NDBC Technical Document 03-02

Handbook of Automated Data Quality Control Checks and Procedures of the National Data Buoy Center

Stennis Space Center
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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Data Buoy Center

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Stennis Space Center, Mississippi 39529-6000
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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ADCP .... Acoustic Doppler Current Profiler
ARES .... Acquisition and Reporting Environmental System
AWIPS .... Advanced Weather Interactive Processing System
C-MAN .... Coastal-Marine Automated Network
DACT .... Data Acquisition and Control Telemetry
DAPS .... Data Acquisition and Processing System
DEU .... DACT Electronic Unit
DQA .... Data Quality Analyst
DWA .... Directional Wave Analyzer
DWA/MO .... DWA Magnetometer-Only configuration
DWPM .... Directional Wave Processing Module
EQC .... Environmental Quality Control
ERL .... Environmental Research Laboratory
ESP .... Edit Station Profile
FFT .... fast Fourier transform
FOS .... Family of Services
ftp .... file transfer protocol
GOES .... Geostationary Operational Environmental Satellite
GRIB .... gridded binary
GTS .... Global Telecommunications System
hPa .... hectoPascals
ID .... identifier
LIFO .... last in/first out
MARS .... Multifunction Acquisition and Reporting System
METAR .... Meteorological Aviation Report, (WMO Code FM-15)
MMS .... Minerals Management Service
NASA .... National Aeronautics and Space Administration
NCEP .... National Centers for Environmental Prediction
NCDC .... National Climatic Data Center
NDBC .... National Data Buoy Center
NESDIS .... National Environmental Satellite, Data, and Information Service
NOAA .... National Oceanic and Atmospheric Administration
NODC .... National Oceanographic Data Center
NTSC .... NDBC Technical Services Contractor
NWS .... National Weather Service
NWSTG .... NWS Telecommunications Gateway
ORG .... Optical Rain Gauge
PAR .... Photosynthetically Active Radiation
PCC .... Profiler Control Center
PDM .... Profiler Data Management
PSOS .... Profiler Surface Observing System
psu .... practical salinity unit
QC .... quality control
s or sec .... seconds
SSC .... Stennis Space Center
VEEP .... Value Engineered Environmental Payload
WA .... Wave Analyzer
WDA .... Wave Data Analyzer

WMO . . . . World Meteorological Organization
WPM . . . . Wave Processing Module

1.0 INTRODUCTION

The National Data Buoy Center (NDBC), a part of the National Oceanographic and Atmospheric Administration's (NOAA) National Weather Service (NWS), operates more than 77 moored buoys and 57 Coastal-Marine Automated Network (C-MAN) stations. These stations acquire environmental data used primarily for preparing weather warnings, analyses and forecasts. Buoys are also used to provide ground-truth measurements for space-based observation platforms and to establish long-term environmental records for engineering applications, climate research, and air-sea interaction studies. NDBC has developed the capability to make a variety of measurements, including:

- Atmospheric pressure
- Wind direction, speed, and gust
- Air and water temperature
- Wave energy spectra (nondirectional and directional)
- Relative humidity
- Ocean current velocity
- Precipitation
- Salinity
- Solar radiation
- Visibility
- Water level

The NDBC network is comprised of sites offshore and along most of the U.S. coastline, including Alaska, Hawaii, and the Great Lakes. The importance of accurate data from these stations cannot be over emphasized. The maritime community has come to rely on the data for the safe conduct of operations, and the network often provides the only real-time measurements available from remote, data sparse areas.

1.1 PURPOSE

This handbook describes the automated quality control (QC) procedures used to ensure the accuracy of NDBC measurements. It may be used as a tutorial for newcomers to NDBC or as a reference for experienced personnel. This handbook incorporates much of the material contained in *Tapered QC,* NDBC Technical Document 98-03, August 1998, and supercedes an earlier version of this handbook, dated January, 1996.

1.2 DATA USES

The primary user of real-time NDBC data is the NWS which uses the data for the issuance of warnings, analyses, and forecasts and for initializing numerical models. The general public has access to the data in real-time via the NDBC Web site. Each month, the data that have been collected during the previous month undergo further quality control and are processed for archival at the National Climatic Data Center (NCDC), Asheville, NC, and the National Oceanographic Data Center (NODC), Silver Spring, MD. Archived data are also available at the NDBC Web site. Only data that have passed all automated QC checks and manual review, and have met NDBC standards for accuracy, are archived.

1.3 THE NDBC QC PROGRAM

The primary objective of the NDBC QC program is to ensure that NDBC sensor systems provide measurements that are within NDBC total system accuracy. NDBC total system accuracy may be defined as the difference between the NDBC measurement and the true ambient value. It is a function of sensor accuracy, errors induced by the buoy or platform, and to some extent, the accuracy to which we can monitor the measurement in its remote environment. See the NDBC Web page, http://www.ndbc.noaa.gov/rsa.shtml for the system accuracies for the various NDBC payloads (i.e. onboard processors).

However, NDBC believes that the accuracy achieved is often considerably better than these stated accuracies based on special field comparisons. These comparisons between duplicate sensors on the same buoy or inferred through post calibrations are given in Table 1. Also listed in Table 1 are the standard required by the WMO (1996). When duplicate sensors were available, the accuracies were computed in an established manner by computing a root mean square combination of bias (or mean difference over the course of a month) and the standard of deviation of differences.

These accuracies are often considerably better than the total system accuracies. For example, the total system accuracy for wind speed is plus or minus 1 m/s. There are two reasons why NDBC states the system accuracies conservatively. First, this states the degree to which we can quality control the measurement in the field. Monitoring tools, such as comparison with numerical model analyses, do not allow us to determine a 0.5 m/s error in wind speed. Second, there are some rare environmental conditions, such as high waves, which may temporarily preclude us from achieving the desired accuracies.

graphical displays, and the results of any automated QC checks to identify the often subtle degradation of systems and sensors. Analysts integrate and compare NDBC data with relevant NWS and National Environmental Satellite, Data, and Information Service (NESDIS) products, such as weather observations, numerical weather analyses and forecasts, weather radar, and satellite images.

TABLE 1. ACCURACIES ACHIEVED DURING FIELD COMPARISONS

Measurement	WMO Requirement	NDBC Accuracy	Basis
Air Temperature	0.1 deg. C	0.09 deg. C	Duplicate sensor comparison
Sea Surface Temperature	0.1 deg. C	0.08 deg. C	Duplicate sensor comparison
Dew Point	0.5 deg. C	0.31 deg. C	Post calibration
Wind Direction	10 degrees	9.26 degrees	Adjacent buoy comparison
Wind Speed	0.5 m/s	0.55 m/s	Duplicate sensor comparison
Sea Level Pressure	0.1 hPa	0.07 hPa	Duplicate sensor comparison

An NDBC Technical Services Contractor (NTSC) staffed by engineers, meteorologists, computer scientists, and other specialists, provides support in response to technical directives initiated by NDBC. Data quality analysts in the NTSC Operations and Maintenance Department review the day-to-day quality of data and delete questionable data from those data sets destined for archival. Physical and computer scientists in the NTSC Data Systems Department develop, test, and implement automated QC procedures.

The NDBC QC program may be viewed in two parts. First, there are real-time automated QC checks done exclusively by computer at the NWS Telecommunications Gateway (NWSTG) at Silver Spring, MD. The first category of these are gross error checks that detect communication transmission errors and total sensor failure. Data flagged by these checks are virtually certain to be erroneous. These checks, however, can be overridden when storms or other unusual environmental phenomena are anticipated that would generate out of the ordinary, but valid measurements. The second category of automated checks identifies data that may not be grossly in error, but for some reason, suspect. Data so identified will be released, but will undergo additional scrutiny within 24 hours by NTSC data quality analysts. They perform manual inspection using computer-generated analytical aids,

2.0 DATA FLOW AND PROCESSING

A discussion of the flow and processing of NDBC data will be useful in understanding the NDBC QC process. This section describes the most important data paths that are used by NDBC and its users to acquire NDBC data. The major steps involved in applying automated QC during the data production process are also briefly described.

2.1 DATA PATHS

The most important data paths from a QC standpoint are those involving the transmission of data from C-MAN and moored buoy platforms (Figure 1).

The acquisition and telemetry of sensor data on each platform are controlled by an onboard microprocessor referred to as “the payload”. Data are transmitted from the platform via a Geostationary Operational Environmental Satellite (GOES) to the NESDIS Data Acquisition and Processing System (DAPS) at Wallops Island, VA. The DAPS sends the data to the NWSTG where redundant NDBC computer systems process the raw GOES data. These systems decode the data, perform automated QC checks, and generate

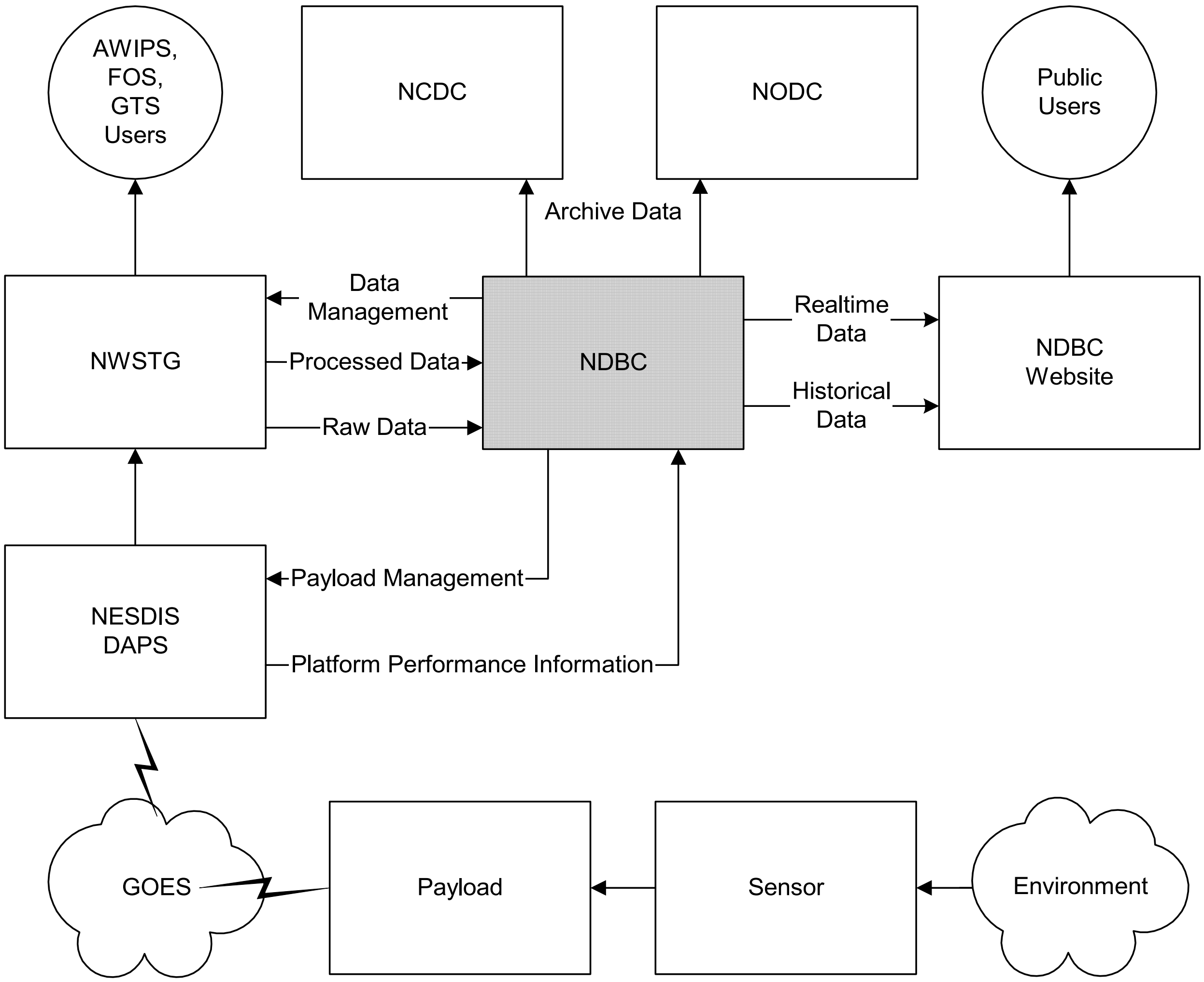

Figure 1. C-MAN and moored buoy data paths.

reports in standard World Meteorological Organization (WMO) format.[1] These real-time reports are released in collective bulletins to users via the NWS Family of Services (FOS) network, the Global Telecommunications System (GTS), and within the NWS through the Advanced Weather Interactive Processing System (AWIPS). WMO bulletins received at NDBC via a FOS feed are used to update real-time observations on the NDBC Web site. Separate, private bulletins that are sent only to NDBC are also generated at the NWSTG to transmit the processed data and quality control flags. These bulletins contain the complete set of data acquired at all stations and are used to update the NDBC Oracle database at Stennis Space Center, Mississippi (SSC) in real-time. Data quality analysts at NDBC access the database to note the occurrence of flagged data and conduct further quality control.

Data management information and parameters to properly process the data are maintained and updated in the NDBC database. When changes are made in the NDBC database, the information at NWSTG is also updated. This information mainly consists of scaling parameters, QC thresholds, or instructions to prevent the release of measurements from failed sensors.

[1] C-MAN stations report using a U.S. National code form, C-MAN code, that closely resembles WMO FM12 SYNDP code.

An identical data processing capability to that at the NWSTG exists at NDBC. This permits processing of raw GOES data at NDBC for test purposes or as a backup to update the database if a system failure occurs at NWSTG. On a monthly basis, data are extracted from the NDBC database in the specified formats required for archival at the NCDC and NODC.

2.2 REAL-TIME PROCESSING

The vast majority of automated quality control checks are performed during real-time processing on the NDBC computers at the NWSTG. A few checks require data that are not available during processing at NWSTG but are applied by programs run at NDBC after the data are inserted into the database. A program that compares NDBC measurements with numerical model fields is an example.

2.2.1 Automated QC

The flow of data during real-time processing at the NWSTG is depicted in Figure 2. The first step involves extracting the raw GOES message data and converting it to meaningful geophysical units. This process not only involves decoding the raw data, but also applying scaling factors and performing calculations for derived data. This is also the first point in the process where automated QC routines are applied. The raw data are checked for errors as a result of truncated or garbled messages. Wave and continuous wind measurements are hard flagged and not released if the message strings containing these data have errors. Other measurements, missing as a result of transmission errors, are also identified and individually flagged at this point in the process. The next steps are the application of the QC algorithms where measurements are checked against QC parameters and hard or soft flagged if necessary. Measurements identified as erroneous with hard flags are deleted from release, and the appropriate encoded messages are generated and grouped under the appropriate geographic bulletin header for transmission. Private bulletins are generated and transmitted to NDBC which contain all measurements and flags to update the NDBC database. A process monitor permits personnel at NDBC to monitor the flow of information at the NWSTG.

During each step in the process, a parameter manager applies the appropriate parameters which include such items as scaling coefficients, quality control limits, sensor hierarchy designations, and output bulletin organization. The parameters are updated and maintained by data analysts through the Edit Station Profile (ESP) interface to the NDBC Oracle database. Whenever changes are made, they are transmitted to update the NWSTG parameter files.

2.2.2 Transmission Errors

Raw GOES messages received at the NWSTG from the DAPS are flagged with a special character if they are identified as being truncated or as having transmission parity errors. The data extraction routines will attempt to decode all the available data in the raw message, regardless if the GOES message has been flagged as containing errors. Measurements which can't be decoded as a result of transmission errors are identified and flagged as missing. Wave and continuous wind measurements are hard flagged and not released if the message strings containing these data are found to have errors.

If the need arises, a station may be set to not release any data if the GOES message from the DAPS is flagged as having transmission errors. This feature is rarely used since the data extraction routines are very robust and have been found to rarely decode and release erroneous data as a result of transmission errors. The feature is set using the Payload Profile page of the ESP database interface.

3.0 NDBC MEASUREMENTS

Brief descriptions of NDBC measurements and the associated instruments, sensors, and techniques used to make these measurements are given in this section. Under each general measurement category is a brief description of the sensor and its basic principle of operation.

There are some diagnostic, or housekeeping, measurements that are acquired each hour at NDBC stations to monitor station performance. These measurements (e.g., battery voltage and charge current) are monitored by the NDBC data quality analysts and engineering personnel for system performance assessment and troubleshooting. These measurements are maintained in the NDBC database but are not archived at the NCDC or NDDC. There are also certain measurements that are not checked directly, such as the relative wind direction and the

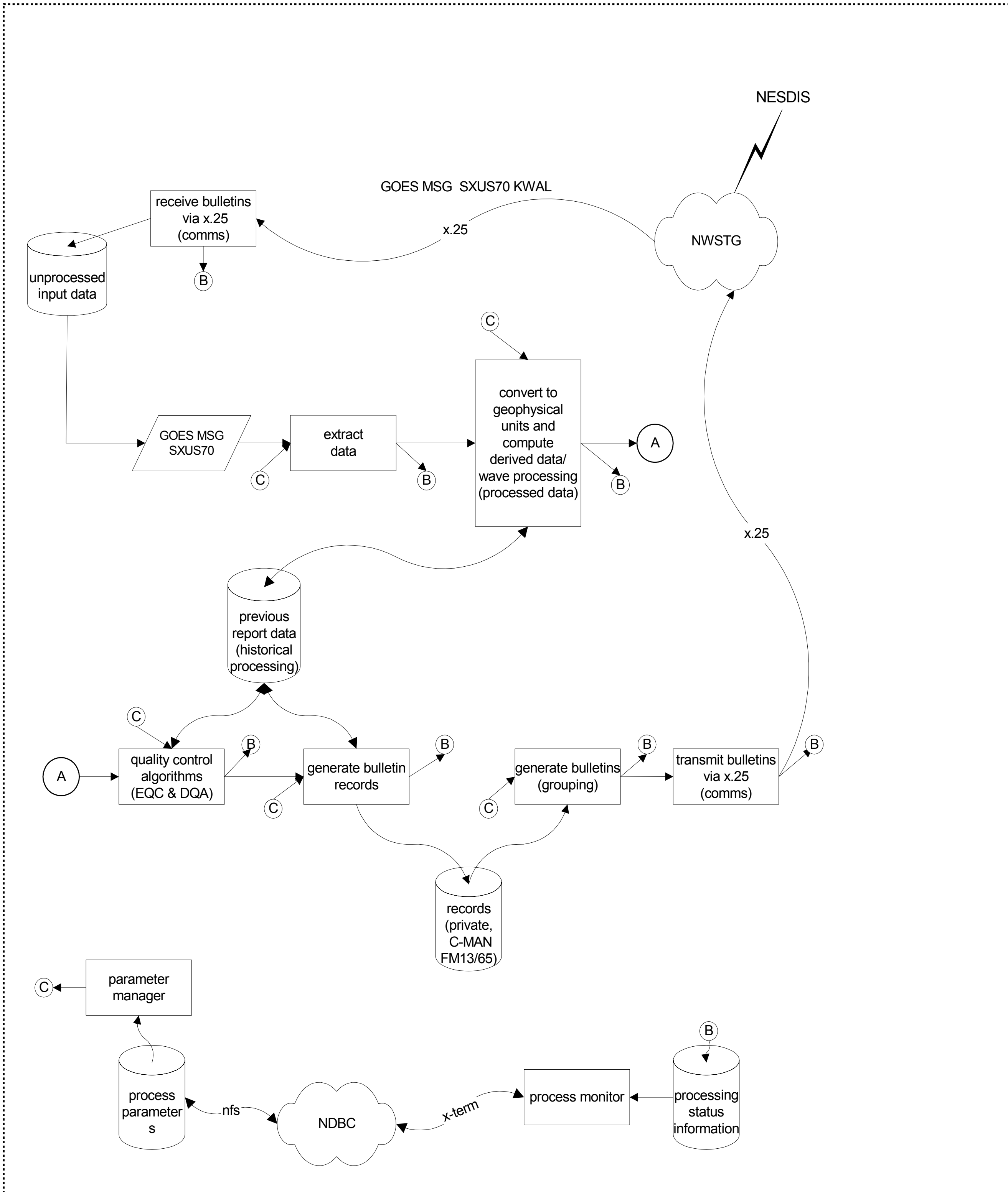

Figure 2. NDBC real-time processing at NWSTG.

components of the wind. Unless measurements are used in automated QC checks, they may not be described in this section. A listing of the most commonly used NDBC geophysical and engineering measurement IDs is given in Appendix A.

3.1 NDBC PAYLOADS

There are a number of payloads used to acquire and transmit NDBC measurements. The payloads now being used operationally were developed at different times, and differ significantly in size, power consumption, and computational power. The following payloads are in use:

- Data Acquisition and Control Telemetry (DACT) Electronic Unit (DEU)
- Value Engineered Environmental Payload (VEEP)
- Multifunction Acquisition and Reporting System (MARS)
- Automated Reporting Environmental System (ARES)

The oldest onboard buoy electronic systems are the DACT and VEEP payloads, which were both developed in the 1980's. The MARS payload became operational in 1995. It was designed to provide improved versatility and reliability over previous payloads. The ARES is the most recent payload to be developed. It incorporates a more sophisticated processor and provides additional housekeeping information over what is available from the MARS. Each payload calculates measurements from a time series of samples taken at a particular sampling rate and interval. When applicable, payloads are noted in the discussions that follow.

3.2 SENSOR HIERARCHY ASSIGNMENT

All moored buoy and C-MAN stations have redundant anemometers and barometers. One of the two redundant sensors is chosen as the primary sensor. The other is designated as the secondary or backup sensor. This hierarchy determines which of the sensors' data is released at the NWSTG. Data from the primary sensor are released if they pass automated gross error QC checks. A measurement from a secondary sensor will be released if the primary sensor measurement cannot be released, and the measurement from the secondary sensor passes QC checks. The hierarchy order is not altered. If the data quality analyst determines that the secondary sensor is performing better than the primary sensor, the hierarchies can be changed through a manual modification to the databases. Sensor hierarchies are normally manually set, although, as will be discussed in Section 4, there are automated routines that will cause a hierarchy change when certain conditions are met.

The hierarchy order also determines the sensor from which data are archived at the national centers. Normally, data from the sensor indicated as primary are extracted for archival. If data from a primary sensor have been flagged for failing QC, data from the secondary sensor will be automatically extracted for archival if that sensor has not been flagged as failing QC.

3.3 STANDARD MEASUREMENTS

The standard suite of sensors on moored buoys samples wind speed peak 5-sec gust; wind direction; barometric pressure; air temperature; water temperature; and nondirectional ocean wave energy spectra, from which significant wave height and dominant wave period are determined. The same package is used at C-MAN sites, but, depending on the location of the C-MAN site, water temperature and wave sensors may not be included.

3.3.1 Atmospheric Pressure

Atmospheric pressure and its variability in both time and space are crucially important in synoptic meteorological analysis and forecasting. All NDBC platforms measure atmospheric pressure by means of digital aneroid barometers. Pressure is found from the electrical capacitance across parallel pressure-sensitive plates. The capacitance between the plates increases as pressure increases. The following pressure measurements are made.

- Station pressure (SBAR1 or SBAR2) is the actual measurement made at the station in hecto Pascals (hPa) by the two barometers.
- Sea level pressure (BARO1 or BARO2) is the pressure reduced to sea level from the station pressure in units of hPa. For most NDBC stations, this is very close to the station pressure. The greatest difference between sea level pressure and station pressure will be from Great Lakes sites. The conversion to sea level pressure is made using the procedures described in the NWS *Technical Procedures*

Bulletin No. 291 (NWS 1980) and Computer Sciences Corporation (1994). Automated QC checks are performed on all barometric pressure measurements.

3.3.2 Wind Measurements

Wind measurements are perhaps the most important measurements made by NDBC. They are essential for the marine weather forecaster. Wind measurements are made at all NDBC stations. NDBC uses 4-blade, impeller-driven, wind-vane sensors. The final measurements are statistical estimates of the wind from time series of instantaneous wind samples taken at a rate of 1 Hertz (Hz) over a particular length of time. C-MAN stations use a 2-minute data-acquisition period, and moored buoys use an 8-minute acquisition period. The following standard wind measurements are produced each hour.

- Wind direction (WDIR1, WDIR2) is the direction from which the wind is blowing in degrees clockwise from true north. It is a unit vector average of the record of wind direction.
- Wind speed (WSPD1, WSPD2) is the scalar average of the wind speed in meters per second (m/s) over the sampling interval.
- Wind speed maximum (GUST1, GUST2) is the highest wind speed (WSPD1 or WSPD2) in the wind record. GUST1 or GUST2 is found from the highest 5-second running mean of the record.

NDBC has also developed the capability to continuously sample the wind on moored buoys and at C-MAN stations. Continuous-wind data are accumulated in segments of 10 minutes, yielding 600 samples per segment, and six 10-minute segments each hour. After each segment period, the mean of the segment is calculated and stored in a temporary buffer. The accumulations are also stored for later hourly statistical processing. The payload saves the most recent six accumulations. At the end of each 10-minute segment, the oldest data, now more than an hour old are removed from memory and replaced with the most recent.

At the end of an acquisition period, statistical processing is performed, and the output message is updated with the new statistics and six 10-minute segments. Statistical processing includes the calculation of the mean for both direction and speed and the standard deviation of the speed. The hour's data do not represent data from minute 0 to minute 59. Rather, it represents the latest, complete six 10-minute segments before the end of the last acquisition. The 10-minute segments are, however, bounded by minutes 0, 10, 20, etc.

Continuous-wind measurement IDs have a number from 1 to 6 attached to them. The last in first out (LIFO) numbering scheme is used such that the first whole 10-minute period immediately prior to the beginning of standard hourly data acquisition is labeled 1; the 10-minute period immediately before that is labeled 2, and so on. For all C-MAN stations, 1 corresponds to the period from minute 50 to minute 59 of the hour, 2 corresponds to the period from minute 40 to minute 49, and 6 corresponds to the period from minute 0 to minute 9. For moored buoys with continuous winds, 1 corresponds to the period from minute 40 to minute 49. The measurement IDs associated with continuous winds are as follows:

- Continuous-wind speed (CWS1, CWS2, CWS3, CWS4, CWS5, CWS6) is the mean wind speed from the primary anemometer in m/s during a 10-minute period.
- Continuous-wind direction (CWD1, CWD2, CWD3, CWD4, CWD5, CWD6) is the mean wind direction, in degrees true, during a 10-minute period. Direction is the mean unit vector wind direction.
- Secondary (or optional) wind speed (OWS1, OWS2, OWS3, OWS4, OWS5, OWS6) is the same as CWS1 through CWS6, but from the secondary wind sensor.
- Secondary (or optional) wind direction (OWD1, OWD2, OWD3, OWD4, OWD5, OWD6) is the same as CWD1 through CWD6, but from the secondary wind sensor.
- Maximum gust (MXGT1, MXGT2) is the maximum 5-second wind speed during the full hour for sensors 1 and 2, respectively.
- Direction of maximum gust (DIRMXGT1, DIRMXGT2) is the 5-second direction in degrees true associated with MXGT1 and MXGT2, respectively.
- Time of maximum gust (MXMIN1, MXMIN2) is the nearest minute during the observation hour associated with MXGT1 and MXGT2, respectively.
- Average wind speed (AVGSPD1, AVGSPD2) is the mean wind speed over a full hour in m/s from wind sensor 1 or 2, respectively. This is the scalar average of the 6 measurements, CWS1 through CWS6 or OWS1 through OWS6, respectively.
- Average wind direction (AVGDIR1, AVGDIR2) is the unit vector mean of all wind directions over a full hour, expressed in degrees true from

wind sensor 1 or 2, respectively. This is the average of 6 measurements, CWD1 through CWD6 or OWD1 through OWD6, respectively.

- Standard deviation of continuous-wind speed (CWSTD1, CWSTD2) is the standard deviation of the wind speed over 1 hour from sensor 1 and 2, respectively.

Wind measurements undergo range, consistency, standard deviation, and gust-to-speed ratio.

Wind speed at 10 m (WSPD11, WSPD21) and 20 m (WSPD12, WSPD22) are derived from an algorithm (Liu et al., 1979) that uses the height of the anemometer, the wind speed (WSPD1 or WSPD2), the relative humidity (RH1 or RH2), the atmospheric pressure (BARO1 or BARO2), and the air (ATMP1 or ATMP2) and water temperature (WTMP1). If air pressure is unavailable, it is assumed to be 1013.25 hPa. If the relative humidity is unavailable, it is assumed to be 85 percent. If either the air or water temperature is unavailable, then the neutral stability is assumed.

3.3.3 Temperature

Temperature is one of the basic NDBC measurements. Electronic thermistors are used to make all temperature measurements which are updated in degrees Celsius (˚C). Temperature measurements undergo both range limit and time-continuity checks and are important for deriving sea level pressure (BARO1) and standard-height wind speeds (WSPD11, WSPD21, WSPD21, WSPD22).

3.3.3.1 Air Temperature

Air temperature measurements (ATMP1, ATMP2) are generally very reliable; however, it is important to note that the physical position of temperature sensors can adversely affect measurements. Air temperature housings can lead to nonrepresentative readings in low wind exposure locations.

3.3.3.2 Water Temperature

While there are generally few problems with water temperature measurements (WTMP1, WTMP2), it should be noted that the depth of water temperature sensors vary with buoy hull or C-MAN site, and that the temperature probes on buoys are attached to the inside of the hull. Since buoy hulls are highly thermally conducting, the temperatures measured may reflect the average temperature of the water around the submerged hull rather than the temperature of the water nearest the probe. The temperature sensors at C-MAN sites do make point measurements, but the sensors are at fixed distances relative to the bottom; therefore, the thermistor is at different depths throughout the day owing to changing water levels. In highly stratified water, especially during afternoon hours in calm wind conditions, the water temperature reported from a station may be 2 to 3 °C below the skin temperature of the water. Limit and time continuity checks are performed on water temperature measurements.

3.3.4 Ocean Wave Estimates

Sea state estimates are probably the most complex measurements made by NDBC and are extremely important to marine forecasters, mariners, ocean engineers, and scientists. On a buoy, all of the basic wave measurements are derived in some way from the estimated energy spectra of a time series of buoy motion. On an offshore C-MAN station, the wave measurements are derived from displacements measured by a laser wave sensor. For wave sampling intervals and averaging periods, see http://www.ndbc.noaa.gov/rsa.shtml.

All NDBC moored buoy stations and some C-MAN stations provide nondirectional wave estimates; some moored buoy stations additionally provide estimates of wave direction. There are several measurement identifiers associated with wave estimates that are described in this section and in Section 3.4.1.

Data quality checking of wave estimates is complicated somewhat by the use of several types of wave measurement system and payload combinations. The types now being used operationally were developed at different times, and differ significantly. The following wave-measurement systems are in operational use:

- DACT/VEEP Wave Analyzer (WA)
- DACT Directional Wave Analyzer (DWA)
- DWA Magnetometer-Only configuration (DWA/MO)
- VEEP/MARS Wave Processing Module (WPM)
- MARS/ARES Nondirectional WPM (NDWPM)
- MARS/ARES Directional WPM (DWPM)

NDBC's oldest wave measurement system is the WA. It uses a segmented fast Fourier transform (FFT) approach for the calculation of spectra. The

WA produces only nondirectional wave estimates. Versions were developed to work with both the DACT and VEEP payloads. The DWA produces directional wave estimates and is used only with the DACT payload. The WA and DWA produce spectra with a frequency range from 0.01 to 0.40 Hz in intervals of 0.01 Hz. The most modern of the operational wave measurement systems is the WPM, developed in the 1990's. This directional wave measurement system was originally coupled with the VEEP payload and later with the MARS payload. Derivative systems include the NDWPM, a nondirectional only system, and the DWPM, a variation of the WPM that permits the use of angular rate sensors to estimate wave direction. The NDWPM and DWPM are used with MARS or ARES payloads. The WPM and derivative systems use a single FFT for each of three spectral frequency ranges and band averaging to derive a spectrum with variable bandwidths. The frequency range of the spectra are from 0.02 Hz to 0.485 Hz with variable bandwidths of 0.005 Hz at low frequencies to 0.02 Hz at high frequencies.

3.3.4.1 Non-directional Ocean Wave Estimates

For nondirectional-measurement systems, NDBC uses either accelerometers to measure buoy heave motion, or laser wavestaffs (Brown and Gustavson 1990) to measure sea-surface displacement. Laser wavestaffs are used at C-MAN stations.

Accelerometers, either fixed to remain vertical relative to the hull or stabilized parallel to the earth vertical, are used in buoys and make the vast majority of ocean wave measurements. Vertical stabilization, when used, is achieved through use of the Hippy 40 sensor. This expensive sensor has built-in mechanical systems for keeping the accelerometer vertical as the buoy and sensor tilt.

NDBC operational nondirectional-wave measurement systems report estimates of acceleration or displacement spectra. If not directly reported, displacement spectra are derived from acceleration spectra as part of the calculations involved in the shore-side processing of the wave data. From these spectra, average wave period (AVGPD), dominant wave period (DOMPD), and significant wave height (WVHGT) are calculated. These nondirectional-wave parameters are defined as follows:

- Average wave period, in seconds, corresponds to the wave frequency that divides the wave spectrum into equal areas.
- Dominant wave period or peak wave period, in seconds, is the wave period corresponding to the center frequency of the frequency band with the maximum nondirectional spectral density.
- Significant wave height, H_{m0}, is estimated from the variance of the wave displacement record obtained from the displacement spectrum according to following equation:

$$H_{mo} = 4\left[\int_{0.03\ Hz}^{x\ Hz} S(f)\,df\right]^{1/2}$$

where $S(f)$ is the spectral density of displacement.

Limit, time-continuity, and relational checks are performed on nondirectional wave estimates. Acceleration or displacement time series statistics (QMAX, QMEAN, and QMIN) are also reported and provide important checks on the quality of wave data. They are defined as follows:

- QMEAN is the mean of all directly sampled heave or acceleration measurements during the data acquisition period. QMEAN should tend to near zero during the entire data acquisition period.
- QMAX and QMIN are the single maximum and minimum heave or acceleration measurements during the data acquisition period, respectively.

Significant deviations from zero of QMEAN may indicate sensor failure (particularly in the case of the Hippy 40), or that the buoy has lost trim (in the case of a fixed accelerometer). For these reasons, limit checks are performed on QMEAN.

3.3.4.2 Directional Ocean Wave Estimates

Directional wave measurement systems require (in addition to the measurement of vertical acceleration or heave (displacement), buoy azimuth, pitch and roll. These allow east-west slope and north-south slope to be computed. NDBC uses several different methods and sensor suites for the measurement of these angles.

Directional-wave systems allow estimates of four directional functions according to the following equations. The directional spectrum function is

$$S(f,\alpha) = C_{11} \cdot D(f,\alpha)$$

where $D(f,\alpha)$ is defined by

$$D(f,\alpha) = \frac{1}{2\pi} + r_1 \cos(\alpha - \alpha_1) + r_2 \cos[2(\alpha - \alpha_2)].$$

$D(f,\alpha)$ is the directional spreading function.

The frequency-dependent angles, α_1 (measurement ID ALPHA1) and α_2 (measurement ID ALPHA2), are the mean and principal wave directions, respectively, measured clockwise from north in the direction from which the waves are coming. NDBC uses this convention because it is consistent with the way wind direction is expressed. The frequency dependent parameters, r_1 and r_2, lie between zero and one and provide information about the directional spreading of wave energy. More on NDBC wave systems and processing can be found in *Nondirectional and Directional Wave Data Analysis Procedures,* NDBC Technical Document 96-01, 1996.

The following buoy motion statistical values are reported by the DWA for use in both automated and manual QC:

- AORIG is the buoy azimuth, in degrees, at the beginning of the data acquisition period. The buoy azimuth is defined as the direction of the buoy bow clockwise from true north.
- SDAMIN is the maximum angular excursion counterclockwise of AORIG, in degrees, that the buoy made during the data acquisition period.
- SDAMAX is the maximum angular excursion clockwise of AORIG, in degrees, that the buoy made during the data acquisition period.
- DELTAMIN is the greatest rate of counterclockwise direction change between two consecutive samples, in degrees per second, during the acquisition period.
- DELTAMAX is the greatest rate of clockwise direction change between two consecutive samples, in degrees per second, during the acquisition period.
- ANGPMEAN is the mean of all pitch angles, positive bow up, in degrees, measured during the data acquisition period.
- ANGPMAX and ANGPMIN are the single maximum and minimum pitch angle measurements, positive bow up, in degrees, during the data acquisition period, respectively.
- ANGRMEAN is the mean of all roll angles, positive port up, in degrees, measured during the data acquisition period.
- ANGRMAX and ANGRMIN are the single maximum and minimum pitch angle measurements, positive port up, in degrees, during the data acquisition period, respectively.
- TILTMAX is the single maximum deflection of the buoy mast from the vertical, in degrees, during the data acquisition period. This value must be greater than or equal to all of the following four measurements:

  – ANGPMAX
  – ANGPMIN
  – ANGRMAX
  – ANGRMIN

- TOTMAG is the mean magnitude of the vector sum of B_1 and B_2, which are measurements of the horizontal component of the earth magnetic field by the magnetometer along the bow and starboard axes of the buoy.

The WPM and DWPM report the above, plus some additional housekeeping quantities, including statistics of east-west and north-south buoy slope (ZXMEAN-MAX-MIN and ZYMEAN-MAX-MIN). The WPM does not, however, report magnetometer statistics under the ID of TOTMAG. A comparable quantity, B2MEAN is reported.

Limit checks are performed on directional-wave environmental and housekeeping measurements to see that they lie within a normal range.

3.3.5 Relative Humidity

Humidity sensors used by NDBC have two individual sensing elements: one element measures the electrical conductivity of the air, and the second element measures the air temperature. The relative humidity is determined from the known relationship between the conductivity and temperature. There are two NDBC humidity measurement IDs used for expressing humidity; relative humidity (RH1), in units of percent (%); and dew point (DEWPT1), in units of °C. The sensor provides RH1, and DEWPT1 is derived from RH1 and ATMP1. If the payload is a DACT or VEEP, DEWPT1 is calculated at the station and sent shoreside where it is converted to RH1. The relative humidity-to-dew point conversions are given in Appendix B. Range limit and standard time continuity checks are performed on DEWPT1 and RH1.

3.3.6 Ocean Current

Ocean current measurements provide essential information for such purposes as assessing the environmental impact of oil releases and water current stresses on offshore structures. NDBC acquires these measurements by a buoy-mounted, downward-looking acoustic Doppler current profiler (ADCP).

ADCPs emit short-duration, high-frequency pulses of acoustic energy along narrow beams into the water, and measure the Doppler-shifted frequency of the return energy backscattered from plankton and nekton. The backscattering particles are assumed to be passive drifters that move with the water. The along-beam Doppler frequency shifts are resolved into orthogonal earth coordinates to obtain water currents. Several automated QC checks have been established to help monitor ADCP current measurements. These include:

- Limit check
- Time continuity check
- Vertical velocity relational check

The limit and time continuity checks are applied to each velocity measurement. The vertical-velocity-relational check deletes horizontal current measurements when the corresponding absolute value of the vertical velocity is too high to be physically reasonable.

The principal ADCP measurements acquired are:

- Eastward current (UV001-UV020) is the measurement of average current toward the east (negative is west) in units of centimeters per second (cm/s).
- Northward current (VV001-VV020) is the measurement of average current toward the north (negative is south) in units of cm/s.
- Vertical current (WV001-WV020) is the measurement of average vertical current (positive up) in units of cm/s. These measurements are the average of the vertical current found from each of the two 2-beam pairs. It has been found that these measurements are not usable representations of the true vertical velocity in the ocean (Winant et al., 1994); however, they do reliably indicate when the horizontal currents are suspicious.
- Echo level (EA101-EA120, EA201-EA220, EA301-EA320, EA401-EA420) is a measurement of the return energy in decibels relative to an electrical automatic gain control current, in the ADCP.

3.3.7 Precipitation

Two types of sensors have been used to make precipitation measurements. These are the optical rain gauge and the siphon rain gauge that have been installed on some moored buoys for NASA and MMS.

No automated QC checks are performed on ORG data. The data are manually checked for correct operation of the sensor.

There are 14 measurement IDs associated with the optical and siphon rain gauges organized into four 15-minute periods and two 30-minute periods. The measurement IDs for the two systems are the same and have the same meaning. They are as follows:

- ORG11 is the mean rainfall rate from minute 56 to minute 10 in units of millimeters per hour (mm/hr).
- ORG12 is the standard deviation of the rate of rainfall from minute 56 to minute 10 in units of mm/hr.
- ORG13 is the maximum 30-second rainfall rate from minute 56 to minute 10 in units of mm/hr.
- ORG14 is the mean rainfall rate from minute 11 to minute 25 in units of mm/hr.
- ORG15 is the standard deviation of the rate of rainfall from minute 11 to minute 25 in units of mm/hr.
- ORG16 is the maximum 30-second rainfall rate from minute 11 to minute 25 in units of mm/hr.
- ORG17 is the percentage of rain sampled from minute 56 to minute 25 for which the rainfall rate was greater than 0.5 mm/hr.
- ORG21 is the mean rainfall rate from minute 26 to minute 40 in units of mm/hr.
- ORG22 is the standard deviation of the rate of rainfall from minute 26 to minute 40 in units of mm/hr.
- ORG23 is the maximum 30-second rainfall rate from minute 26 to minute 40 in units of mm/hr.
- ORG24 is the mean rainfall rate from minute 41 to minute 55 in units of mm/hr.
- ORG25 is the standard deviation of the rate of rainfall from minute 41 to minute 55 in units of mm/hr.

- DRG26 is the maximum 30-second rainfall rate from minute 41 to minute 55 in units of mm/hr.
- DRG27 is the percentage of rain sampled from minute 26 to minute 55 for which the rainfall rate was greater than 0.5 mm/hr.

3.3.8 Salinity

Salinity measurements have been made at a number C-MAN stations. Several different measurement IDs have been used, depending on the application. The data base identifier for salinity is ZSAL1. Conductivity of seawater is the primary measurement for determining its salinity. The unit of conductivity is the milliSiemen per centimeter (mSiemen/cm). Since the actual quantity of interest is salinity, rather than conductivity, automated QC algorithms have only been applied to salinity measurements.

NDBC salinity measurements are based on the practical salinity scale that uses the accepted empirical relationship between salinity and the conductivity of seawater (Grassoff 1983). The unit of measure is the practical salinity unit (psu). Time continuity and range checks have been performed on salinity measurements. Also, post-measurement scaling must be done to compensate for sensor drift due to biological fouling.

3.3.9 Solar Radiation Measurements

Solar radiation is an important influence on physical, biological, and chemical processes near the air-sea interface, and is therefore of interest to scientists and engineers. Solar radiation measurements taken at the surface have been used to calibrate visible range radiometers aboard satellites. NDBC has supported a number of sponsors by providing measurements of radiation from sensors mounted above and below the water’s surface. Measurement IDs, such as ZRAD, and the unit of measure have varied depending on the application. Solar radiative flux is measured in Watts per square meter and Photosynthetically Active Radiation (PAR) is measured in micromols per square meter per second. Automated QC for these measurements has typically been limited to upper limit checks.

3.3.10 Visibility

Visibility sensors have been placed on some C-MAN stations where visibility is a critical concern for safe navigation. The sensor measures the extinction of light across a small volume of air between an emitter and a collector. It is important to note that these are measurements at a single point and extrapolated, and that there are several similar but different definitions. Appendix C explains some of the various terms used. The NDBC measurement IDs for visibility are VISIB1, VISIB2, and VISIB3. VISIB1 is the visibility in a coded format. VISIB2 is the reading from the Impulsphysik sensor, and VISIB3 is the visibility reading from the Belfort visibility sensor. The units of measurement are the nautical mile (nmi) and kilometer (km) (1 km = 0.621 mi = 0.541 nmi).

As explained in Appendix C, there are two algorithms for the determination of visibility. Nighttime visibility measurements of VISIB1 are measurements of nighttime visual range. Daytime visibility measurements are of daytime visual range. Also, it is important to note that all range values greater than or equal to 6.95 nmi are reported as 6.95 nmi. NDBC archives visibility measurements in nmi. There is an automated QC check that flags visibility and humidity measurements if the visibility is determined to be too high or too low in relation to the measured humidity.

3.3.11 Water Level Measurements

Water level measurements are useful to NWS forecasters for monitoring storm surge. Such measurements are made at several C-MAN stations using pulse-sounding tide gauges. A total of 31 measurement IDs are reported each hour: ten 2-minute tide averages (TGAUG01 through TGAUG10), ten counts of the number of failed samples made during each 2-minute period (TGCNT01 through TGCNT10), standard deviations of each of the10 averages (TGSTD01 through TGSTD10), and an hourly tide measurement (TIDE1). A 2-minute estimate is made every 6 minutes. The measurements and standard deviations are given in units of feet.TGAUG01, TGCNT01, and TGSTD01 correspond to measurements made during the first 2-minute measurement period of each hour. The hourly measurement, TIDE1, is the same as TGAUG01. Automated range and time-continuity checks are performed on TIDE1 and TGAUG01-10.

4.0 QUALITY CONTROL ALGORITHMS AND WARNING FLAGS

This section describes the algorithms used to assign QC flags to NDBC measurements. The basic mechanism used to flag a measurement is to compare it with a threshold value which, when exceeded, assigns a flag. Algorithms differ by measurement and by how the thresholds are derived. Some thresholds are fixed, and some are a function of season or location. The various flags and how they should be interpreted are also described.

4.1 QUALITY CONTROL ALGORITHMS

The number and the complexity of the algorithms have grown steadily over the years. The first developed, the simplest, and the most extensively used algorithm is the range check that simply compares measurement values against pre-established limits stored in the NDBC database. Other simple checks are the time continuity and consistency checks. The vast majority of automated checks are performed in real-time during processing at the NWSTG. There are a few that are performed at NDBC on measurements soon after entering the database. Appendix D provides additional examples and details of selected algorithms to augment the discussions that follow.

There are two types of flags that can be assigned to a measurement as a result of the automated QC process. A hard flag, or EQC flag for Environmental Quality Control, is assigned to a measurement when there is virtually no doubt that it is degraded. Hard flags will remain with the affected parameter and prevent it from being released or archived unless the flag is manually removed. A soft flag is assigned to a measurement to indicate that there may be some question about its validity. Soft-flagged measurements will be archived unless it is removed manually by a qualified data analyst. Capital letters are used to denote hard flags, and lower case letters are used to denote soft flags.

Some measurements are dependent on others. For example, the dewpoint is corrupted from the air temperature and relative humidity. If either is degraded, then the dewpoint will be incorrect. To prevent any propagation of error into derived measurements, a QC routine determines whether *any* hard flagged data are used in deriving other data. If so, the latter are flagged as related with an **R**, indicating they are based on flagged data.

Some measurements are closely related to other measurements in such a way that if one measurement is bad the other is also likely to be bad. Examples are wind speed and gust, and wave spectrum and height. If a measurement is related in this manner to another measurement that has been hard flagged, it will be **R** flagged, and will not be released. Some relationships are hard coded in the QC routines while others are assigned and maintained in the database by data analysts using the Maintain Met Measurements tool under Station Profiles in ESP.

4.1.1 <u>Range Check</u>

The simplest of the automated QC checks is the range limit check. It consists of comparing a measurement with pre-established upper and lower limits. If the measurement is greater than the hard upper limit or less than the hard lower limit, that measurement will be **L** flagged and deleted from real-time release and archival. There are also flexible range checks that vary according to geographic area and season. They work in the same way but do not prevent the release or archival of a measurement. An **a** flag indicates a measurement is above a soft limit, and a **b** flag indicates a measurement is below a limit.

Although range limit checks are station dependent, stations are grouped into climatologically similar regions. All stations within one of these regions will have the same hard EQC and soft seasonal limits. The areas are maintained in the NDBC database and may be viewed in the Regions Table under Location Profiles using the ESP interface to the database.

The hard limits are set at three standard deviations from mean climatology values taken from the *U.S. Navy Marine Climatic Atlas of the World*, Version 1.0, March 1992. They may also be adjusted when new record high and low values are observed from NDBC stations within the area. The hard EQC and soft seasonal limits for each region can be found in the NMCA Regions Table under Location Profiles using the ESP interface. For those parameters that are not supported by the *Navy Marine Climatic Atlas*, default hard limits in Table 2 are used.

Soft seasonal limits are usually set at two standard deviations from the mean climatology value for a specific area and month.

4.1.2 <u>Time Continuity</u>

Time continuity checks track the change over time of a particular variable. NDBC has derived empirically limits that are used to check the time rate of change of pressure; temperature; wind

TABLE 2. DEFAULT UPPER AND LOWER LIMIT VALUES

	Lower	Upper
Dominant Wave Period (s)	1.95	26
Average Wave Period (s)	0	26
Solar Radiation (w/m^2)	0 W	1500
Dew Point (°C)	-30	40
Precipitation (mm/hr)	0	400
ADCP Current (cm/s)	-200	200
Salinity (ppt)	10	70
PAR (μmol m^2/s)	0	2500

speed; wave period; wave height; and relative humidity. As with range checks, there are both hard and soft seasonal time continuity checks. A hard flag is indicated by a **V** and a soft flag by an **f**.

NDBC uses two different time continuity algorithms. While the basis for each is the same, i.e., comparing the time rate of change in a quantity with a given threshold, the derivations of the limits used for the checks are different. A standard hard time continuity check is used on most NDBC measurements, and some special measurements undergo checks that were derived using statistical formulations unique to the type of measurement.

4.1.2.1 The Standard Time Continuity Check

The standard time continuity check developed at NDBC is based on the following expression:

$$\sigma_\tau = \sigma\sqrt{2(1 - R(\tau))}$$

where σ_τ is the standard deviation about the mean difference between measurements at a specific time and the corresponding measurements τ hours later, $x(t+\tau)$. σ is an estimate of the standard deviation of an ensemble of measurements, and $R(\tau)$ is the autocorrelation function of an ensemble of measurements for a time lag, τ.

Statistics were gathered for a number of stations ranging from the Gulf of Alaska to the Gulf of Mexico. It was determined that there is an approximate linear relationship between $R(\tau)$ and τ for values of τ less than 12 hours. Therefore, σ_τ was recast as follows:

$$\sigma_\tau = c\ \sigma\ \sqrt{\tau}.$$

This is a practical representation of the general change of a normally distributed meteorological or oceanographic variable with time.The mean 1- to 24-hour changes in atmospheric pressure were determined for a number of stations, and it was found that c equal to 0.58 provided a suitable limit for the naturally allowable change in barometric pressure with time, yielding the following:

$$\sigma_\tau = 0.58\sigma\sqrt{\tau}.$$

This equation is used to check:

- Pressure (BARO1, BARO2)
- Temperature (ATMP1, ATMP2)
- Wind speed (WSPD1, WSPD2)
- Wave period (AVGPD, DOMPD)
- Wave height (WVHGT)
- Relative humidity (RH1)

The time continuity check compares the difference between the last acceptable measurement with the current measurement, Δx, with σ_τ. If Δx is greater than σ_τ, then the measurement fails, is flagged, and is deleted. If τ is greater than 3 hours, then 3 hours is used. Special logic is added in the algorithm for checking relative humidity. This is to prevent erroneous flagging during frontal passage when large changes in relative humidity can occur.

In practice, it has not been necessary to use station-specific values of the standard deviation of measured variables. The general values in use are listed in Table 3. As with the general range limits, it has been necessary to depart from the general values of σ_T for some stations. For example, since sea surface temperatures at stations close to the Gulf Stream can change abruptly, σ_T for water-temperature measurements off the east coast has been increased to 12.1 °C, based on actual units.

TABLE 3. GENERAL VALUES OF TIME CONTINUITY PARAMETERS

Variable	σ
Sea-Level Pressure (hPa)	21.0
Air Temperature (°C)	11.0
Water Temperature (°C)	8.6
Wind Speed (m/s)	25.0
Wave Height (m)	6.0
Dominant Wave Period (s)	31.0
Average Wave Period (s)	31.0

There are four exceptions to the time continuity test due to the very rapid changes that occur in wind, pressure, air temperature, and wave height during the passage of tropical cyclones and severe extratropical cyclones. First, air pressure measurements that fail the first time continuity check are re-accepted and released if both $BARO_{current}$ and $BARO_{previous}$ are both less than 1000 hPa. Second, wind speed measurements that fail the first time continuity check are re-accepted and released if both $BARO_{current}$ and $BARO_{previous}$ are less than 995 hPa. Third, ATMP1 measurements that fail the first time continuity check are re-accepted and released if either $WSPD_{current}$ is greater than 7 m/s or if the wind direction change ($WDIR_{current}$ compared with $WDIR_{previous}$) is greater than 40°. Finally, WVHGT measurements that fail the first time continuity check are re-accepted and released if the current wind speed is equal to or greater than 15 m/s.

Soft seasonal time continuity checks are also applied to standard NDBC measurements. Like range checks they are applied according to geographic region. The soft seasonal time-continuity limits for each region can be found in the NMCA Regions Table under Location Profiles using the ESP interface to the database.

4.1.2.2 Time Continuity Algorithm for Special Measurements

Some measurements require an algorithm for time continuity that is much simpler than the standard time continuity algorithm. Let Δx/Δt be the time rate of change of a variable, let τ be the time between consecutive measurements, and let $k(\tau)$ be an empirical function (or constant) that defines the maximum allowable change for a given τ. Any measurement $x(t+\tau)$ will pass the time continuity check if the following expression is true:

$$\left| \frac{x(t+T)-x(t)}{T} \right| \leq k(T)T$$

The function $k(\tau)$ is determined empirically for each measurement to which this algorithm is applied. This algorithm is applied to check the time continuity of wave height and ADCP current measurements. The algorithm for this check, as it is applied to ADCP measurements, and the standard time continuity check can be seen in Appendix D.

4.1.2.3 The Relationship between Time Continuity and Range Limits

The relationship between hard time continuity and hard range limit checks is very important. The two are coupled, and time continuity is always checked first. This coupling will only permit a standard measurement to be hard flagged as a result of failing a limit check if it has first failed the time continuity check. This is to prevent loss of data due to erroneous range limit flagging during severe storm or hurricane conditions, since it is assumed that the onset of severe conditions will be gradual, and time continuity limits will not be exceeded. Also, if a measurement fails either a time-continuity check or a range limit check over two successive reports, it will be automatically hard flagged to prevent further release of that measurement until manually reviewed and reset by a data analyst. Details of these algorithms can be seen in Appendix D.

4.1.3 Storm Limits

Hard range and time continuity limits can be removed in advance of unusual weather situations, such as hurricanes and severe winter storms. The data quality analyst can deactivate the checks by station at NWSTG through the ESP interface to the database. When the abnormal situation has passed, the regular range-limit and time-continuity limits are reactivated by the data quality analyst.

4.1.4 Hierarchy Reversal and Duplicate Sensor Checks

Sensor hierarchy of duplicate sensors (WDIR, WSPD, BARO, and related measurements) determines which of the sensors' data will be released at the NWSTG. Normally, hierarchy is manually set by the data analyst and is not changed unless the primary sensor fails or suffers an obvious deterioration in performance. Often, sensor degradation is sudden, as may be caused by a severe storm, or of such short duration it goes undetected by a data analyst. To overcome this, hierarchy is reversed automatically under certain conditions. This is a powerful algorithm that prevents the release of data from a primary sensor that has suddenly degraded in relation to the secondary sensor. The algorithm identifies data from the primary sensor as degraded when it exceeds region and season specific differences in relation to the secondary sensor in a particular way. When this occurs, the primary sensor is hard flagged with an **H** and hierarchy is reversed, thus releasing the measurement from the sensor formerly identified as secondary. Sensor hierarchy is reversed only when the data from the secondary sensor has not already been hard flagged. Hierarchy will remain reversed until it is manually reset, or another automatic reversal occurs. Details of the hierarchy reversal algorithm can be found in Appendix D.

This capability can be disabled for some stations that have legitimate reasons for larger than normal differences between two anemometers. For example, bird roosting effects or wake turbulence could cause these differences.

Several other tools have been developed that assign a soft flag to measurements from redundant sensors that suddenly diverge or do not track together. One check identifies when the difference between measurements of duplicate sensors is too high based on established regional and seasonal limits. Both measurements will be flagged with a **k** when this occurs. Another check identifies when the time-continuity of differences between measurements of duplicate sensors exceeds regional and seasonal limits. The measurements will be flagged with a **t**, and one of the two sensors will be suspect if

$$|x_1(t_1) - x_1(t_0)| - |x_2(t_1) - x_2(t_0)| > T, \quad t_1 > t_0$$

where $x_1(t)$ and $x_2(t)$ are measurements from duplicate sensor, and T is a threshold value determined from past experience. At present, only hourly changes are compared (t_1-t_0 = 1 h). The algorithm is not used if any of the four measurements in the left side of above equation are missing. Seasonal and regional limits that apply to these checks can be found using ESP under the in the NMCA Regions Table under Location Profiles.

4.1.5 Internal Consistency

Internal-consistency checks are based on a physical relationship between measurements. There are both hard and soft internal consistency checks. Examples of hard internal consistency checks are:

- GUST1(2) is hard flagged with an **L** and not released if it is less than WSPD1(2).
- Mean, maximum, and minimum heave (QMEAN, QMAX and QMIN) are hard flagged with an **S** if QMEAN does not fall between QMIN and QMAX. This will prevent the release of all wave related measurements.
- A measurement is **E** flagged when a value used in its calculation exceeds limits, or is otherwise determined to be in error. The flag is applied to WVHGT when the displacement spectrum used to calculate its value is determined to be in error.
- If BATT1 is below 10.5 volts, BARO1 and BARO2 measurements are **R** flagged. Low voltage has caused the barometric pressures, BARO1 and BARO2, to report incorrect values.

Examples of soft internal-consistency checks include the following:

- If the ratio of wind gust (GUST) to wind speed (WSPD) is greater than a maximum value, which is a function of wind speed, wind gust is **g** flagged. This check is also applied to hourly maximum gust (MXGT) and hourly average wind speed (AVGSPD). Details are in Appendix D.
- Hourly wind speed (WSPD) and the continuous wind speed (CWS) whose time interval includes the averaging period of wind speed are compared. If the absolute difference is greater than 2.0 m/s (buoy), or 3.0 m/s (C-MAN), continuous winds are **i** flagged.
- Wind direction (WDIR) and average buoy "bow" azimuth (FWDIR) are **z** flagged if they differ by more than 35 deg and if wind speed is greater than 7 m/s. This check is only applied to 3-m discus buoys that have fins which keep the buoy bow headed into the wind.
- If visibility is either too high or too low relative to the reported dew point depression, RH1, DEWPT1, and VISIB3 are soft flagged with a **v**.

Some data are deleted or adjusted for practical considerations:

- WVHGT, DOMPD, and AVGPD are set to zero and **c** flagged to indicate they are corrected if WVHGT is less than 0.15 m. This prevents fictitiously high wave periods from being reported during calm seas.
- GUST1 is labeled as missing with an **M** flag, if the gust speed is less than 0.5 m/s.
- If DEWPT1 is not less than or equal to the ATMP1, it is set equal to ATMP1and **c** flagged.

4.1.6 <u>Wave Validation Checks</u>

Wave checks have been developed that use limit or internal consistency to validate the accuracy of directional and nondirectional wave measurements. Some of these checks are applied during real-time processing while others are run NDBC after wave data are resident in the database.

4.1.6.1 Wind Wave Algorithms

There are two QC methods that compare the wind to wave energy. The Lang algorithm (1987) is used for hour-by-hour checking. The Palao-Gilhousen algorithm (1993) looks at a months' worth of data to find more elusive sensor degradation.

The statistical wind-wave comparison algorithm developed by Lang uses a relationship between high frequency wave energy and wind speed. The sum of the spectral energy densities in the frequency range from 0.20 to 0.27 Hz during the current hour are compared with the square of the mean of the wind speed of the current and previous three hours. When measured wave energy falls beyond pre-established limits when compared to the wind energy, WVHGT is soft flagged. An **x** assigned to WVHGT indicates wave energy is higher than expected relative to wind speed. A **y** indicates wave energy is lower than expected. The Lang algorithm performs well but has limitations, especially during cases of light winds and at stations with fetch restrictions. Because of these limitations, observations can be incorrectly flagged as erroneous.

The Palao-Gilhousen wind-wave algorithm represents a departure from the earlier NDBC QC schemes. Rather than looking at data points hourly, this algorithm looks at hundreds of hours of data. The basis of the algorithm is similar to that of the Lang algorithm: to compare an observed wave energy value to upper and lower limits based on the square of the corresponding 4-hour average wind speed. Limits are not universal. It has been found that buoys of like-hull type exhibit similar wave response characteristics. Therefore, the wind-wave algorithm is dependent on hull type. It has also been found that Great Lakes stations require unique limits.

Through the use of this tool, the characteristic relationship of wind to wave energy can be visualized. The plots are divided into sectors and the conditional probability density distribution calculated. The density distribution decomposes the entire data cloud into probabilities of occurrences per sector. The upper and lower limits are delineated by the 0.1 percent contour. A month of wind-to-wave observations are depicted on scatter plots superimposed on the station's characteristic 0.1 percent contour. A significant number of points falling outside of the contour may indicate sensor degradation. An example of output from the algorithm is shown in Figure 3. The points inside the outer contour indicate good correlation between wind and wind-wave energy.

4.1.6.2 Directional Wave Validation Report

The *Directional Wave Validation Report* is generated daily by a data analyst using a program that conducts a series of hourly checks on specific directional and nondirectional wave environmental and housekeeping measurements. All checks unique to this report are limit checks set and maintained by the data analyst and are based on each station's geographical location, hull type, and type of directional wave system employed. The flags on this listing are for review only. Unlike the hard and soft flags assigned for real-time processing, which are also indicated on the report, these do not become part of the NDBC database. Measurements that fail to pass one or more of these checks are manually analyzed to determine if degradation of directional wave data has occurred.

4.1.6.3 Swell Direction Check

Buoys near the coast with directional wave systems should not measure significant swell energy coming from shore. For example, the west coast buoy at station 46042, near Monterey Bay, is sheltered from any long-period swell coming from directions 355° clockwise to 135° because of the coastline. Lower and upper limits of the sector from which swell energy should not come can be specified using the Wave System Profile page of the ESP interface. Each hour the nondirectional wave spectrum in the frequency bands from 0.03- to 0.10-Hz is checked for spectral wave energy (C11) that is both greater than 0.5 m^2/Hz and at least 5 percent of the wave energy of the frequency band with the highest energy ($C11_{MAX}$). If any of the frequency bands meets the above two conditions and has a corresponding mean wave direction (ALPHA1) from a sheltered direction, then the wave measurements for that hour are soft flagged with a **q**.

4.1.6.4 High Frequency Spectral Spikes

In general, spectral energy of wind generated waves decays with increasing frequency (*f*) proportionally with f^{-4} . Studies have shown that the maximum hourly change of spectral density at higher frequencies is also proportional to f^{-4} . At frequencies above 0.08 Hz, the limit of hourly spectral density change can be represented by:

$$\frac{d(\ s(\ f\ )\ )}{dt} = 0.006 f^{-4} \quad (m^2/Hz/hr)$$

This relationship is used to identify anomalous spikes in the high frequency portion of wave displacement spectra. When hourly changes in spectral density exceed the above limit, wave height is flagged with an **m**.

4.1.6.5 Wave Height Verses Average Wave Period

WVHGT and AVGPD are compared in a manner similar to the that by which GUST1 or GUST2 is compared to WSPD1 or WSPD2. The threshold value is calculated for two ranges of average period. If the test fails, WVHGT is flagged with a **p**. For wave periods of up to 5 seconds, flags will result when the WVHGT exceeds the threshold h_{max} as given by

$$h_{max} = 2.55 + \frac{AVGPD}{4} \quad (AVGPD \leq 5\ s).$$

For measurements of AVGPD greater than 5 seconds, h_{max} is defined by

$$h_{max} = 1.16 \cdot AVGPD - 2 \quad (AVGPD > 5\ s).$$

4.1.6.6 Wave Direction Verses Wind Direction

If the difference between mean wave direction (ALPHA1) at 0.35 Hz and wind direction are greater than 25 deg, mean wave direction (MWDIR) is **w** flagged. This check is only made if wind speed is greater than 7 m/s, the wind direction has not varied by more than 30 deg since the previous report, and wave spectral density at 0.35 Hz is greater than 0.003 m^2/Hz.

4.1.7 <u>NCEP Fields</u>

A program that is run at NDBC uses NCEP numerical model fields to determine if sensor performance has degraded. This is particularly valuable for offshore buoys whose remoteness do not permit comparison with other stations. The program compares NDBC measurements with first-guess fields (6-hour forecasts) generated by the NCEP Aviation Model. The fields are pulled from the NCEP ftp site in GRIB format four times daily, corresponding to valid times of 00Z, 06Z, 12Z, and 18Z. The model fields used in the comparison include sea level pressure, the10-m

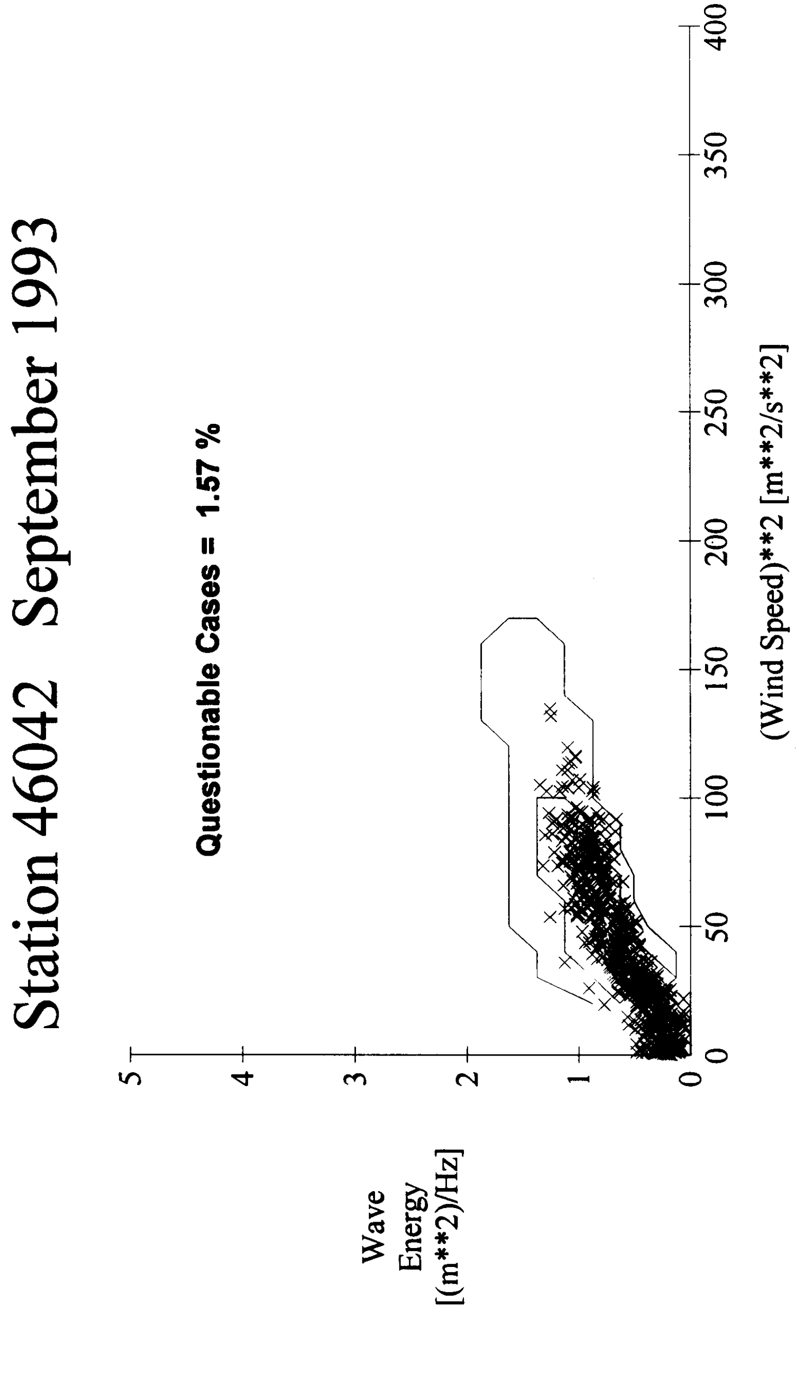

Figure 3. Example of output from Palao-Gilhousen wind-wave algorithm

winds, and relative humidity and air temperature at 2-m. Sea surface temperature fields are from a daily sea surface analysis. The program opens the GRIB file, extracts the fields of interest, and interpolates gridded values from a 1.0 by 1.0 degree global grid to station locations. Differences between model output and corresponding station measurements are checked against allowable tolerances. If any are exceeded, the measurements are flagged with an **n**. Tolerances can be a function of the measurement being compared or another measurement, and can vary by geographic location. Model output quantities interpolated to station locations are provided measurement IDs and retained in the database. They may be treated as any other database measurement. The algorithms used to compute tolerances are contained in Appendix D.

4.1.8 Continuous-Wind Checks

The range limit, time continuity, and dual sensor checks that are performed on continuous winds are the same as those applied to hourly winds. Continuous wind measurements involving speed will not be released if the hourly wind speed fails hard QC checks, nor will those involving direction, if the hourly wind direction fails QC. There are a few additional checks that only apply to continuous winds.

The continuous wind portion of a raw GOES message is checked for transmission errors during real-time processing. If a single error is detected, the individual measurement is flagged with a **T**. If more than one error is detected, then all continuous winds from both sensors are flagged with a **T** and not released.

The standard deviation check of speeds measured during the hour is properly correlated to the hourly average wind speed. It can be shown that the standard deviation of the wind increases with increasing wind speed. The maximum allowable standard deviation is defined by the relation

$$\sigma = 0.8 + 0.142v,$$

where v is either WSPD1 or WSPD2 and σ is the maximum allowable standard deviation. The relation for the minimum allowable standard deviation is defined by

$$\sigma = 0.07v \quad (v \leq 8 \ m/s)$$

and

$$\sigma = -0.57 + 0.142v \quad (v > 8 \ m/s).$$

Measurements with a standard deviation falling outside these limits will produce a **d** flag.

4.2 NDBC FLAGS

The use of flags is indispensable in the NDBC data QC effort. Flags signal to the data quality analyst that a measurement has failed one or more automated data QC checks. Flags can appear on any of several reports and graphical displays available to the data analyst. The previous section discussed the various QC algorithms and the flags they would trigger. This section describes the various meanings behind the flags without the detail of the previous section. A very abbreviated version of flag meanings is given in Appendix E.

There are two types of flags, and each type has several names. An "EQC" flag is also called a "hard" flag, an "upper case" flag, or a "capital" flag. Only manual intervention by a data analyst to remove the flag will allow the data to be released and archived. A "soft" flag, "lower case" flag, or "small" flag warns the data quality analyst that the data warrants closer inspection. It does not prevent real-time release or archival. Henceforth, flags will be referred to as either hard or soft flags.

4.2.1 Hard Flags

Hard flags prevent a measurement from being released in real-time and must be manually removed before a measurement can be archived.

Most QC displays that show the presence of flags can only indicate one flag. When a measurement fails two or more hard QC checks, the flag with the higher priority is printed.

4.2.1.1 D Flag — Delete Sensor from NWS Report

If measurements from a sensor are not to be released in real-time, the **D** flag for that measurement is set. Normally, it is manually set by a data analyst who has assessed the reliability of the sensor. A **D** flag does not mean that a measurement has necessarily failed any automated QC checks. However, if a measurement has been flagged with either a **V** or **L** flag over two successive reports, it will automatically be **D** flagged, and all subsequent reports will be **D** flagged. Only intervention by a data analyst will prevent continued flagging.

4.2.1.2 E Flag — Spectrum Exceeds Calculation Limits

A measurement is **E** flagged when a value used in calculation exceeds limits, or is otherwise determined to be in error. The flag is applied to WVHGT when the displacement spectrum used to calculate its value is determined to be in error.

4.2.1.3 H Flag — Sensor Hierarchy Has Reversed

Hierarchy of dual sensors is reversed automatically under certain conditions. A measurement from the primary sensor is identified as degraded when it exceeds region and season specific differences in relation to the secondary sensor in a particular way. When this occurs, the primary sensor is hard flagged with an **H** and hierarchy is reversed. Hierarchy will remain reversed until it is manually changed or another hierarchy reversal occurs. The algorithm is discussed in Section 4.1.4.

4.2.1.4 L Flag — Failed Range Limits Test

If a measurement is less than a lower limit or greater than an upper limit, then an **L** flag is set. **L** is also used to flag wind gust (GUST1 or GUST2) if it is less than the corresponding wind speed (WSPD1 or WSPD2).

4.2.1.5 M Flag — Missing Sensor Data

The **M** flag is assigned to missing measurements as a result of corrupted or truncated messages during real-time processing. Also, if data are missing in the database as result of a GOES message not being received at the NWSTG from DAPS, an **M** is assigned. In most data extraction reports, an **M** flag will appear next to the default value (0.0) if data are missing.

4.2.1.6 R Flag — Related Measurement Failed

Measurements may be defined in the database as related. An **R** flag is assigned to a measurement if a measurement to which it is related is hard flagged.

4.2.1.7 S Flag — Invalid Statistical Parameter

Mean, maximum, and minimum heave (QMEAN, QMAX and QMIN) are hard flagged with an **S** if QMEAN does not fall between QMIN and QMAX. When an **S** flag is set, WVHGT is also **T** flagged, and no wave related measurements are released.

4.2.1.8 T Flag — Transmission Parity Error

If a single error is encountered in the continuous winds portion of a GOES message, the individual measurement having the error will be **T** flagged. If more than one error is encountered in the continuous winds portion of a GOES message, all continuous wind measurements, from both sensors, are **T** flagged. For non-WPM wave systems, if an error is encountered anywhere in the waves portion of a GOES message all wave data are **T** flagged.

4.2.1.9 V Flag — Failed Time-Continuity Test

The **V** flag is set when a measurement exceeds the allowable change in a variable over time. Several algorithms for calculating the allowable change are used. They are discussed Section 4.1.

4.2.1.10 W Flag — WPM Transmission Errors

If the WPM portion of a raw GOES message is short, or if parity errors or checksum failures are detected, WVHGT will be flagged with a **W,** and all wave related data will not be released. This is similar to the **T** flag assigned to non-WPM wave messages.

4.2.2 <u>Soft Flags</u>

Soft flags are set on measurements that are suspect. These flags alert the data quality analyst to take a closer than normal look at the measurement and other related measurements to determine the quality of the data. Data that have been soft-flagged will continue to be released and archived until the data quality analyst decides that the data are bad and should no longer be released.

4.2.2.1 a and b Flags — Above or Below Regional and Seasonal Limits

The **a** and **b** flags are set on a measurement if its value falls above (**a**) or below (**b**) regional and monthly limits. Regional and seasonal limits are discussed in section 4.1.1.

4.2.2.2 c Flag — Calm Sea State Flag or Corrected Value

A **c** flag is assigned to indicate a measurement has been adjusted or corrected in some way. A **c** flag is assigned to WVHGT measurements that are less than 0.15 m. When the **c** flag is assigned, WVHGT is changed to 0.0 m and the corresponding DOMPD and AVGPD measurements are changed to 0.0 seconds.

When DEWPT1 is greater than the corresponding ATMP1, DEWPT1 is set equal to ATMP1 and flagged with a **c**.

4.2.2.3 d Flag — Failed Standard Deviation Check (Continuous Winds Only)

When continuous wind measurements fail the standard deviation check discussed in section 4.1.9, they are flagged with a **d**.

4.2.2.4 f Flag — Failed Hourly Time Continuity Check

Measurements that exceed seasonal time rate of change (time continuity) limits are flagged with an **f**. Seasonal limits are described in Section 4.1.2.1.

4.2.2.5 g Flag — Failed Gust-to-Mean Speed Ratio Check

A **g** flag is assigned to wind gust (GUST1 or GUST2) measurements when the gust-to-mean speed (WSPD1or WSPD2) ratio exceeds established limits that are a function of wind speed.

4.2.2.6 i Flag — Continuous and Hourly Wind Speeds Don't Agree

If the difference between standard wind speed and the corresponding continuous wind speed exceeds established limits, then continuous wind speeds are flagged with an **i**.

4.2.2.7 j Flag — Continuous Wind Transmission Error

If one transmission error is detected anywhere in the continuous winds portion of a GOES message, the measurement having the error is **T** flagged and all other continuous wind measurements are **j** flagged. If more than one error is detected, all continuous winds are flagged with a **T** and not released.

4.2.2.8 k Flag — Deltas Between Duplicate Sensors Too High

If the difference between measurements from dual sensors is greater than the regional and seasonal limits, both are flagged with a **k**. The check is described in Section 4.1.4.

4.2.2.9 m Flag — Failed Spectral Time-Continuity Check(C_{11})

If spikes in the high frequency wave spectrum are detected, WVHGT is flagged with an **m**. The check is described in Section 4.1.7.4.

4.2.2.10 n Flag — Faliled NCEP Model Comparison

If a measurement exceeds limits established for comparison with NCEP model fields, it is **n** flagged.

4.2.2.11 p Flag — Failed Wave Height/Wave Period Check (Wave Periods Only)

WVHGT and AVGPD are compared in a manner similar to the that by which GUST1 or GUST2 is compared with WSPD1 or WSPD2. The threshold value is calculated for two ranges of average period. If the test fails, AVGPD is flagged with a **p**. The algorithm is discussed in Section 4.1.7.5.

4.2.2.12 q Flag — Failed Directional-Wave Algorithm

When mean wave directions (ALPHA1) in the low frequency range imply that swells are coming from shoreward, a **q** flag is assigned to WVHGT. The directional-wave algorithm that assigns this flag is described in Section 4.1.7.3.

4.2.2.13 r Flag — Relate Measurement Failed (Continuous Winds Only)

If a related message has failed a QC check then the measurement is flagged with an **r**. This applies to continuous winds only.

4.2.2.14 s Flag — Failed Stuck Compass Check

If raw compass measurements (RCOMP) do not change over three consecutive reports, RCOMP and wind direction (WDIR) are flagged with an **s**.

This indicates that the compass may have failed, and as a result, wind directions may be inaccurate.

4.2.2.15 t Flag — Tendency Deltas Between Duplicate Sensors Too High

The time rate of change of the differences between measurements of dual sensors are compared. If the difference is too much, based on seasonal and regional thresholds, a **t** is assigned to both measurements. WSPD1 and WSPD2 and BARO1 and BARO2 are compared. The check is discussed in Section 4.1.4.

4.2.2.16 v Flag — Failed Humidity Verses Visibility Check

If visibility is either too high or too low when compared to the reported dew point depression, RH1, DEWPT1, and VISIB3 are soft flagged with a **v**.

4.2.2.17 w Flag — Failed Wave Direction Verses Wind Direction Check

If the difference between mean wave direction (ALPHA1) at 0.35 Hz and wind direction are greater than 25 deg, mean wave direction (MWDIR) is **w** flagged.

4.2.2.18 x and y Flags — Failed Wind-Wave Algorithm Limits

When wind generated wave energy is higher than expected based on the recent wind speed measurements wave height (WVHGT) is assigned an **x** flag. When wind generated wave energy is lower, it is flagged with a **y**. The algorithm is discussed in Section 4.1.7.1.

4.2.2.19 z Flag — Failed Average Bow Azimuth Verses Wind Direction

Wind direction (WDIR) and average buoy bow azimuth (FWDIR) are **z** flagged if they differ by more than 35 deg and if wind speed is greater than 7 m/s. This check is only applied to buoys equipped with fins (3-meter discus buoys).

4.2.3 PSOS Flags

PSOS measurements are flagged in the same way as other NDBC station data. The threshold values used are station-specific and unique to PSOS. The general meaning of the flags are the same as those described in Sections 4.2.1 and 4.2.2.

5.0 DATA QUALITY REPORTS AND GRAPHICS

Flags that have been assigned to measurements through automated QC checks are retained in the NDBC database. There are variety of reports and graphic displays available to the data analyst for reviewing data that have been flagged. Some of these applications are run on a daily basis, in batch mode, and others are initiated by the data analyst as required (National Data Buoy Center, 1998). In either case, measurements are extracted from the database and displayed in tables or graphical format. Any flags that have been assigned to a measurement are indicated on the display. This section will describe some of the applications used in this process.

5.1 PRE-GENERATED REPORTS AND GRAPHICS

Applications that are run daily in a batch mode may produce output in tables or graphic format.

They are run at the same time each day and display previous reports over a preset period of time, typically 24 or 72 hours. The most important of these are the Meteorological Differences (MET DIFFS) Report and automatically generated time series plots available through the Data Quality Analyst (DQA) Interface to the database. Both indicate the presence of flags.

5.1.1 MET DIFFS Report

Each page of the MET DIFFS Report contains a table of station measurements taken over a 24-hour period from a single station. Primary station measurements are included in the report, as are the differences between the measurements of dual sensors. Some important housekeeping measurements are also contained in the report, including battery voltage and current. Buoy positions determined by GPS or LORAN are also indicated. Flags appear to the right of any measurements that have failed automated QC checks.

5.1.2 Data Quality Analyst (DQA) Interface

The DQA Interface to the NDBC database provides another method for the data analyst to review flagged data. Through the interface, the analyst may page through listings, by station, of measurements that have been flagged. The analyst may review pre-generated time series plots of flagged and related measurements that were generated as a result of failing QC checks over the previous 24 hours. Most flags will cause time series plots of several related measurements to be generated in addition to a plot of the flagged measurement. These plots are created once each day and cover reports received over the last 72 hours. They are written to files that are accessed through the DQA Interface. Tables indicating what plots are generated by each flag can be seen in Appendix F.

The DQA Interface is also used by the analyst to remove hard flags that were assigned to measurements, initiate new hard flags on measurements, or defer action pending further review. Comments on any actions taken are entered into the database through this interface.

5.2 USER SPECIFIED REPORTS AND GRAPHICS

There are a variety of reports and graphics that can be generated by the analyst to extract and view measurements from the NDBC database. They offer a degree of flexibility over pre-generated products to suit a variety of needs by data quality analysts.

5.2.1 <u>The NDBC Plotting Server</u>

The plotting server retrieves data from the Oracle database and delivers it in graphical format to the user's Web browser. Available plots include:

- Single and Stacked Time Series. Plots of any station measurement contained in the NDBC database may be plotted. Gridded model fields interpolated to station location and METAR observations may also be plotted. Up to three measurements from two stations may be plotted on a single plot. Stacked plots offer the user the option to plot up to six measurements for a given station on up to three stacked plots. Time periods are user specified.
- General Purpose Scatter Plots. These permit plotting any two measurements available in the database. The measurements may be from the same or different stations.
- Spectral Wave Plots. These provide the option of plotting wave spectral density, spectral direction, or both.
- Wave Energy vs Wind Speed Scatter Plots. These plots are useful for determining if wind-wave energy is high or low relative to wind speed, and if a heave sensor may be degraded. Their use is described in Section 4.1.7.1.
- Station Position Plots. These display station position in relation to a station's watch circle.

5.2.2 <u>User Specified Reports</u>

The NDBC Oracle database interface offers the user a variety of reports that will extract and display data. These are intended primarily as computer screen displays, but they may be printed if required by the user. These include:

- MET DIFFS. This is the same as the pre-generated report discussed in Section 5.1.1, but the user may specify the stations and time period of the report.
- Time Tabulation (TIME TAB) Report. Allows the user to specify up to 10 measurements from a single station to create a measurement vs. time display. This application is useful for extracting and writing data to files for use in other applications.
- Meteorological Measurements by Station (MET MEAS) Report. This report displays a listing of all measurements expected from a station, their value, and any flags that have been assigned. Single or multiple hours may be requested. The report is useful in determining what environmental and housekeeping measurements are actually being reported by a station.
- Station Location Report. This report displays station position in a table over a time period specified by the user for each of the station's applicable locating systems (GPS, LORAN, etc.). The distance from mooring in nautical miles and as a percentage of the watch circle are indicated for each position.
- Wave Summary Report. This report displays the primary wave measurements (WVHGT, DOMPD, and AVGPD) and nondirectional and directional spectral values for each frequency for a specified hour. Other environmental and statistical housekeeping measurements relevant to determining the health of the wave measuring system are also displayed.

6.0 REFERENCES

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APPENDIX A

NDBC MEASUREMENT IDENTIFIERS

ASCII IDENTIFICATION, DESCRIPTION, AND RELATIONSHIPS

ASCII ID	DESCRIPTION	RELATED SENSORS/COMMENTS
ACQMIN	END OF ACQUISITION TIME	
ANALOG1	ANALOG CHANNEL 1	
ANALOG2	ANALOG CHANNEL 2	
ANALOG3	ANALOG CHANNEL 3	
ANALOG4	ANALOG CHANNEL 4	
ANGPMAX	MAX PITCH ANGLE	DWA, WPM
ANGPMEAN	MEAN PITCH ANGLE	DWA, WPM
ANGPMIN	MIN PITCH ANGLE	DWA, WPM
ANGPSTD	PITCH STANDARD DEVIATION	WPM
ANGRMAX	MAX ROLL ANGLE	DWA, WPM
ANGRMEAN	MEAN ROLL ANGLE	DWA, WPM
ANGRMIN	MIN ROLL ANGLE	DWA, WPM
ANGRSTD	ROLL STANDARD DEVIATION	WPM
AORG	DIR. OF BOW AT START OF ACQ.	DWA, WPM
ATMP1	#1 AIR TEMPERATURE	RH1
AVGPD	AVERAGE WAVE PERIOD	DOMPD, WVHGT
AVGDIR1	CONT. WIND #1 AVERAGE DIR.	
AVGDIR2	CONT. WIND #2 AVERAGE DIR.	
AVGSPD1	CONT. WIND #1 AVERAGE SPEED	
AVGSPD2	CONT. WIND #2 AVERAGE SPEED	
B10, B11, B12	HULL MAGNETIC CONSTANTS	
B20, B21,B22	HULL MAGNETIC CONSTANTS	
B1MAX	MAX TOTAL MAG	VERT AND HORIZ COMPONENTS, WPM
B1MEAN	MEAN TOTAL MAG	
B1MAX	MIN TOTAL MAG	
B1STD	STANDARD DEVIATION OF B1	
B2MAX	MAX TOTAL MAG	HORIZ COMPONENTS, ONLY, WPM
B2MEAN	MEAN TOTAL MAG	
B2MIN	MIN TOTAL MAG	
B2STD	STANDARD DEVIATION OF B2	
BARO1	#1 SEA LEVEL PRESSURE	SBAR1, ATMP1, BATT1
BARO2	#2 SEA LEVEL PRESSURE	SBAR2, ATMP1, BATT1
BATT1	SECONDARY BATTERY VOLTAGE	
BEY	EARTH MAG FIELD HORIZ COMP	
BEZ	EARTH MAG FIELD VERT COMP	
BOPWHT	BUOY PEAK WAVE HEIGHT	WA
BOWHT	BUOY SIG. WAVE HEIGHT	WA
BOWPD	BUOY WAVE PERIOD	WA
CCOMP1	#1 CORRECTED COMPASS	RCOMP1
CCOMP2	#2 CORRECTED COMPASS	RCOMP2
CWD1	CONT. WIND #1 DIR 1st SET	
through	through	
CWD6	CONT. WIND #1 DIR 6th SET	
CWS1	CONT. WIND #1 SPD 1st SET	
through	through	
CWS6	CONT. WIND #1 SPD 6th SET	
CWSTD1	CONT. WIND #1 STD. DEVIATION	
CWSTD2	CONT. WIND #2 STD. DEVIATION	
DELTAMAX	MAX RATE OF ROTATION	DWA
DELTAMIN	MIN RATE OF ROTATION	DWA
DEWPT1	#1 DEW POINT	RH1, ATMP1
DIRMXGT1	CONT. WIND #1 DIR MAX GUST	
DIRMXGT2	CONT. WIND #2 DIR MAX GUST	
DNIMPV	DAY/N IMPULPHYSIK VG	
DOMPD	DOMINANT WAVE PERIOD	AVGPD, WVHGT
FWDIR	FORWARD DIRECTION	DWA, WPM
GPSLAT	GPS LATITUDE	
GPSLON	GPS LONGITUDE	

GPSSEC	HOURS SINCE MIDNIGHT	
GUST1	#1 WIND MAX 5" GUST	
GUST2	#2 WIND MAX 5" GUST	
IPCURR	INPUT CURRENT	
MAGVAR	LOCAL MAGNETIC VARIATION	
MWDIR	MEAN WAVE DIRECTION	
MXGT1	CONT. WIND #1 MAX 5" GUST	
MXGT2	CONT. WIND #2 MAX 5" GUST	
MXMIN1	CONT. WIND #1 MIN OF MXGT1	
MXMIN2	CONT. WIND #2 MIN OF MXGT1	
ORG11	MEAN PRECIP (MINS 51-05)	
ORG12	STD DEV (MINS 51-05)	
ORG13	MAX PRECIP (MINS 51-05)	
ORG14	MEAN PRECIP (MINS 06-20)	
ORG15	STD DEV (MINS 06-20)	
ORG16	MAX PRECIP (MINS 06-20)	
ORG17	PCT. OF RAIN (MINS 51-20)	
ORG21	MEAN PRECIP (MINS 21-35)	
ORG22	STD DEV (MINS 21-35)	
ORG23	MAX PRECIP (MINS 21-35)	
ORG24	MEAN PRECIP (MINS 36-50)	
ORG25	STD DEV (MINS 36-50)	
ORG26	MAX PRECIP (MINS 36-50)	
ORG27	PCT. OF RAIN (MINS 21-50)	
OWD1	CONT. WIND #2 DIR 1st SET	
through	through	
OWD6	CONT. WIND #2 DIR 6th SET	
OWS1	CONT. WIND #2 SPD 1st SET	
through	through	
OWS6	CONT. WIND #2 SPD 6th SET	
PKWVHT	PEAK WAVE HEIGHT	
PREC1	#1 PRECIPITATION	
PREC2	6-HOUR ACCUM. PRECIP.	
QMAX	MAXIMUM HEAVE	
QMEAN	MEAN HEAVE	WVHGT, DOMPD, AVGPD
QMIN	MINIMUM HEAVE	
QSTD	STANDARD DEVIATION OF HEAVE	WPM, NDWPM
QSPIKES	NUMBER OF SPIKES IN TIMESERIES	NDWPM
RCOMP1	#1 RAW COMPASS	CCOMP1, WDIR1
RCOMP2	#2 RAW COMPASS	CCOMP2, WDIR2
RH1	#1 RELATIVE HUMIDITY	DEWPT1, ATMP1
RWD1	#1 WIND RAW DIRECTION	
RWD2	#2 WIND RAW DIRECTION	
SBAR1	#1 STATION PRESSURE	
SBAR2	#2 STATION PRESSURE	
SDAMAX	MAX MAGNITUDE OF ROTATION	DWA, WPM
SDAMIN	MIN MAGNITUDE OF ROTATION	DWA, WPM
SRAD1	#1 SOLAR RADIATION	
SWDIR	SWELL DIRECTION	
SWHGT	SWELL HEIGHT	
SWPD	SWELL PERIOD	
TGAUG01	TIDE HEIGHT, 1st SET	
through	through	
TGAUG10	TIDE HEIGHT, 10th SET	
TGCNT01	TIDE COUNTS, 1st SET	
through	through	
TGCNT10	TIDE COUNTS, 10th SET	
TGSTD01	TIDE STD. DEV., 1st SET	
through	through	
TGSTD10	TIDE STD. DEV., 10th SET	
TIDE1	TIDE HEIGHT	
TILTMAX	MAXIMUM BUOY TILT	DWA, WPM
TOTMAG	TOTAL MAG	DWA
UV001	EAST WATER VEL.COMP. #01	ADCP
through	through	ADCP
UV020	EAST WATER VEL.COMP. #20	ADCP
UV001	EAST WATER VEL.COMP. #01	ADCP
through	through	ADCP
UV020	EAST WATER VEL.COMP. #20	ADCP

VISIB1	VISIBILITY	
VISIB2	VISIBILITY	
VISIB3	VISIBILITY	
VV001	NORTH WATER VEL.COMP. #01	ADCP
through	through	ADCP
VV020	NORTH WATER VEL.COMP. #20	ADCP
WSPD1	#1 WIND SPEED	GUST1, WSPD11, WSPD12
WSPD11	#1 WIND 10 METER SPEED	
WSPD12	#1 WIND 20 METER SPEED	
WSPD2	#2 WIND SPEED	GUST2, WSPD21, WSPD22
WSPD21	#2 WIND 10 METER SPEED	
WSPD22	#2 WIND 20 METER SPEED	
WTMP1	WATER TEMPERATURE #1	
WV001	VERT. WATER VEL.COMP. #01	ADCP
through	through	ADCP
WV020	VERT. WATER VEL.COMP. #20	ADCP
WVAGE	WAVE AGE	DWA
WVHGT	SIGNIFICANT WAVE HEIGHT	AVGPD, DOMPD, QMAX
WWDIR	WIND WAVE DIRECTION	
WWHGT	WIND WAVE HEIGHT	
WWPD	WIND WAVE PERIOD	
ZXMAX	MAX BUOY EAST-WEST SLOPE	WPM
ZXMIN	MEAN BUOY EASTWEST SLOPE	WPM
ZXMIN	MIN EAST-WEST BUOY SLOPE	WPM
ZXSTD	STANDARD DEVIATION OF SLOPE	WPM
ZYMAX	MAX NORTH-SOUTH BUOY SLOPE	WPM
ZYMEAN	MEAN NORTH-SOUTH BUOY SLOPE	WPM
ZYMIN	MIN NORTH-SOUTH BUOY SLOPE	WPM
ZYSTD	STANDARD DEVIATION OF SLOPE	WPM

APPENDIX B

RELATIVE HUMIDITY CONVERSIONS

The dew point is calculated on board all payloads using the following series of equations. First, e_s, the saturation vapor pressure, is calculated from the air temperature measured inside the humidity probe, T, by using

$$e_s = \exp\left[\left(-\frac{5438}{T + 273.15} \right) + 21.72 \right] \quad . \quad \textbf{(B1)}$$

Using B1 and the assumption that the vapor pressure, e, can be calculated using

$$e = \exp\left[\left(-\frac{5438}{T_d} \right) + 21.72 \right] \quad , \quad \textbf{(B2)}$$

the formula for dew point is

$$T_d = \left[\frac{5438}{\ln\left(\frac{e_s\, r}{100} \right) - 21.72} \right] - 273.15 \quad . \quad \textbf{(B3)}$$

where r is the observed relative humidity.

On all but the ARES payload, the relative humidity is not transmitted from the buoy. It is recalculated onshore by backsolving (B1) to obtain e_s, backsolving (B2) to obtain e, and then calculating the relative humidity using

$$r = 100\frac{e}{e_s} \quad . \quad \textbf{(B4)}$$

One of the weaknesses behind this recalculation is that the air temperature used to backsolve (B1) is not identical to the temperature measured inside the relative humidity probe. Rather, it is the standard air temperature sensor measured under a separate shield. The ARES overcomes this by bringing back both air temperatures and the observed relative humidity.

APPENDIX C

ATMOSPHERIC VISIBILITY MEASUREMENTS

The formula, also known as Koschmieder's law, is the fundamental equation of visual range theory, relating the apparent luminance of a distant black object, B_b, the apparent luminance of the background sky above the horizon, B_h, and the extinction coefficient of the air layer near the ground, σ. The daytime visual range, v_{day}, is given as:

$$v_{day} = -\frac{\ln\left(\frac{B_b - B_h}{B_h}\right)}{\sigma} \qquad \textbf{(C1)}$$

where the extinction coefficient is a result of Beer's law

$$I = I_o e^{-\sigma x}. \qquad \textbf{(C2)}$$

I is the illuminance at a distance x from a light source of illuminance, I_o.

The quantity $(B_b$-$B_h)/B_h$ is known as the contrast. The value of the contrast used by NDBC instruments in calculations of daytime visual range is 0.05. This yields

$$v_{day} = -\frac{\ln(0.05)}{\sigma} = \frac{2.99573}{\sigma} \approx \frac{3}{\sigma} \quad , \qquad \textbf{(C3)}$$

where the units of visual range are in units of kilometers (km). The measurement of σ is in units of km^{-1}.

In the theory of the night visual range of artificial light sources, Allard's law is a basic relationship governing the variation of illuminance with distance from a point source. Let I be the illuminance received on a unit area of a given surface expressed in units of lumen per unit area, let x be the distance from source to observer, and let L be the luminous intensity of a point source in units of candela. Allard's law is then expressed as

$$I = L\frac{e^{-\sigma x}}{x^2} \quad , \qquad \textbf{(C4)}$$

where the threshold illuminance I_T and the nighttime visual range, v_{night}, are related as follows

$$I_T = \frac{Le^{-\sigma v_{night}}}{v_{night}^{\ 2}}. \qquad \textbf{(C5)}$$

It has been found that the threshold illuminance varies inversely as v_{night}, such that $I_T \propto I_o/v_{night} \equiv S_v$, yielding,

$$S_v = \frac{Le^{-\sigma v}}{v} \quad . \qquad \textbf{(C6)}$$

Letting S_v = 0.084 candela/mile and L = 25 candela (from NWS internal memo of September 11, 1991, regarding ASOS visibility measurements), then

$$0.00336v = e^{-\sigma v} \quad . \qquad \textbf{(C7)}$$

This equation cannot be applied directly using the measured σ from the NDBC instrument, so an approximation must be used. An approximation follows

$$v_{night} = \left(\frac{\sigma}{6}\right)^{6/5} \qquad \textbf{(C8)}$$

where the units are in km and km^{-1}, respectively.

APPENDIX D

QUALITY CONTROL ALGORITHMS

This Appendix is intended to provide details and/or examples of QC algorithms beyond what is covered in the main sections of the Handbook. The most important EQC algorithms are covered, as are some others that are to complex to be discussed in the main sections of the Handbook.

<u>Perform "Transmission Parity Error" Checks:</u> **T and W Flags**

Check for errors in continuous winds portion of the raw GOES message and "T" flag individual measurements with errors.

If more than one error is encountered in the continuous winds "T" flag all continuous wind measurements from both sensors.

For non-WPM wave systems, if an error is encountered anywhere in the waves portion, "T" flag all waves.

For WPM systems, "W" flag all wave related measurements if the wave message is short, there is a checksum error, or parity errors are detected.

<u>Perform Time Continuity Check</u> **V Flag**

Checks the amount of change in each measurement's value over the given time period ("V" flag). This is done by computing the amount of change between the current value and the last good value and then comparing this change to the time continuity limit and delta time for that measurement. Following is the algorithm used for time continuity:

```
delta_time = (last good time - current time)
delta_value = ABS(last good value - current value)
if an ADCP station and a horizontal water current velocity measurement (UV0xx,VV0xx) then
        if (delta_time = 1) then
                if (delta_value > 13.14) set the "V" flag
                else if (delta_value > 11.26) set the "f" flag
        else if (delta_time = 2) then
                if (delta_value > 19.35) set the "V" flag
                else if (delta_value > 16.59) set the "f" flag
        else if (delta_time = 3) then
                if (delta_value > 24.96) set the "V" flag
                else if (delta_value > 21.39) set the "f" flag
        end if
        last_good_value = current_value
        last_good_time = current_time
else if meas_id = RH then
        change_limit = .58 * nws_time_cont * SQRT(delta_time)
        delta_wdir = ABS(current_wdir - last_good_wdir)
        delta_atmp = ABS(current_atmp - last_good_atmp)
        if ( delta_value > change_limt) and (WSPD < 4 m/s) and
          (delta_wdir < 90) and (delta_atmp < 2) then set "V" flag
else
        if (delta_time > 3) then delta_time = 3
        change_limit = .58 * nws_time_cont * SQRT(delta_time)
```

```
        if (delta_value > change_limit) then set the "V" flag
end if
```

Perform the above for all measurements, unless storm limits evoked, in this order {sea lvl. press. or sta. press., wind spd., wind dir., air temp., water temp., waves}. If sea level pressure fails either the V or L check, also flag station pressure. If sea level pressure can’t be calculated because of a missing air temp., perform the check on the station pressure. Provision is made to consider the possibility of frontal passage in the case of relative humidity (RH).

Perform the following time continuity rechecks for time continuity flagged (V) data:

If the sea level pressure time continuity fails, pass it if the sea level pressure for both the current hour and the last acceptable hour is less than 1000 hPa.
If the wind speed time continuity fails, pass it if the sea level pressure for the current hour or the last acceptable hour is less than 995 hPa.
If the air temperature time continuity fails, pass it if either of the following conditions are met:
- The wind speed is greater than 7 m/s.
- The wind direction changes by more than 40 degrees since the last acceptable report and the current wind speed is at least 4 m/s.

If the wave height time continuity fails, pass it if the wind speed is greater than 15 m/s.

<u>Range Check</u> **L Flag**

Checks the Range Limits for each measurement. If the measurement's value is below the lower limit or above the upper limit then set the "L" flag for that measurement. Battery voltage is checked for a value less than 10.5 (volts). This condition has caused the barometric pressure(s) (BARO1 and/or BARO2) to report incorrect values. If the battery voltage is below the 10.5 minimum, an "R" flag will be placed on the BAROs.

```
If measurement != (.NE.) V flagged:
  If m={sea lvl. press., sta. press., air temp., water temp.}:
        If measurement < lower limit or measurement > upper limit:
              If measurement was either V or L flagged for the previous report:
                    L Flag the measurement
              End If
        End if
  Else if m = {wind speed, dom. Wave pd., sig. wave ht.}:
        If measurement > upper limit:
              If measurement was either V or L flagged for the previous report:
                    L Flag the measurement
              End If
        End if
  End If
```

<u>Repeat Flag Validation Section</u> **D Flag**

The Repeat Flag Validation algorithm sets the “D” flag for any measurement that has been V/L flagged for two consecutive hours.

```
If a measurement is either L or V flagged and was either V or L flagged for the previous report:
        Set the delete flag for that measurement to withhold it from further release.
End If
```

Duplicate Sensor Validation Section **H Flag**

Wind Direction Check

```
If both directions and at least one speed are working[2] and at least one speed is > 2.5 m/s:
   Compute difference between wind directions.
            If this difference > 25°[2], and at least one speed from the previous report[3] is > 2.5 m/s:
                        Compute differences of wind direction for both sensors from previous report
                        If sensor with smallest difference is #2 hierarchy for wind direction:
                                   Switch hierarchies[4] for both regular & continuous winds.
                        End If
            End If
End If
```

Wind Speed Check

```
If both wind speeds are working:
   Compute difference between two wind speeds:
            If the difference is > 1.5 m/s:
                        If sensor with highest speed is #2 hierarchy for wind speeds:
                                   Switch hierarchies[4] for both regular & continuous wind speeds and wind gusts
                        End If
            End If
End If
```

Sea Level Pressure Check

```
If both sea level pressures (SLPs) are working:
   PressDif = ABS(BARO1 - BARO2)
Else If both station pressures are working:
   PressDif = ABS(SBAR1 - SBAR2) ; SBAR is Sta. Press.
Else
   PressDif = -99
End If
If PressDif != -99:
   If PressDif > 1.0 hPa:
            If sensor with lowest pressure difference since last report is #2 hierarchy:
                        Switch hierarchies for SLP and SBAR
            End If
   End If
End If
```

---

[2] Working means that the measurement is not “D” flagged, nor has the measurement been “L” or “V” flagged by the just-completed range limits and time continuity checks.

[2] Tolerances that are italicized must be made region-specific.

[3] Previous report means last previously working report if it happened in the last 3 hours.

[4] Report the lower hierarchy (backup) sensor and continue to report the backup for ensuing reports.

Gust-to-Speed Ratio Test **g flag**

Perform this check to validate both the standard wind gust and the maximum hourly gust. First, compare the standard (8 minute or 2 minute averaged) wind speed, WSPD , to the wind gust, GUST, measured in that time period. Then, if a station is equipped with continuous winds, use this algorithm to compare the highest gust during an hour (let GUST = MXGT) to the average wind speed in an hour (let WSPD = AVGSPD).

```
GZERO = 1.98 - ( 1.887*exp(-0.18*GUST))
RATIOMAX = 1.5 + (1.0/GZERO)
RATIO = GUST/WSPD
        If (WSPD < 0.3) then
        RATIOMAX = RATIOMAX + 5.0
        Else If ( WSPD < 1.0) then
        RATIOMAX = RATIOMAX + 3.0
        Else If ( WSPD < 3.0) then
        RATIOMAX = RATIOMAX + 0.7
        Else If ( WSPD < 6.0) then
        RATIOMAX = RATIOMAX + 0.35
        Else
        RATIOMAX = RATIOMAX + 0.2
        End If

If RATIO > RATIOMAX flag with a g
If RATIO <= 0.9 flag with a g
```

Continuous Winds Speed Validation Algorithm **i Flag**

The only continuous wind speed validated is the single, 10-minute average continuous wind speed (CWS) whose time interval includes the 2- or 8-minute averaged standard wind speed (WSPD).

If standard wind speed averaging interval is greater than or equal to 8 minutes and the Met. acquisition time ends at minute 50 (typically a buoy):

"i" flag CWS if the absolute difference between CWS and WSPD exceeds 2.0 m/s.

Else If the Met. acquisition time ends at minute 0 (typically a C-MAN station):

"i" flag CWS if the absolute difference between CWS and WSPD exceeds 3.0 m/s

Otherwise: Don't check

NCEP Fields **n Flag**

Comparing NDBC measurements with NCEP fields interpolated to station location is a powerful way to identify sensor degradation. Though the checks are essentially range checks, some of the checks have range limits that vary in a simple manner with geography and values of other measurements.

For the following NCEP-produced 6-hour forecast fields, valid at 00, 06, 12, and 18Z, calculate the **absolute value** of the difference: (interpolated value - the measurement):

Sea Level Pressure

Pressure variation at low latitudes is less than at high latitudes. Model performance is better in areas of high pressure where there is less of a gradient.

```
If Latitude < 30 degrees:
        If difference > 2.5 hPa: Flag
Else:
        If Obs. Sea Lvl. Pressure > 1008 hPa:
                If difference > 2.5 hPa: Flag
        Else If Obs. Sea Lvl. Pressure > 995 hPa:
                If difference > 4.0 hPa: Flag
        Else:
                If difference > 6 hPa: Flag
        End If
End If
```

Air Temperature

Near the West Coast model performance is sometimes poor because of the tight temperature gradients between the sea and nearby inland areas.

```
If Longitude > 110 W and < 129W:
        If difference > 10°C .OR. difference < -5 °C:
                Flag
Else:
        If ABS (difference) > 3.0°C:
                Flag
End If
```

Sea Surface Temperature

```
If difference > 4.0°C:
        Flag
```

Wind Direction

Check is not applied in light wind speeds, because direction is often variable. Tolerance increases with higher wind speed, to a point. Observed wind speeds are adjusted to 10 m.

```
A = Min {model wind speed, observed wind speed extrapolated to 10m}

If A > 10 m/s:
        If difference > 30°:
                Flag
Else If A > 5 m/s:
        Tolerance = (A - 15.6) / (-0.188)
        If difference > Tolerance:
                Flag
End If
```

Wind Speed

Tolerance increases with higher wind speeds. Uses the same variable A as wind direction.

If A > 12.35 m/s
If difference > 2.25 m/s:
Flag
Else If A > 6 m/s:
Tolerance = (A -16.1) / (-1.67)
If difference > Tolerance:
Flag
Else If Obs. Sped. < 6 m/s:
If difference > 5 m/s:
Flag
End If

Wave Height Time Continuity **f Flag**

If a one hour time difference between measurements
TOL = (WVHGT $_{(t-1)}$) + 0.9)/3.92
End If
If a two hour time difference between measurements
TOL = 1.41 * the last hourly TOL
End If
If time difference $\leq$ 2 then
If ABS(WVHGT$_{(t)}$-WVHGT$_{(t-1)}$)) > TOL then
Flag = on
Else
End If

where

t	is the current hour
t-1	is the previous hour
TOL	is the allowable tolerance

For stations that report half-hourly, compute hourly time differences using the observation before the last one.

Wind Direction & Wave Direction Agreement **w Flag**

This algorithm proposes that the wave direction at 0.35 Hz and the primary wind direction should agree within 25˚ provided that the primary wind speed is greater than 7 m/s, the wind direction is constant, and wave energy (at 0.35 Hz) is not nominal.

If WSPD > 7 M/S & ABS(ΔWDIR) < 30˚ & C_{11}(0.35,t) > 0.003 m^2/hz
If ABS(ALPHA1(0.35) - WDIR) > 25 then
Flag = on for ALPHA1
End If
End If

where

AWDIR	is the change in wind direction since last hour
ALPHA1	is the mean wave direction
C_{11}(0.35,t)	is the wave energy (at 0.35 Hz) at time “t”

Bow Azimuth & Wind Direction Agreement **z Flag**

This algorithm, for 3-meter discus buoys (only) proposes that the mean buoy bow azimuth and the primary wind direction should agree within 25˚. The database will have to have the hull diameter.

```
If Diameter = 3 m & WSPD > 7 M/S then
        If ABS(BOWAZ - WDIR) > 25 then
                Flag both FWDIR & WDIR
        End If
End If
```

where

BOWAZ is the buoy azimuth angle
DIAMETER is diameter of the buoy hull

Water Level Time Continuity Algorithm **f Flag**

The algorithm is based on the standard Time Continuity Check discussed in Section 4 of the Handbook which calculates an allowable deviation between successive measurements:

$$\sigma_\tau = 0.58\ \sigma\ \mathrm{sqrt}(\tau)$$

where

- σ_τ is the allowable water level change between sensors
- σ is the standard deviation of an ensemble of water level data
- τ is the time delta (in hours) between measurements.

The above equation was modified to quality control water level. The only modification necessary is to calculate the appropriate σ value. One year of water level data from several stations indicated an average value of 0.81 for σ. In testing the above algorithms, it was found that many data points would have been flagged erroneously due to small τ values (6-minutes or 0.10 hours). Therefore, the algorithm was modified as follows to accommodate small time deltas:

$$\sigma_\tau = 0.58\ 3\sigma\ \mathrm{sqrt}(\tau)$$

For a six-minute time delta and σ equal to 0.81, this equation allows a maximum change in water level of 0.45 feet. This is a reasonable 6-minute change in water level. If the measurement fails the tolerance, the “f” flag is set.

Humidity versus Visibility Check **v Flag**

Flag observations when the where the visibility appears high:

$$V > 3\,(Ta - Td) + 4, \text{ and } (Ta - Td) < 1$$

And in the low visibility case when:

$$V < .5\,(Ta - Td) - 1, \text{ and } 4 < (Ta - Td) < 10 \text{ or,}$$

$$V < 4, \text{ and } (Ta - Td) > 10$$

Where V is visibility in nm, Ta is air temperature, and Td is dew-point temperature in deg C.

APPENDIX E

QUALITY CONTROL FLAGS

EQC Hard Flags (by hierarchy - highest to lowest):

T Transmission parity error (Applies to continuous winds and non-WPM wave data).

M Missing sensor data (A result of a garbled or missing message).

W A WPM wave message is short, missing a checksum, or parity errors are detected.

E Calculation limits are exceeded or are in error (waves only, flags WVHGT).

D Delete measurement from release and archive (A Data Analyst or automated QC has failed the sensor).

S Invalid statistical parameter (in waves, QMEAN is not between QMIN and QMAX, flags WVHGT).

V Failed time continuity.

L Failed range limits.

H Hierarchy reversal has occurred (BARO, WSPD, WDIR only).

R A related measurement has failed a hard QC check.

Small Flags (in alphabetical order)

a Measurement is above monthly, regional limit.

b Measurement is below monthly, regional limit.

c Measurement has been adjusted, or corrected (applies to DEWPT and WVHGT, DOMPD and AVGPD).

d Failed standard deviation test (continuous winds only).

f Measurement failed hourly time continuity.

g Failed gust-to-mean wind speed ratio (applies to standard and continuous winds).

i Continuous and hourly wind speeds don't agree.

j One, and only one, transmission error detected in the continuous wind string of a GOES message (all continuous wind measurements are flagged, if more than one error detected, than flag is upgraded to a **T** flag).

k Difference between duplicate measurements is too high.

m High frequency spikes detected in the wave spectrum (C_{11}), WVHGT is flagged.

n Measurement failed comparison with NCEP model fields.

p Failed wave height to wave period comparison test.

q Swell direction is from an improbable direction.

r Related measurement failed (continuous winds only).

s Stuck raw compass (RCOMP and WDIR are flagged).

t Tendency difference between duplicate sensors is too high.

v Failed relative humidity verses visibility check.

w Failed wind direction verses wave direction check.

x Wind wave energy is too high for prevailing wind speed.

y Wind wave energy is too low for prevailing wind speed.

z Failed bow azimuth verses wind direction check.

APPENDIX F

TABLES RELATING FLAGS TO GRAPHICS

Tables F1 and F2 define plots that are graphed upon certain flagging situations. Across the top is a listing of measurements. The letters that follow in the column are a list of individual character flags (defined in Section 4.2) corresponding to that measurement. The left hand side of the table corresponds to specific plots which are made for the measurement/flag combination. Generally, graphics depicting the past seventy-two hours of data will be sufficient for the DQA to determine the validity of a measurement.

Table F1 describes relevant time-series plots based upon the flag present for the measurement being analyzed. A description of the plots are as follows:

- TS PLOT is a time series plot of the flagged measurement.
- DUPL SNSR is a plot of the measurement if a dual sensor is installed on the same payload.
- DIFF PYLD is a plot of the measurement from the dual payload if a dual payload is installed.
- NCEP is a plot of the corresponding NCEP-model field (grib data).
- NEAR STN is a plot of the measurement observed at the nearest station in the same region. A database is available of station specific, relevant nearby stations.
- WW PLOT is a wind-wave plot of the summation of wave energy from 0.30 through 0.35 Hz (y-axis) versus the square of the wind speed (x-axis) as defined by the algorithm "Wind-Wave QC Procedure."
- G/W PLOT is a plot of the gust-to-wind ratio of the payload.

Table F2 contains time-series plots used to assist the data analyst in the determination of a passing frontal or low pressure system. A description of the plots is as follows:

- ATMP is a plot of the air temp.
- WTMP is a plot of the water temp.
- BARO is a plot of baro. pressure.
- WSPD is a plot of the wind speed.
- WDIR is a plot of the wind.
- GUST is a plot of the wind gust.
- CWND is a plot of the continuous wind data.
- WVHGT is a plot of the significant wave height.
- AVGPD is a plot of the average wave period.
- DOMPD is a plot of the dominant wave period.
- DEWPT is a plot of the dew point temperature.

- VIS is a plot of the visibility.
- BATT is a plot of the battery voltage.

TABLE F1
MEASUREMENTS

SPECIFIC DATA QUALITY PLOT COMBINATIONS

	ATMP	WTMP	BARO	WSPD	WDIR	GUST	CWND	WVHGT	AVGPD	DOMPD	MWDIR	DEWPT	VIS	TIDE
TS PLOT	LV abf knt	LV abfn	HLV abf knt	HLV afg knt	H knstz	L gkt	L dir	ELS VW afmq xy	ELV W p	ELV W af	w	LV cv	v	LV f
DUPL SNSR	LV abf knt		HLV abf knt	HLV afg knt	H kntz	L gkt	L dir					LV cv		
DIFF PYLD	LV abf knt	LV abfn	HLV abf knt	HLV afg knt	H kntz	L gkt	L dir	ELS VW afmq xy	ELV W p	ELV W af	w	LV cv		
NCEP	LV abf knt	LV abfn	HLV abf knt	HLV afg knt	H knt			ELS VW afmq xy	ELV W p	ELV W af				
NEAR STN	LV abf knt	LVab fnt	HLV abf knt	HLV afg knt	H knt	L gkt	L dir	ELS VW afmq xy	ELV W p	ELV W af		LV cv		f
WW PLOT								ES amxy						
G/W PLOT						L gkt		ES mxy						

TABLE F2
MEASUREMENTS

INDIVIDUAL TIME SERIES PLOTS

	ATMP	WTMP	BARO	WSPD	WDIR	GUST	WVHGT	AVGPD	DOMPD	MWDIR	DEWPT	VIS	TIDE
ATMP		LV abf	LV abf	LV af		L	LV afxy	LV	LV af		LRV c	v	
WTMP	LV abf										LV c	v	
BARO	LV abf			LV af		L	LV afxy	LV	LV af				
WSPD	LV abf	LV abf	LV abf			L g	LV afm qxy	LV	LV af	w	LV c	v	f
WDIR	LV abf	LV abf	LV abf	LV af		L	LV afm qxy	LV	LV af	w	LV c	v	f
GUST				LV af									
CWND				LV af		L							
WVHGT				LV af				ELV W	ELV W a	w			
AVGPD							ELSV W abmx y		ELV W a				
DOMPD							ELSV W abmx y	ELV W					
MWDIR					w								
DEWPT	LV abf											v	
VIS											LV c		
BATT			R										
FWDIR					z								
RCOMP					s								