QUALITY CONTROL OF MARINE DATA

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1. Introduction

There is ample evidence of the progress made in the development of numerical forecasting techniques. However, improvement in operational forecasting may well be seriously impeded by the current, insufficient data base and the poor quality of some data. In the past, marine surface reports have not been subjected to formal quality control (QC) prior to transmission on the Global Telecommunications System (GTS) or ingestion by numerical models. The result is that data of questionable quality have been distributed internationally and have negatively affected operational numerical analysis schemes and archival files used for research purposes.

The National Data Buoy Center (NDBC) recognized the importance of good quality data and over 10 years ago initiated a rigorous QC program on buoy data. Most of the procedures discussed here were developed by NDBC. Since its inception, the techniques have improved, and the types and numbers of stations have increased so that now about 50 moored buoys, 50 coastal stations, and 150 drifting buoys routinely have QC performed on them by NDBC.

National Meteorological Centers (NMCs) have realized the impact of poor quality data and have instituted QC techniques on reports, including marine observations, used by numerical models. The Ocean Products Center of the U.S. NMC is developing a program to conduct QC on mobile ship reports and other marine data.

A few figures will be provided in the text of this paper, however during the lecture at ECMWF, slides or viewgraphs of pertinent figures will be extensively used.

2. Procedures

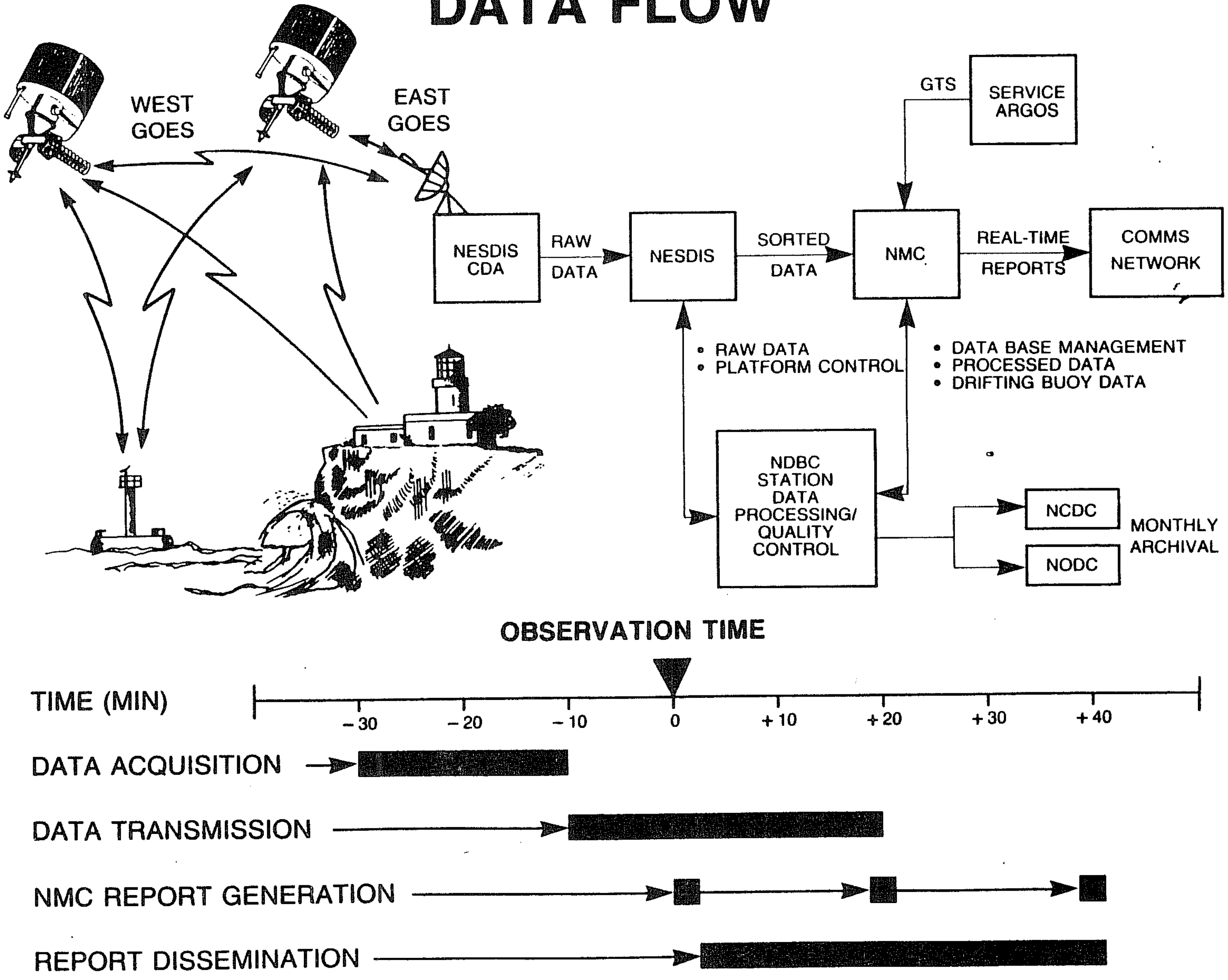
2.1 Real-Time Data Validation

Figure 1 shows the data flow for the transmission, processing, and dissemination of reports being quality controlled by NDBC. A description of NDBC QC procedures can be found in (2). Moored buoy and Coastal-Marine Automated Network stations transmit through the Geostationary Operational Environmental Satellite system for communication through ground stations to the National Weather Service Telecommunications Gateway (NWSTG) at Suitland, Maryland. Drifting buoys transmit through NOAA/-TIROS polar-orbiting satellites and data from North American drifters are processed at the Argos U.S. Global Processing Center (USGPC) in Landover, Maryland and sent to the NWSTG.

Real-time processing of all the data occurs on the NWSTG IBM 4341 computer. Several validation procedures are performed every five minutes and real-time distribution is made every 20 minutes. Data are checked for transmission parity errors,

Figure 1.

DATA FLOW



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gross range and time-continuity checks are performed, and wind-gust-to-speed ratios are examined. Furthermore, an NDBC-maintained status file is read to determine sensor calibration coefficients, which sensors are permanently failed, and which sensors are primary when two duplicate sensors exist. The formula used for performing the time-continuity check is

$$M = 0.58\ \sigma\sqrt{\Delta T}$$

where M is the maximum allowable difference, σ is the standard deviation of each measurement, and ΔT is the time difference in hours since the last acceptable observation. $\sqrt{\Delta T}$ is never greater than three hours, regardless of the actual time difference. This limits the maximum allowable difference and reduces the chance of disseminating bad data.

The time-continuity algorithm is based on a formula that relates the time rate of change of a normally distributed measurement to an autocorrelation coefficient. NDBC obtained a variety of time-rate-of-change statistics for sea-level pressure at several of our buoys. We discovered that the autocorrelation was proportional to the $\sqrt{\Delta T}$. The coefficient, 0.58, was then determined empirically, and represents a time change likely to be seen only once every two to three years at any given site.

Table 1 lists the upper and lower limits that the data must fall between and the standard deviation for each element for typical moored buoys. These parameters vary somewhat depending on location. All limits are removed well ahead of tropical cyclones because the maximum change of pressure allowed in one hour, 12.2 hPa, can easily be exceeded near the eye. Obviously,

Table 1.

TYPICAL LIMITS USED FOR RANGE CHECKS AND STANDARD DEVIATIONS USED FOR TIME-CONTINUITY CHECKS FOR REAL-TIME VALIDATION.

Measurement	Units	Lower Limit	Upper Limit	Standard Deviation
Sea level pressure	hPa	905.0	1060.0	21.0
Air temperature	°C	-14.0	40.0	11.0
Water temperature	°C	- 2.0	40.0	8.6
Wind Speed	m/s	0.0	60.0	25.0
Significant wave height	m	0.0	15.0	6.0
Average wave period	s	1.95	26.0	31.0

no range or time-continuity checks are performed on wind direction. Wind gusts are checked by computing the gust-to-speed ratio, and ensuring that the ratio lies between one and four.

These real-time checks are very efficient at removing the large errors caused by intermittent data transmission problems between the station and the satellite and severe instrument or electronic payload problems. These errors typically account for 0.5 percent data loss and our checks remove over 99 percent of these errors. On the other hand, these checks do a poor job of detecting errors caused by sensor degradation. Examples of sensor degradation include cases where the pressure suddenly drops 10 hPa due to ice accretion and the wind speed drops 15 percent due to worn anemometer bearings. Only about 25 percent of these problems are caught by our real-time checks, yet these problems cause persistently bad data. In order to remove these bad data from distribution, more stringent QC is performed at NDBC within 24 hours via a man-machine mix. When sensor deficiencies are detected, the status file on the IBM 4341 is updated to withhold release of that sensor's data.

2.2 NDBC Data Validation

Data QC at NDBC is philosophically different from real-time QC. Real-time validation detects only gross errors. As explained above, it catches a small percentage of bad data caused by sensor degradation. However, what is detected is virtually certain to be wrong. This approach is necessary because real-time validation is completely automated. On the other hand, data validation algorithms at NDBC are more stringent. Only one-third of the data they flag as suspicious are really bad data. About 98 percent of sensor degradation errors are detected by these algorithms. The different approach was taken because of a man-machine mix. Five different validation algorithms are used at NDBC.

First, more stringent range and time-continuity limits are applied. These limits are station-specific for each month. Limits chosen are extremes likely to occur once every two or three years.

Second, measurements obtained from duplicate sensors are checked to make sure that they track along together. For example,if the pressure from the first sensor is 0.5 hPa higher than that obtained from the second sensor, but for the next report the first sensor reads 0.2 hPa lower, the data are flagged as suspect. The analyst must decide which sensor is more erratic.

Third, the wind gusts are checked by the following scheme. As expected gust-to-mean speed ratio G, is calculated

$$G = 1 + 1/(1.98 - (1.89\ e^{-0.18g}))$$

where g is the measured wind gust. The actual gust-to-mean speed ratio is then compared to the expected ratio. If the ratios disagree by more than a tolerance factor, the data are flagged as suspect. The tolerance factor is higher at low wind speeds where gustiness is more sporadic.

Fourth, an elaborate algorithm was developed by NDBC to check the consistency between wind speeds and the energy in the wind-wave part of the sea spectrum (0.20 - 0.27 Hz). The algorithm was developed using regression to estimate the wave energy based on the average wind speed in the last three hours. The development sample consisted of 22 months of good data from a variety of NDBC buoys. If the observed wave energy between 0.20 and 0.27 Hz differs greatly from the estimated, the data are flagged, providing that the average wind speed is above four m/s and that the sea is building.

Finally, NDBC developed a procedure to check that a sensor's output is not stuck. Eight consecutive hours of data are examined, and the data are flagged if they do not change by more than a certain tolerance.

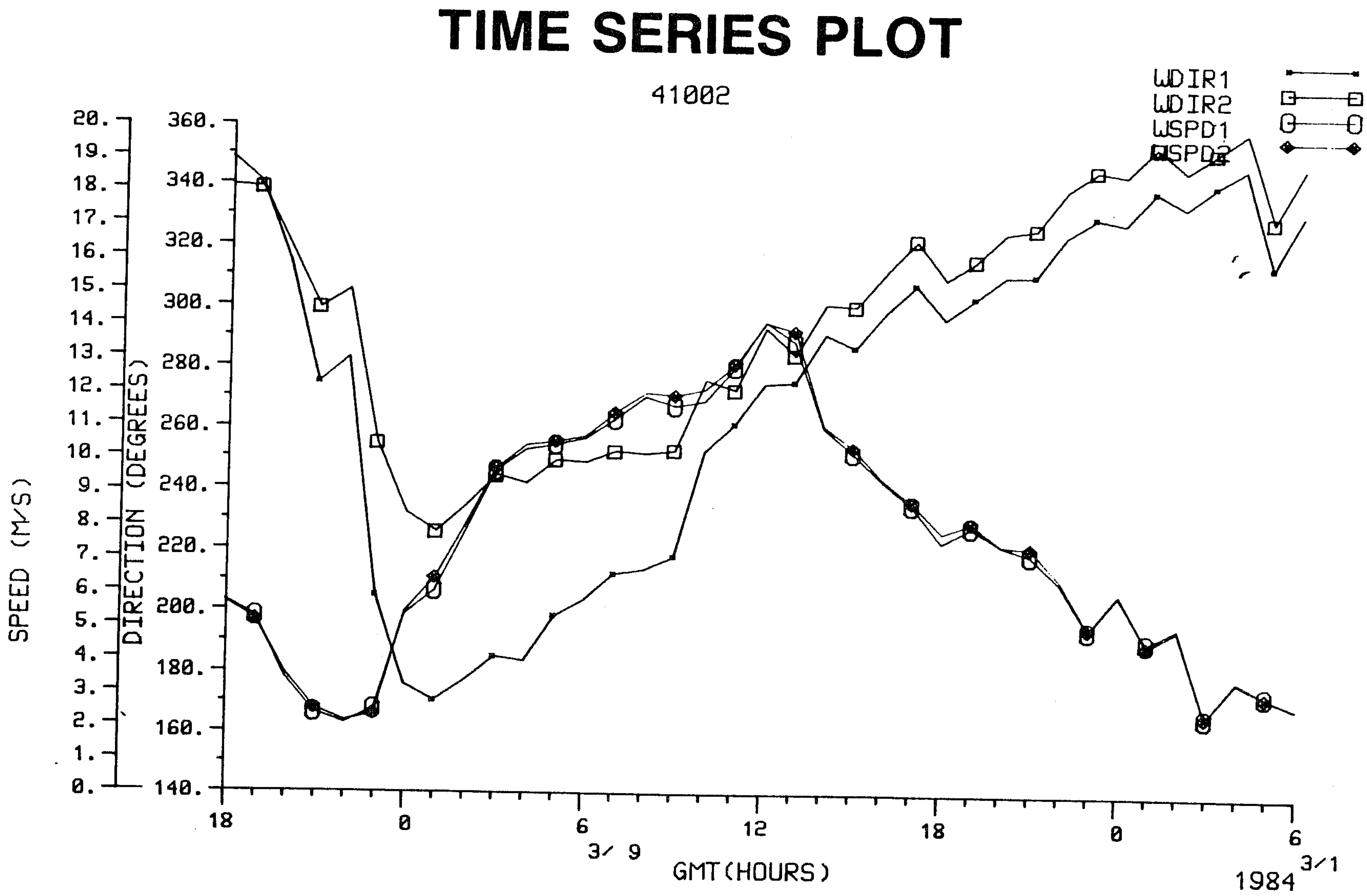
Though all of the validation procedures detect sensor failures, several are most powerful. The duplicate sensor check is often the first to spot problems with anemometers and barometers. This is because anemometers have the highest failure rate of any component installed in the field. Therefore, all NDBC moored and coastal stations have duplicate anemometers; many have duplicate barometers and air-temperature sensors. The wind-wave algorithm is helpful in several situations. It can detect anemometer problems at a station with a single working anemometer. Also, it can detect low significant wave height, usually caused by processing with the wrong set of coefficients.

Currently, NDBC is developing algorithms to monitor directional wave data. One approach taken is to compare the average wind direction over the last three hours with the average wave direction in a high frequency band (0.35 Hz). When the wind speed exceeds seven m/s and no wind direction shifts greater than 30 degrees have been reported in the last three hours, the difference between the mean wave direction and the wind direction is generally 0-5 degrees with a standard deviation of 10-20 degrees.

After the data analysts review flagged data, they can produce a variety of computer graphics to help them distinguish between true sensor or system failures and legitimate data. Time-series plots of multiple measurements from two nearby stations have proven to be a powerful tool. Surface observations from non-NDBC stations are also available for plotting. Also, plotting measurements whose time variability are often highly correlated, such as temperature and wind direction, can help determine the legitimacy of the data.

A sample time-series plot is shown in Figure 2. Wind speed and direction values are given for dual sensors at buoy station 41002. It can be seen that the wind speed reports agree very closely while the wind direction measurements disagree by as much as 75 degrees when the wind is southwesterly. The data analyst had to make a decision as to which sensor should be released to the user community. In this case, the discrepancy was due to a malfunctioning compass on the buoy.

Figure 2.



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This is a good example of the need for a man-machine mix and how it is used.

2.3 Drifting Buoy Data Quality

Bad sea-level pressures from drifting buoys have, on occasion, wreaked havoc with analyses used for numerical weather prediction. One example is the analysis of 1200 UTC, October 22, 1986, computed by the U.S. Navy Fleet Numerical Oceanography Center shown in Figure 3. A low pressure report from a drifter located between New Zealand and Australia resulted in a small, intense low-pressure area. Six hours later, when no report was received from the drifter, there was no low-pressure area produced and the analyzed pressures were about 14 hPa higher. This analysis is shown in Figure 4. Six months earlier, The U.S. NMC reported that a similarly erroneous report from a drifter east of Tahiti produced a fictious easterly wave. Postanalysis showed that the buoy pressures had been at least 10 hPa too low for the previous two weeks.

Recognizing these QC problems, in March 1988, NDBC started to QC North American drifting buoy reports that USGPC transmits to NWSTG. These reports are from drifters sponsored by North American countries, even though the buoys may be deployed in the Southern Hemisphere. QC is similar to that used for moored buoys. Gross checking is performed in real time on the IBM 4341 before the data are disseminated on the GTS and more stringent checks are applied at NDBC within 24 hours. NDBC similarly maintains the data base on the 4341. Drifters located outside tropical cyclone belts in high latitudes have

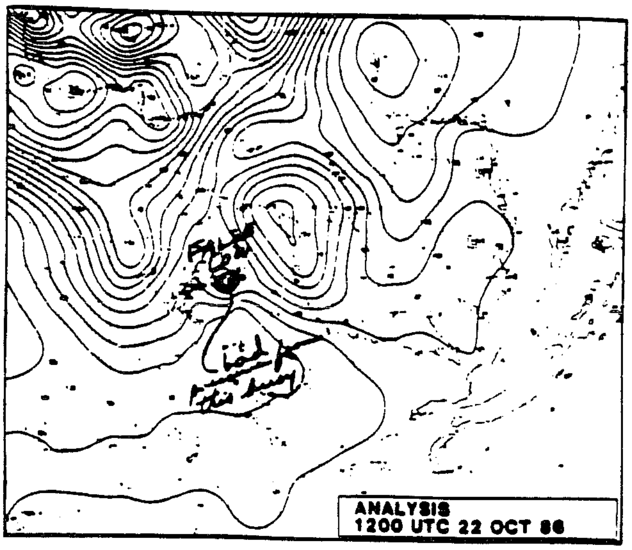


Figure 3. The FNOC analysis of sea level pressure at 1200 UTC on October 22, 1986. The small, low-pressure center between New Zealand and Australia resulted from a bad drifting buoy report.

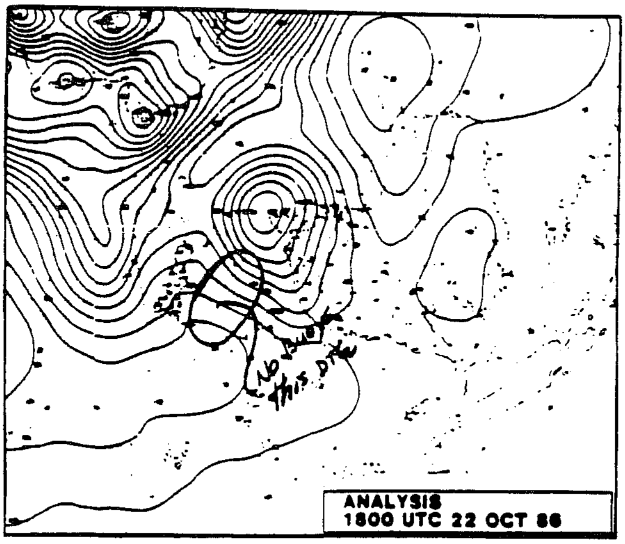


Figure 4. The FNOC analysis 6 hours later showing the removal of the spurious low.

broader limits and higher standard deviations like the moored buoys.

Using the buoy positions, movement accelerations are computed in both the north-south and east-west directions to validate positions. Acceleration was chosen because locations that are slightly in error result in high accelerations, but may not result in high velocities. If the acceleration exceeds about four knots per hour (0.0006 m/s) in either component, that report will be removed from distribution and will not be used in subsequent acceleration computations.

QC of drifting buoys poses different and more difficult problems than for moored or coastal stations. Dual sensors on these other NDBC platforms have been found to be the most important factor in maintaining good QC. Since drifters normally have single sensors, additional approaches have to be taken. For one thing, drifter pressures and temperatures are compared to NMC analysis and "first guess" fields. The 0000 and 1200 UTC fields are acquired from NMC on a 2.5-degree latitude by 5-degree longitude grid. If a drifter observation is within two hours of 0000 or 1200 UTC, a spatial interpolation is performed on the relevant fields to obtain an analysis value at the drifter location. These analysis values are then compared to the drifter observation.

One problem that clouds this comparison is that the analysis could be contaminated by a bad drifter observation. To accomodate this problem, we use 12-hour forecasts from the previous model run as an alternate analysis field. This is somewhat analagous to using a "first guess" field. If a bad observation contaminated the surface analysis, 12 hours of model time would tend to reduce the error. On the other hand, a bad forecast could ruin the comparison. However, this is much less likely to occur and is primarily limited to areas of explosive cyclogenesis.

Some failures are easy to detect by comparing the observations with analysis and short-range forecast values. One such failure is depicted in Figure 5. The sea-level pressure observed by 54814 is about 14 hPa lower than both the NMC 12-hour sea-level pressure forecasts and analysis values.

Other less dramatic failures are more difficult to detect, especially in deep low-pressure areas south of 40 S. The NMC fields are often too conservative. The pressures are too high in cyclones and too low in anticyclones. This is especially apparent in the 12-hour forecasts. The time-series plots given in Figure 6, illustrate this point by comparing drifter 33807, located at 52 S, 69 E, with the NMC analysis and forecast values. These 5-to-10-hPa differences would have to exceed 10 hPa to be flagged as suspicious.

Failures of less than this would be detected by looking at statistical summaries or scatterplots showing these comparisons over at least a two-week period. As a supplemental check, biases and root mean square errors of drifting buoy reports against "first guess" fields computed at the European Centre for Medium Range Weather Forecasts are used and are very helpful.

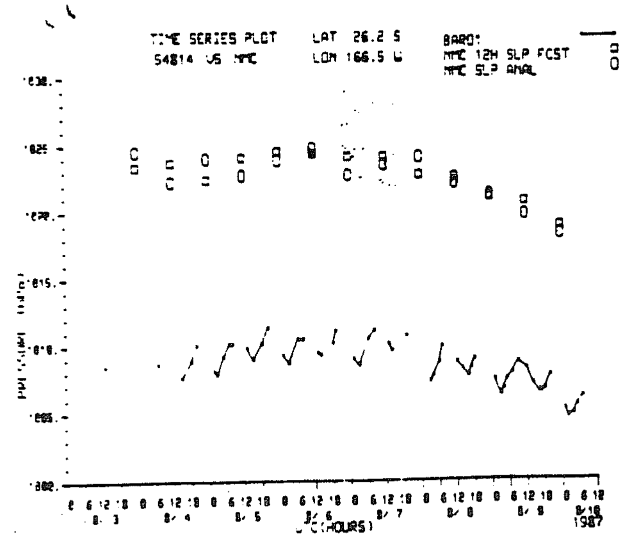


Figure 5. Sea level pressures reported by drifter 54814 are compared to NMC analyses and 12-hour forecasts.

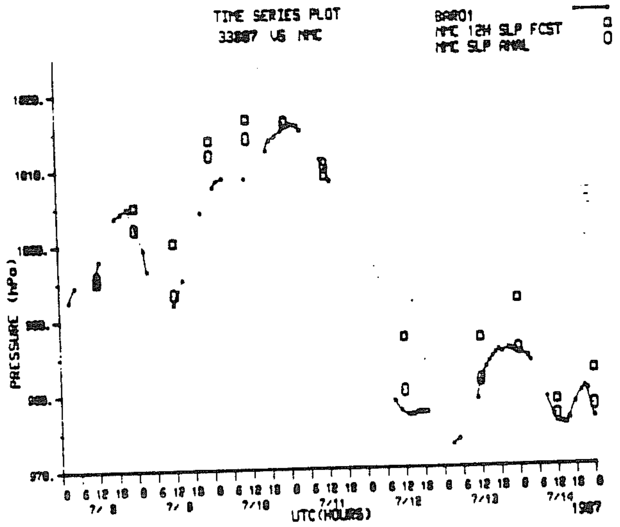


Figure 6. Sea level pressures reported by 33807 are compared to NMC analyses and 12-hour forecasts.

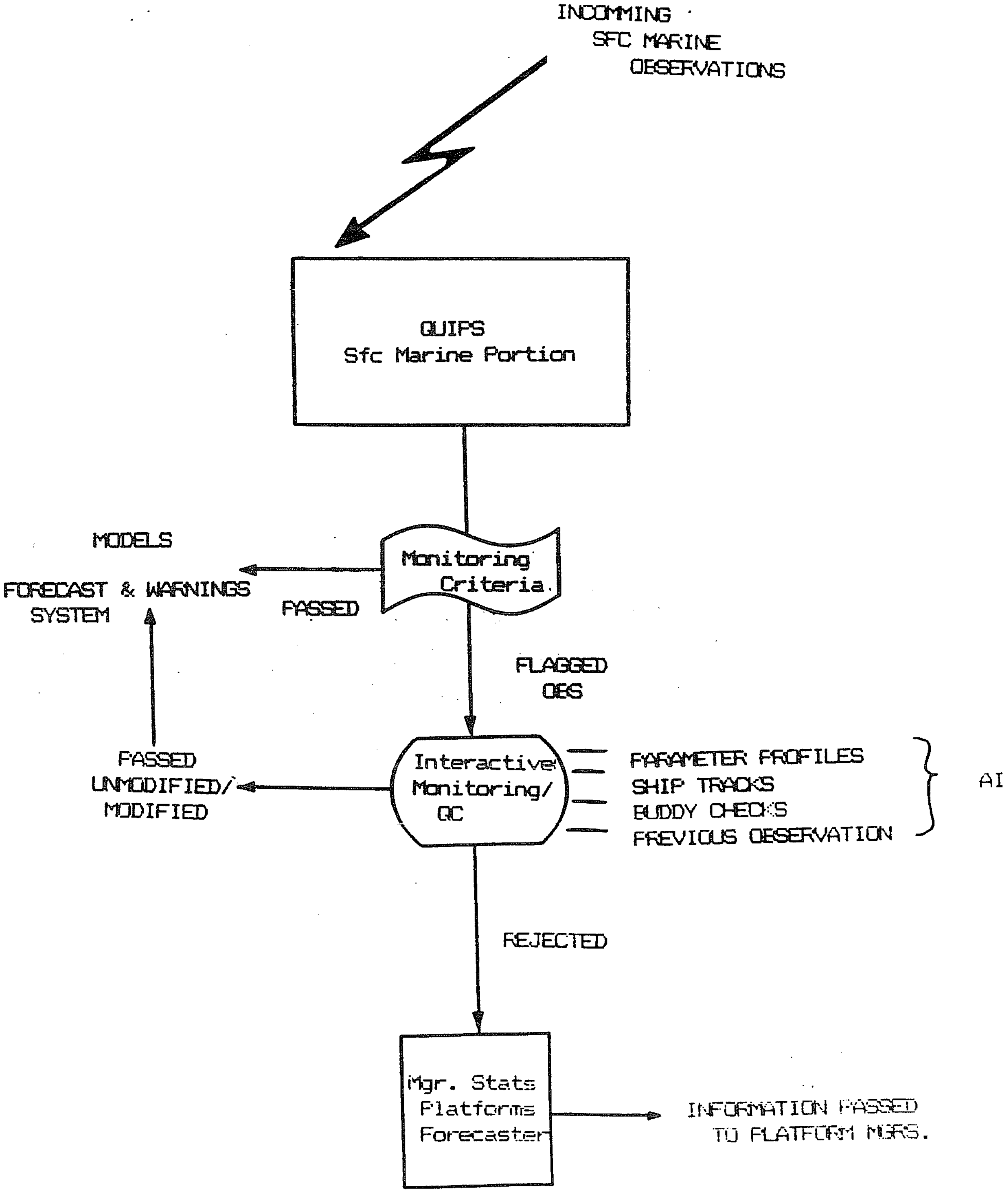
2.3 Mobile Ship Reports

2.3.1 Present Operations

Mobile ship reports are included in the marine surface observations from fixed and non-fixed platforms in the QC program being developed at the U.S. NMC Ocean Products Center (OPC). The present surface marine monitoring and QC system, a portion of the Quality Improvement and Performance System (QUIPS II), automatically flags sea-level pressure (SLP). However, other surface parameters, such as wind speed and direction and air and sea-surface temperature (SST), may be manually checked . The automatic SLP check compares the SLP observation to a pressure interpolated from a first guess field (Global Data Assimilation System or Aviation Model). If the absolute value of the difference between the observation and the first guess is four hPa or more, the observation is flagged. The geographic locations of all observations are graphically displayed. Flagged values are highlighted and quality controlled on a priority basis by location. Priorities are set by the forecaster. Flagged observations, in data sparse areas of National Weather Service forecast responsibility, are quality controlled first. Menu-driven commands, activated by a mouse, assist the forecaster in checking flagged data against cruise and parameter plots. The forecaster also has available Digital Weather Information System loops for additional checks.

Figure 7 depicts data flow and activities of the surface marine monitoring and QC portion of the QUIPS II. Interactive activities, visual inspection of time series plots of observed-

Figure 7 Data/information flow and activities of the surface marine monitoring and quality control portion of QUIFS.



/measured parameters, plots of platform location, buddy checks, and references to previous observations are being reviewed for automation. Statistics on platform performance and forecaster actions are extremely important as feedback into the system to improve platform and forecaster performance.

Preliminary statistics, based on a two-week sample of monitoring activities, indicate that approximately eight percent (60 observations) of the approximately 735 observations received during a six-hour watch are flagged. After monitoring and QC procedures, 47 percent (28 observations) of the flagged SLP are kept.

The four hPa SLP flagging criterion is under review for latitudinal and seasonal variability. Early findings suggest that a three hPa check that varies with latitude, lower values near the equator, may be a better criteria.

2.3.2 Plans

Algorithms that QC wave spectra, acoustic doppler currents, air temperature and SST, water levels, and wind speed and direction are being reviewed and evaluated by a contractor for coding and incorporating into QUIPS. If algorithms are incomplete or do not exist, new algorithms will be developed. Artificial Intelligence techniques are also being explored as possible enhancements to the next generation QUIPS. A description of the OPC and its plans can be found in (1).

REFERENCES

1. Barazotto, R. M. and J. S. Lynch, 1987: "Real Time Quality Control of Drifting Buoy Data at the NOAA Ocean Products Center", Proceedings, 13th Service Argos International Users Conference.

2. Gilhousen, D.B., 1988: "Quality Control of Meteorological Data from Automated Marine Stations", Preprints, Fourth AMS International Conference, Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology.