model, and seasonal subsurface climatologies (used to QC subsurface measurements) are made available to QUIPS. Surface observations/measurements that differ from first guesses by predetermined threshold values (see Table 1) are flagged and referred to a VAX workstation for operator review.

TABLE 1. Flagging criteria used by QUIPS

Parameter	Threshold
Sea-level pressure	+/- 4 mb
Air temperature	+/- 8 °C
Wind direction	≥ 140 degrees
Wind speed	+/- 15 kts
Sea surface temperature	+/- 6 °C

Menu driven commands, activated by a mouse, assist the QC analyst in checking flagged data with cruise/parameter plots and nearest neighbors' plots. A composite of the QUIPS display is shown in Figure 3. In addition to numerical model first guess fields, the analyst also has available near-global coverage of satellite imagery (visible, thermal, and water vapor) for additional checks and comparisons as might be appropriate.

For a typical synoptic period, approximately 10 percent of all measurements are flagged for SLP alone. Another 10 to 15 percent are flagged for review due to "questionable" wind speed, wind direction, air temperature, or sea surface temperature. QUIPS software also allows flagged measurements to be displayed in a color-coded format with different symbols for the various types of platforms. Five other windows that can be called up by QUIPS show differences between the interpolated first guess values and platform measurements and decision columns for "reject" and "keep" flags, platform history (up to 8 days for each platform), a window which allows a display of first guess contour fields, a cruise plot displaying the platform's cruise track, and a line graph of a platform's reported parameters over the last 8 days along with the associated first guess parameters.

Real-time QC decisions on the data are made available to NMC models whereas the subsurface data (to be discussed in the next section) are inserted on the GTS (see Figure 2). By-products of this QC process are statistics generated on each platform. These data are made available to platform managers on a semimonthly (subsurface data) and monthly (surface data) basis via electronic mail (OMNET).

Surface platform (ships, buoys, and coastal stations) statistics are computed for sea-level pressure, wind speed and direction, air and sea surface temperatures, and combined wave height. Statistics include mean differences from first guesses, standard deviations of mean differences, and number of gross errors. Measurements containing gross errors are not used in calculation of mean differences and standard deviations. Approximately 140 000 reports are used in calculating monthly statistics for nearly 5000 marine platforms. These statistics are transmitted to the British Meteorological Office, the World Meteorological Office coordinator for marine surface data, the National Data Buoy Center, Canada's Marine Environmental Data Service, and the Drifting Buoy Cooperation Panel.

5. SUBSURFACE DATA QC

Subsurface temperature and salinity data, transmitted by ships, buoys and aircraft, are also QC'ed by QUIPS. Approximately 110 temperature and salinity profiles are QC'ed each day. QUIPS allows interactive editing and display of these profiles. QC is done by changing the coded message on one part of the screen while viewing the graphic display of the profile. Sea surface temperature charts, cruise track histories, and climatological data serve as a reference source during this interactive QC process.

A semimonthly report that summarizes, by error type, all subsurface temperature and salinity data received at NMC/OPC is electronically transmitted to all managers of platforms that measure subsurface temperature and salinity. Errors are categorized by spikes (large, "unrealistic" temperature or salinity fluctuations occurring over small depth intervals), temperature/salinities out of range, and depths not increasing. Subsurface profiles which fall outside of climatological bounds (+/- 4 standard deviations of a NOAA seasonal, 5 x 5 degree climatology) are also flagged for containing a possible error. These statistical summaries, generated by this computer-based interactive system, inform platform managers of instrumentation that may be producing "questionable" data and aid OPC managers in developing QC training programs.

6. NEXT GENERATION QC

Data volumes, both conventional and satellite-derived, are increasing from all sources. These data need to be QC'ed before dissemination and ingestion into numerical models. While QUIPS takes advantage of the judgement of the QC analyst, it is labor-intensive and the percentage of the number of observations which can be QC'ed will diminish as the number of observations and parameters to be examined expands. The number of marine parameters derived from satellite-borne remote sensors is growing at an ever expanding rate from a QC viewpoint. Measurements from the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I) alone account for more than 6000 "superobs" (averaged over a 1 - degree square) of wind speed estimates during a synoptic period. This is only the start, with satellite measurements from scatterometers and altimeters just around the corner.

When the task of QC'ing large volumes of satellite data is coupled with QC'ing multivariables and the interactions of these variables, an expert system is not just necessary, but is essential. An expert system will capture individual expertise while eliminating subjectivity and will speed up the throughput time of the data. The development of the SMARTQC and the interfacing of SMARTQC with QUIPS is a step toward making the QC of large amounts of data manageable at the OPC. The SMARTQC, a rule-based, interactive, expert system checks and corrects, if needed, platform location, sensor bias, digit transpositions, and allows for internal consistency checks among variables. SMARTQC may be queried for explanations, for changes, and for suggested recommendations. All changes and recommendations are assigned levels of confidence based on past platform sensor performance and weighted neighboring platform agreement/disagreement. Low confidence decisions are referred to a workstation with recommendations, where a QC analyst makes a decision. The analyst will need only to review changes outside assigned thresholds.

All SMARTQC rules, in "plain language", are located in the shell of the expert system. These rules, including scanning radii for nearest neighbors and flagging criteria, which can be a function of location, can be easily and quickly changed. This facility allows for feedback into SMARTQC as experience is gained through use of the system.

7. FUTURE PLANS

The OPC plans to implement, test, and tune SMARTQC by comparing the SMARTQC decisions/recommendations with changes made by the OPC analysts. During this testing and tuning phase, SMARTQC/QUIPS will be used to QC measurements/observations collected by conventional platforms, satellite-derived SSM/I, and altimeter wind speeds as well as scatterometer wind vectors. With regard to SSM/I measurements, those superobs that have departed from the first guess by +/- 15 kts or more are, more often than not, clustered when they are found to be out of range. Approximately 1.5 percent of the SSM/I superobs have been found to fall into this category during an operational test at the NMC (Waters et al. 1992). The QC analyst must decide whether to keep or reject observational clusters as opposed to individual observations (with respect to conventional data). The analyst can call up a SMARTQC window in QUIPS. Figure 3 shows an example of a SMARTQC recommendation. The SMARTQC window (lower left portion of Figure 3), shows that SMARTQC has found the SSM/I wind in agreement with the measured scatterometer and altimeter winds and has recommended that the SSM/I be accepted with 95 percent confidence.

Work is in progress to obtain SSM/I wind measurements from two DMSP satellites on an operational basis. This will double the number of available SSM/I measurements (the tests at NMC have only utilized the output of one SSM/I). Scatterometer wind data (speed and direction) and altimeter wind speed and wave measurements from the European Space Agency's first European Remote Sensing Satellite (ERS-1) are now being obtained on a routine basis within three hours of observation. Experiments are being conducted at NMC to understand how best to use these new measurements and to assess their reliability and accuracy. Follow on missions, such as the continuing DMSP series, ERS-2, the Japanese Advanced Earth Observing Satellite (ADEOS), and the U.S., European, and Japanese polar platforms will assure that passive microwave, altimeter and scatterometer data will be continuously available on an operational basis.

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