The Man–Machine Mix in Operational Product Quality Control and Verification at Fleet Numerical Oceanography Center

WILLIAM M. CLUNE

Fleet Numerical Oceanography Center, Monterey, California

PATRICK A. HARR

Department of Meteorology, Naval Postgraduate School, Monterey, California

L. ROBIN BRODY

Naval Oceanographic and Atmospheric Research Laboratory, Monterey, California

(Manuscript received 25 February 1991, in final form 29 January 1992)

ABSTRACT

The Quality Control (QC) Division of the U.S. Navy's Fleet Numerical Oceanography Center (FNOC) is responsible for the quality control of meteorological and oceanographic analyses and forecasts issued to operational users, and for the verification of FNOC numerical model products.

The FNOC QC Division ensures the quality and consistency of data to be included in the meteorological and oceanographic analyses, adding artificial data ("bogus technique") when needed in sparse areas or in cases of significant discrepancies. Bogus data from various sources have a direct effect on the optimum interpolation analyses for the global forecast model and are used to modify the marine wind field, the spectral wave model, the upper-level winds for the Optimum Path Aircraft Routing System, and tropical cyclone warnings. Bogus sea surface temperature data are used to enhance the FNOC ocean thermal structure analysis.

The FNOC QC performs model verifications on a daily, monthly, and seasonal basis, providing a statistical summary of the performance of the meteorological and oceanographic models and identifying their strengths and weaknesses.

1. Introduction

Operational product quality control and verification are important functions at Fleet Numerical Oceanography Center (FNOC). The Quality Control (QC) Division is required to maintain product reliability and assure credibility of the global and regional meteorological and oceanographic analyses and forecasts for operational fleet users. The man–machine mix is an intrinsic part of the FNOC watch organization as described in the FNOC Quality Control Division Standard Operating Procedures Manual (FNOC 1991). The more important aspects of the mixture are highlighted in this paper.

The U.S. Navy's requirements for environmental analyses and forecasts are complex and diverse. Therefore, many of the products and approaches to the quality control of these products are not found at other operational centers. Part of the diversity stems from the fact that fleet units are positioned globally. In many cases the standard observation network is very sparse and cannot support the high resolution of the required analyses and forecast information. Therefore, enhancement of the operational analyses through the use of bogus procedures (i.e., the creation of artificial data) has always been an important aspect in the quality control of FNOC products. FNOC's philosophy has been to maintain some human control over bogus procedures. Bogus data from fleet users are used to enhance the observational network in data-sparse regions. Because of the great diversity in operational products that are monitored by the QC Division, personnel must be familiar with many aspects of the environmental conditions over large portions of the globe. Several of these diverse responsibilities are explained in sections 2 and 3.

Another function of the QC Division is to constantly monitor the performance of the numerical Navy Operational Global Atmospheric Prediction System (NOGAPS), Navy Operational Regional Atmospheric Prediction System (NORAPS), and Global Spectral Ocean Wave Model (GSOWM) forecast products. This important function is achieved by assessing the operational usefulness of the forecasts. Past and current

Corresponding author address: William M. Clune, FNOC, Quality Control Division, Monterey, CA 93943.

NOGAPS, NORAPS, and GSOWM model performance is described in terms that are operationally relevant. These verification reports of the global and regional weather forecast models are discussed in section 4.

2. Meteorological products quality control

The FNOC QC Division utilizes observations, analyses, and satellite cloud interpretation to evaluate the weather conditions over the world's ocean areas on a continuous and routine basis and monitor regional naval oceanography center wind and high seas warnings.

Accurate, timely data analyses are critical to the skill of numerical forecast models. Bogusing, the development of artificial data, is a technique used to improve analyses in situations where comparisons with observations and/or satellite images suggest that model analysis discrepancies are evident. Such discrepancies are usually due to sparse, erroneous, or missing data. However, meteorologically inconsistent or incorrect bogus can be as harmful to analysis models as erroneous observational data.

A procedure file named BOGUS is the primary tool used to apply quality control procedures to meteorological analyses and forecast products. The BOGUS procedure is executed from an interactive remote terminal from which additions, deletions, changes, and corrections are made to the BOGUS record file contained in the primary operational computer.

During the normal watch period, the BOGUS record is reviewed and updated as necessary. Information entered into the BOGUS record has a direct influence on the operational global optimum interpretation analysis (Goerss and Phoebus 1992), marine wind field, spectral wave models, and upper-level forecast winds used by the Optimum Path Aircraft Routing System (OPARS) (FNOC 1986). The QC Division modifies the OI sea level pressure (SLP) analyses, marine wind analysis, and input tropical cyclone warnings using some 15 BOGUS-record options.

a. Sea level pressure and wind bogus

During a normal operational cycle, a surface analysis is available at the preliminary and final data cutoff times in both gridpoint and graphical form. These are examined for potential position errors of individual ship reports. When examining the Northern and Southern Hemisphere SLP analyses, emphasis is placed on maintaining the proper continuity of pressure systems, detecting developing systems and compatibility of the wind field. Errors are corrected by forcing the acceptance of rejected reports, rejecting erroneous reports, or by modifying reports from both ships and land stations. Current satellite imagery and forecasts for the areas in question are used extensively. Erroneous ship and land reports are deleted in areas where surrounding data accurately describe the pressure and wind fields. In regions of sparse data, deepening low pressure systems tend to be weak in the FNOC OI analysis. Bogus is therefore used to maintain the central pressure of these features, using satellite imagery interpretation techniques found in Parke (1986) and Weldon and Holmes (1991).

Figures 1 and 2 illustrate the effect of a central pressure bogus to the final OI analysis. The preliminary North Pacific Ocean OI SLP analysis depicted a deep low near 50°N, 178°W at 1200 UTC 06 September 1991 (Fig. 1) with a central pressure of 984 mb. However, satellite imagery indicated a lower central pressure and a location near 51°N, 179°W. A bogus entry of 980 mb was converted by the procedure (Goerss 1989) to a set of eight wind observations shown surrounding the low center. The final OI analysis, shown in Fig. 2, illustrates the impact of the bogus in this system.

b. Tropical cyclone bogus

Tropical cyclone warnings are entered into the QC bogus file whenever a new warning is received from regional naval oceanography centers. Tropical cyclone warnings are issued by the Joint Typhoon Warning Center (JTWC), described by Guard et al. (1992), collocated with the Naval Oceanography Command Center (NOCC), Guam, for the Pacific Ocean west of 180° longitude, and the Indian Ocean. The Naval Western Oceanography Command (NWOC), Pearl Harbor, Hawaii, disseminates tropical cyclone warnings for the Pacific Ocean east of 180°, while the Naval Eastern Oceanography Command (NEOC), Norfolk, Virginia, issues tropical cyclone warnings for the North Atlantic Ocean, including the Gulf of Mexico and Caribbean Sea.

The purpose of the tropical cyclone bogus input is to create synthetic surface and upper-air observations to 400 mb, to be assimilated into the operational global OI analysis as described by Goerss and Phoebus (1992). The tropical cyclone bogus program accepts input from warnings issued on tropical cyclones that have an intensity of 34 kt or higher. Elements of the warning message include position, maximum sustained wind speed, and radius of 50- and 30-kt wind speeds, depending on the tropical cyclone's strength, as described by Goerss et al. (1991).

Figures 3 and 4 show the effect of a tropical cyclone bogus to the final OI SLP analysis. At 1200 UTC 16 July 1990, Hurricane Genevieve was located at 22.4°N, 120.4°W, with maximum sustained winds of 65 kt (box A). The preliminary OI SLP analyzed a poorly defined and misplaced circulation southwest of Baja California (Fig. 3). The OI SLP analysis was modified by the tropical cyclone bogus program, using the warning to improve the horizontal and vertical structure within the OI analysis at the Hurricane Genevieve warning position. The effect of the bogus on the final OI SLP

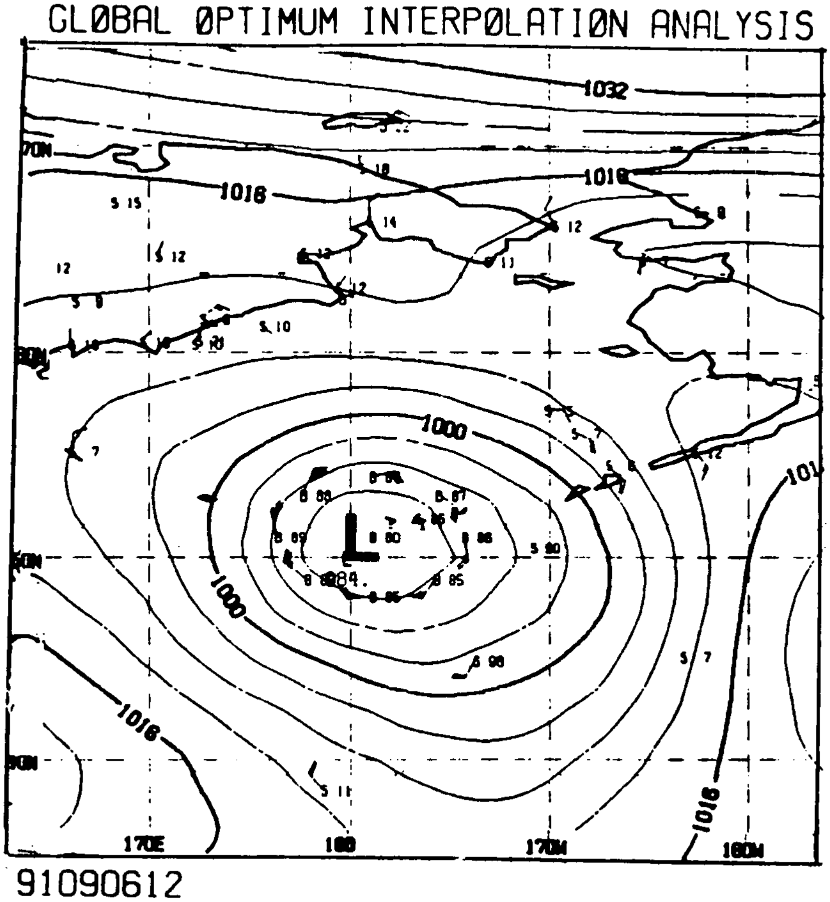

FIG. 1. Preliminary optimum interpolation sea level pressure analysis with bogus wind reports for gale low at 51°N, 179°W, 1200 UTC 06 September 1991.

analysis is shown in Fig. 4, and provides a more correct representation of Hurricane Genevieve, which ultimately helps to improve the NOGAPS model's skill in forecasting tropical cyclones.

FNOC is also responsible for generating the Department of Defense (DOD) tropical cyclone wind speed probability and strike probability (WINDP/STRIKP), and Department of State (DOS) tropical cyclone threat index messages. WINDP/STRIKP messages are prepared for all tropical cyclones. The messages provide an instantaneous and accumulated probability of 30- and 50-kt wind speeds during the time span of the tropical cyclone (TC) warning, usually extending out to 72 h. This product is provided to all threatened DOD activities.

In addition to the WINDP/STRIKP messages, the DOS is interested in identification of populated coastal regions where the potential for death, injury, and damage from tropical cyclones is high. The navy, with the cooperation of the DOS Office of Foreign Disaster Assistance, has developed a series of computer models that interpret tropical cyclone forecasts and warnings in terms of potential threat indices and their economic cost (as described in NEPRF 1982). The state department messages provide a quantitative and qualitative evaluation of the latest TC warning and its potential threat to specific geographic locations in the tropical cyclone's forecast path and ocean basin.

c. *Tropical cyclone forecast models*

Quality Control personnel oversee the running of the tropical cyclone forecast models at FNOC. These provide tropical cyclone forecast support to the regional forecast centers at Guam, Pearl Harbor, and Norfolk. Two models are run: the operational One-Way Interactive Tropical Cyclone Model (OTCM) and a regional Tropical Cyclone Forecast Model for the western Pacific. The latter is a tropical western Pacific version of the NORAPS as described by Bayler and Lewit (1992).

The OTCM is executed in response to a request from JTWC or other regional ocean center. This model is initialized using the latest analysis position and 6-, 12-, or 18-h forecast fields as described by Harrison and Elsberry (1972). The OTCM output is a graphic and alphanumeric message of forecast track.

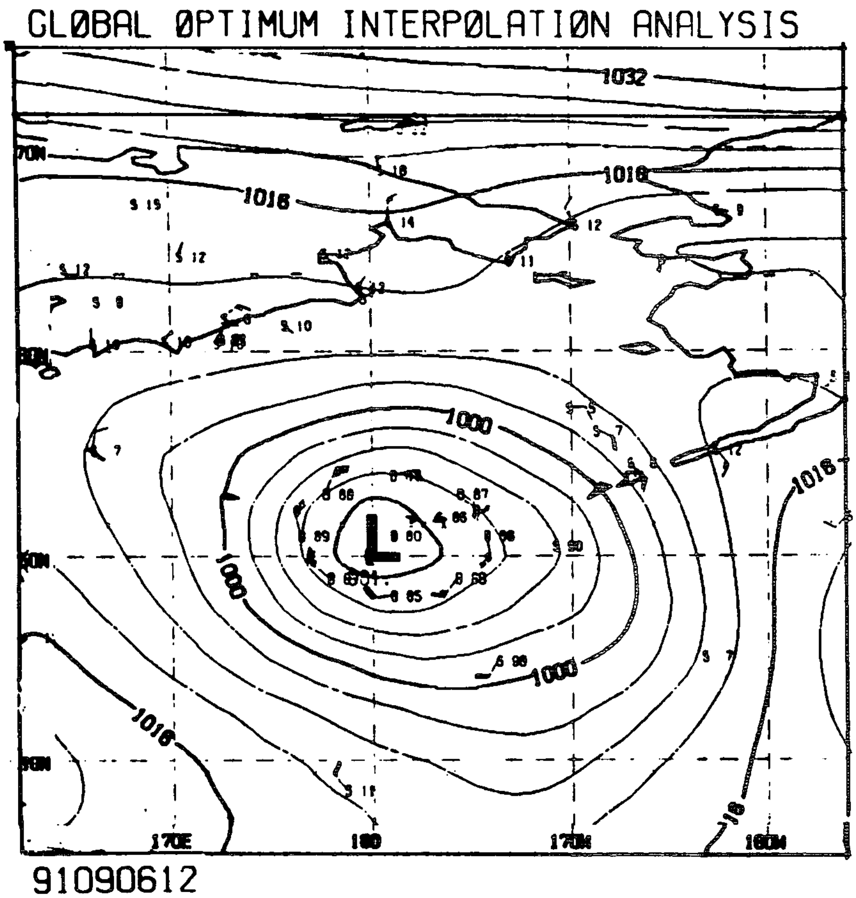

FIG. 2. Final optimum interpolation sea level pressure analysis with bogus wind reports for gale low at 51°N, 179°W, 1200 UTC 06 September 1991.

d. Global Spectral Ocean Wave Model

Current quality control efforts for the Global Spectral Ocean Wave Model emphasize the surface wind analysis input to the NOGAPS model wind's atmospheric planetary boundary layer (PBL) package, which is coupled to the GSOWM analysis and prediction portion of the operational run as described by Clancy et al. (1986, 1992). Quality Control watch personnel also evaluate GSOWM output analyses and forecasts for unreasonable values. This correction effort is aimed at catching erroneous observations or SLP gradient information in the wind analysis.

e. Upper-level wind bogus

The QC Division is responsible for the operational evaluation, verification, and modification of the upper-level forecast wind speed fields used by OPARS. Areas of possible wind speed forecast errors are located by correlating and projecting past forecast errors to the new 300-mb analysis and forecast series. Wind speed forecast errors from the previous forecast sequence are located using the current 300-mb wind speed analysis and verifying reports, along with the previous 12-h, 300-mb wind speed forecast. The past wind speed errors are further evaluated against the current 300-mb analysis and the new 12-h, 300-mb wind speed forecast to see if the previously verified errors are continuing. The 300-mb forecast fields are then modified using an option in the BOGUS procedure. Modifications made at the 300-mb level affect the layer between 500 and 100 mb by adjusting the wind speed linearly from the center out to the boundary, as described in chapter 6 of FNOC (1991).

3. Oceanographic products quality control

The Ocean Services branch of the Quality Control Division is responsible for monitoring ship and bathythermograph (BT) observations, the correction and reentry of rejected BT reports, and the maintenance of the ocean bogus file.

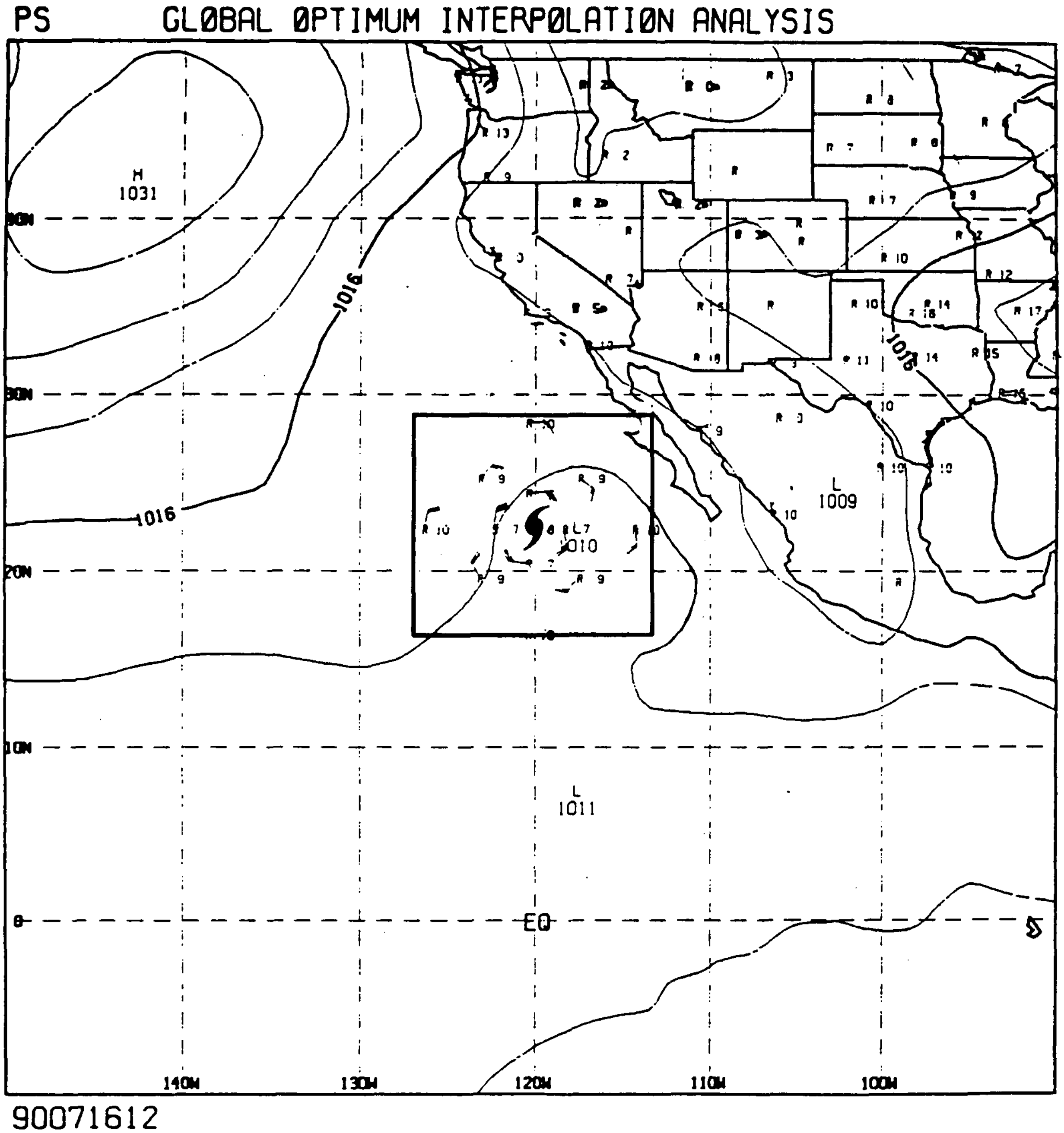

FIG. 3. Preliminary optimum interpolation sea level pressure analysis with bogus wind reports (box A) for Hurricane Genevieve at 22°N, 120°W, 1200 UTC 16 July 1990.

The quality of each synoptic ship observation received via the Automatic Digital Information Network (AUTODIN), and all U.S. Navy and Coast Guard BT observations, are summarized in statistical reports. These reports are monitored daily to identify units with consistent reporting errors, so that corrective action may be taken. Additionally, monthly summaries for ship and BT observations are distributed to navy regional oceanography centers and the fleet.

All BT observations received at FNOC pass through the Ocean Automated Data Processing (OCNADP) quality control software. One-third of the BT observations contain some type of error. The most common BT reporting errors are found in format, position, and

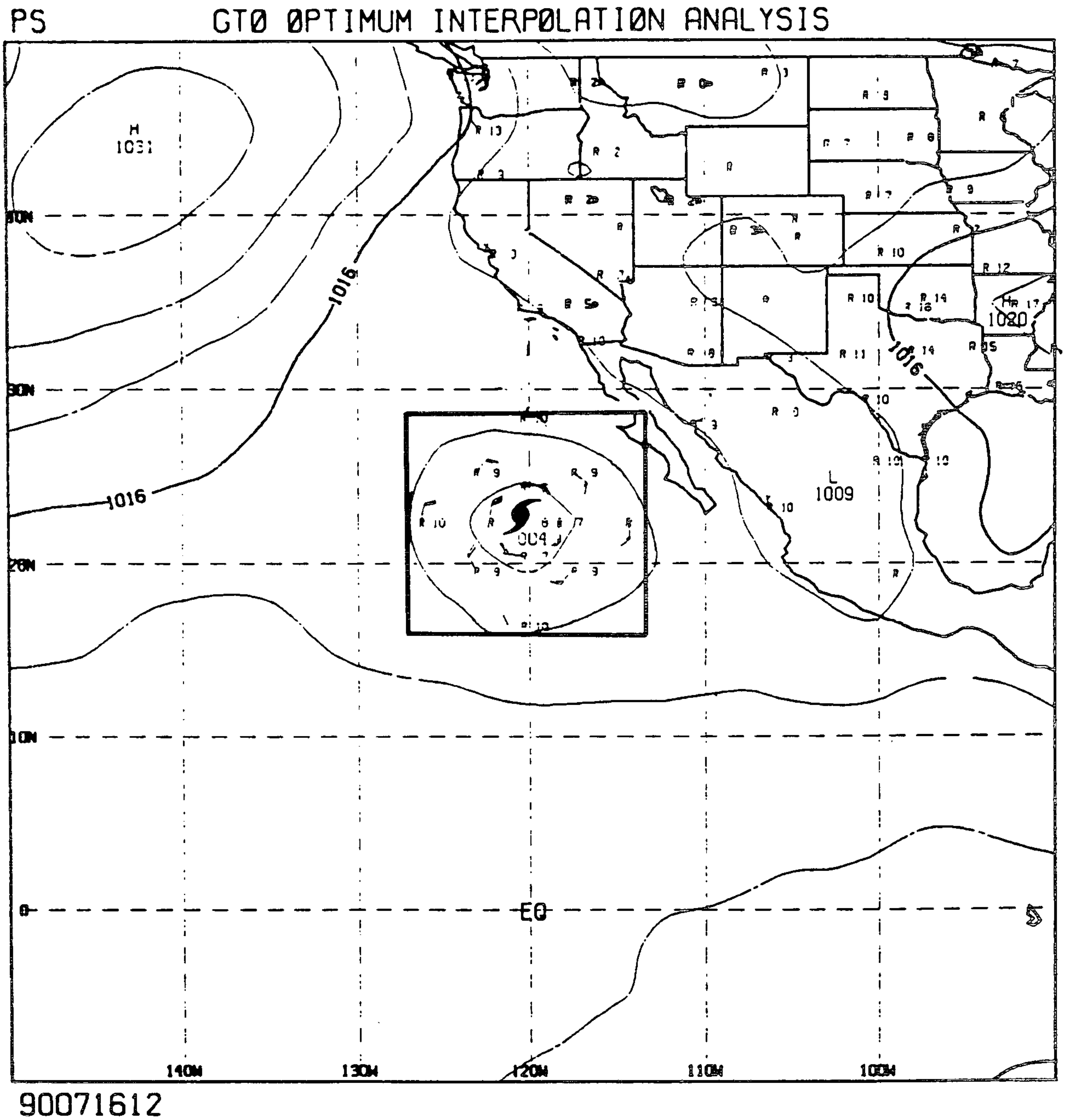

FIG. 4. Final optimum interpolation sea level pressure analysis with bogus wind reports (box A) for Hurricane Genevieve at 22°N, 120°W, 1200 UTC 16 July 1990.

date–time group. Some of the errors are automatically corrected by OCNADP, chiefly by truncation.

The majority of the reporting errors are passed to Ocean Services for correction using the Quality Improvement Profile System (QUIPS) interactive software. Using QUIPS, Ocean Services is able to salvage 90% of the originally rejected BT observations. QUIPS-corrected BTs again pass through the OCNADP software before being added to the database. This is to ensure no errors remain or have been introduced in the quality control process. All BT observations are further quality controlled within each of the oceanographic analysis programs.

An ocean bogus system became operational on 1 February 1990. Under this system, the Naval Oceanography Office in Bay St. Louis, Mississippi, using high-resolution infrared imagery and input from navy regional ocean centers, provides ocean fronts and eddies bogus data to the regional Optimum Thermal Interpolation System and the Expanded Ocean Thermal Structure analyses (Clancy and Sadler 1992). Triggered by the incoming AUTODIN bogus messages, an automated decoder, quality control, and file-maintenance program keep the ocean bogus files current. Ocean QC personnel ensure the ocean bogus files are correct and perform manual quality control using interactive software.

4. Numerical weather forecast verification

FNOC requires a verification system that provides Navy Oceanographic Command forecasters with information that helps them identify strengths and weaknesses of the FNOC model forecasts. Secondly, traditional statistical measures of forecast performance are maintained for comparative evaluations of model performance.

A forecast verification system that conveys performance characteristics of operationally relevant parameters increases the utility of the product to the forecaster. To achieve this, the forecast verification process covers the following time scales:

1) *Daily:* Results of NOGAPS/NORAPS model performance and forecast evaluation of active SLP cyclones over the North Pacific and Atlantic oceans are provided daily in the QC Model Summary Bulletin messages available on the Automated Weather Network and the Naval Environmental Data Display Station.

2) *Monthly:* Summaries of all North Pacific and Atlantic Ocean SLP cyclones automatically tracked by NOGAPS within each month over the Pacific and Atlantic oceans are supplied to each command center via the FNOC QC Monthly Summary.

3) *Seasonal:* A combination of statistically derived performance data and the SLP cyclone summaries for the North Pacific and Atlantic oceans valid for each season are summarized in the FNOC Quarterly Performance Summary. The expected NOGAPS/NORAPS model tendencies for the coming season are also provided.

Statistical analyses of the corresponding model forecasts and analyzed data are important performance measurements of many aspects of a numerical model verification. FNOC routinely produces and examines numerical model performance using these types of analyses. However, these indices identify few of the model tendencies concerning the behavior of SLP cyclones that are of obvious importance to the U.S. Navy. Because of this, emphasis has been placed on measuring model skill or improvements by verifying forecasts of SLP cyclone characteristics. The QC Division of FNOC performs a number of operational statistical evaluations designed to determine systematic forecast model errors and model tendencies related to maritime SLP cyclones. This has proven to be beneficial to the navy forecaster, and is used to quickly familiarize personnel with model forecast characteristics when they are assigned to a new duty station.

The technique of vortex tracking developed by Williamson (1981) was adapted to follow analyzed and forecast SLP cyclones. This automated technique, described by Harr et al. (1983), has simplified a once–labor-intensive process of identifying, tracking, and cataloging individual cyclone characteristics and forecasts of these characteristics. The automated verification of sea level cyclone characteristics is only performed for NOGAPS. The movement, deepening, and filling characteristics of the valid maritime cyclones are continually monitored as they are depicted in the global model's analyses and forecasts. This monitoring process determines various operationally important features, including location, timing, and intensity of cyclogenesis, explosive deepening, and cyclolysis.

Model performance data can be produced on an individual cyclone or group of cyclones. Examples of several of the evaluations of model performance concerning SLP cyclones are found in Hogan and Rosmond (1991) and Harr et al. (1992).

5. Summary

The Quality Control Division of FNOC has the responsibility of providing operationally accurate analysis of atmospheric and oceanographic products. The quality control of meteorological analyses consists of BOGUS procedures used to modify the OI surface pressure analysis, marine wind analysis, upper-level wind, and input tropical cyclone warnings.

The quality control of oceanographic analyses consists of monitoring and correcting ship and BT observations. The primary tools used are the OCNADP quality control software and the QUIPS interactive software. Ocean QC personnel are also responsible for ensuring that ocean front and eddy bogus files by NAVOCEANO are correct.

A verification system has been developed that determines FNOC model performance characteristics in a relevant manner for use by operational forecasters. The verification process covers the daily, monthly, and seasonal time ranges, and includes such information as storm track verification as well as cyclone central pressure and displacement errors from NOGAPS and NORAPS. The presentation of this verification information in an operationally relevant manner has aided the quality control process and helped forecasters identify model tendencies and systematic model errors. Furthermore, combinations of these synoptic feature–oriented statistics with traditional field-oriented verification data (i.e., root-mean-square error) provide an effective method of communication between the field forecaster and numerical forecaster.

Acknowledgments. The authors thank Prof. Carlyle Wash, and the reviewers for providing many helpful suggestions and ideas.

The support of the Naval Postgraduate School direct research funding is gratefully acknowledged. NOARL Contribution No. 432:002:92. Approved for public release; distribution unlimited.

REFERENCES

Bayler, G., and H. Lewit, 1992: The navy operational global and regional atmospheric prediction systems at Fleet Numerical Oceanography Center. *Wea. Forecasting,* **7,** 273–279

Clancy, R. M., and W. D. Sadler, 1992: The Fleet Numerical Oceanography Center suite of oceanographic models and products. *Wea. Forecasting,* **7,** 307–327.

——, J. Kaitala, and L. Zambreskey, 1986: The Fleet Numerical Oceanography Center Global Spectral Ocean Wave Model. *Bull. Amer. Meteor. Soc.,* **67,** 498–512.

FNOC, 1986: *Fleet Numerical Oceanography Center's Numerical Environmental Products Manual.* Volumes I and II. Fleet Numerical Oceanography Center, 214 pp. [Available from the Commanding Officer, Fleet Numerical Oceanography Center, Monterey, CA 93943-5005.]

——, 1991: *Fleet Numerical Oceanography Center's Quality Control Division Standard Operating Procedures Manual.* Fleet Numerical Oceanography Center, 195 pp. [Available from the Commanding Officer, Fleet Numerical Oceanography Center, Monterey, CA 93943-5005.]

Goerss, J., 1989: The impact of bogus observations upon the Navy Operational Global Atmospheric Prediction System. Preprints, *Twelfth Conf. Wea. Anal. and Forecasting,* Monterey, CA, Amer. Meteor. Soc., 41–45.

——, and P. A. Phoebus, 1992: The navy's operational atmospheric analysis. *Wea. Forecasting,* **7,** 232–249.

——, L. Brody, and R. Jeffries, 1991: Assimilation of tropical cyclone observations into the Navy Operational Global Atmospheric Prediction System. Preprints, *Ninth Conf. Num. Wea. Prediction,* Denver, Amer. Meteor. Soc., 638–641.

Guard, C. P., L. E. Carr, F. H. Wells, R. A. Jeffries, N. D. Gural, and D. K. Edson, 1992: Joint Typhoon Warning Center and the challenges of multibasin tropical cyclone forecasting. *Wea. Forecasting,* **7,** 328–352.

Harr, P., T. Tsui, and L. Brody, 1983: Model verification statistics tailored for the field forecaster. Preprints, *Eighth Conf. Prob. and Stat. in Atmos. Sci.,* Hot Springs, AR, Amer. Meteor. Soc., 177–180.

——, R. Elsberry, T. Hogan, and W. Clune, 1992: Forecasts of North Pacific maritime cyclones with the navy's operational global atmospheric prediction system. *Wea. Forecasting,* (submitted).

Harrison, E., and R. Elsberry, 1972: A method for incorporating nested finite grids in the solution of systems of geophysical equations. *J. Atmos. Sci.,* **29,** 1235–1245.

Hogan, T., and T. Rosmond, 1991: The description of the Naval Operational Global Atmospheric Prediction System Spectral Forecast Model. *Mon. Wea. Rev.,* **119,** 1786–1815.

NEPRF, 1982: *Department of State Tropical Cyclone Strike, Wind and Storm Surge Probability Warnings.* Naval Environmental Prediction Research Facility, 17 pp. [Available from the Commanding Officer, Naval Oceanographic and Atmospheric Research Laboratory, Monterey, CA 93943-5006.]

Parke, P., 1986: *Satellite Imagery Interpretation for Forecasters.* National Weather Service Handbook No. 6, National Oceanographic and Atmospheric Administration.

Weldon, R., and S. Holmes, 1991: *Water Vapor Imagery: Interpretation and Applications to Weather Analysis and Forecasting.* National Oceanographic and Atmospheric Administration Tech. Rep. No. 57, 213 pp.

Williamson, D. L., 1981: Storm track representation and verification. *Tellus,* **33,** 513–530.