QUALITY CONTROL OF OPERATIONAL PRODUCTS AT FLEET NUMERICAL OCEANOGRAPHY CENTER

by

CAPT J. B. TUPAZ

Based on contributions by:
L. Clarke
W. Clune
J. Goerss
P. Haar
E. Hesse

December 1987

TABLE OF CONTENTS

I. Quality Control and Product Verification

Quality control and product verification are very important and critical functions at FNOC, and are required in order to maintain product reliability and credibility with our operational Fleet users. Man-Machine Quality Control is intrinsically part of the watch organization. Clearly, it is enhanced and nurtured by personnel motivation and pride for excellence. The following sections describe the procedures used to achieve Man-Machine-Mix Quality Control for meteorological and oceanographic products.

Meteorological Products Quality Control

The Quality Control Duty Officer (QCDO) has primary responsibility for product excellence. A procedure file named BOGUS is the primary tool used to apply quality control procedures for meteorological products. Normally the BOGUS procedure is executed from an interactive remote terminal from which the QCDO can make additions, deletions, changes and corrections to the BOGUS record file contained in the primary operational computer.

The QCDO reviews the BOGUS record and alters its contents as necessary as updated information is received or developed. Information in the BOGUS record has a direct influence on the analyses of the global surface pressure, upper air, and spectral wave models. The QCDO can modify the surface pressure, marine wind analyses, and input tropical cyclone warnings using some fifteen available BOGUS-record options.

Surface Pressure and Wind

During a normal operational run, surface analysis information is available to the QCDO in the form of data cuts and surface pressure analyses in both printout and chart form. These data cuts are also examined for individual ship tracks for potential position errors.

When examining the surface pressure analyses charts, emphasis is placed on maintaining continuity of pressure systems, detecting developing systems and checking wind field compatibility. Errors are corrected by forcing the acceptance of rejected reports, rejecting reports or by modifying reports from both ships and land stations. Current satellite imagery and forecasts for the area in question are used for comparison.

Ship and land reports considered to be in error are deleted in areas where the data sufficiently describes the pressure and wind field. In areas of sparse reports, low pressure systems tend to fill and highs tend to weaken in the FNOC models. BOGUS is used to maintain these features as necessary using satellite interpretation.

The grid point surface wind field analyses are determined by the pressure pattern. The wind field may be directly modified in both direction and speed by the BOGUS procedure.

Optimum Path Aircraft Routing System (OPARS) Wind Field Bogus

The QCDO is responsible for modification of the OPARS wind fields. The technique for locating areas of possible upper level wind errors requires correlating and projecting past forecast errors to the new forecast series at the 300MB level for the 500MB to 100MB layer.

Past forecast errors are located using the current OPARS 300MB wind verifying error chart (forecast versus observations) along with the previous TAU 12 300MB forecast. The past errors are then evaluated against the current 300MB analysis and the new TAU 12 300MB forecast to see if the past (verified) error is continuing. Modifications to the OPARS wind fields are then made, if necessary, using an option in the BOGUS procedure.

Tropical Cyclone Bogus

A tropical cyclone bogus is entered into the bogus file by QC whenever a new warning is received. Exceptions are made when winds are less than 30 knots and the forecast does not extend to TAU 24.

The Quality Control program <u>BOGUS</u> accepts input for three stages of tropical cyclone intensity: 1) tropical depression (winds less than 34 knots); 2) tropical storm (winds 34 to 63 knots); and 3) typhoon or hurricane (winds greater than 63 knots).

Tropical cyclone bogus includes analysis and forecast position, movement, maximum sustained wind speed; and radius of 100, 50, and 30 knot wind speeds depending on cyclone strength.

Tropical Cyclone Forecast Models

The tropical cyclone forecast models at FNOC provide tropical cyclone forecast support to Joint Typhoon Warning Center/Naval Oceanography Command Center (JTWC/NOCC) Guam, Naval Western Oceanography Center (NWOC) Pearl and Naval Eastern Oceanography Center (NEOC) Norfolk. Two models, the One-Way Interactive Tropical Cyclone Model (OTCM) and the Nested-Grid Tropical Cyclone Model (NTCM) provide forecasts for the North Atlantic, Pacific, and Indian Oceans. A regional Tropical Cyclone Forecast Model (Navy Operational Regional Atmospheric Prediction System NORAPS) for the Western Pacific is currently under evaluation.

The OTCM is run in response to a request from the JTWC. This model initializes with a pre-warning position and the 6, 12 or 18 hour forecast fields valid at the pre-warning time. The boundary condition update fields are shifted by 6, 12 or

18 hours. The OTCM output is a graphic and alpha-numeric message.

The NTCM is run whenever a tropical cyclone or tropical storm (winds greater than 33 knots) or greater strength exists. The NTCM is initialized with the 00Z and 12Z warning position and respective analysis fields. Output to respective centers is via NEDN in both alpha-numeric and graphic format.

Ocean Products Quality Control

The FNOC Quality Control Division has responsibility for ocean products quality control. This includes monitoring of incoming bathythermograph (BT) data to identify units with consistent errors, examining varian charts of oceanographic products, and inserting sea surface temperature (SST) gradient boguses into our ocean thermal structure analysis. The SST gradient boguses are forwarded to us by our Oceanographic Centers The Centers attempt to identify front and eddy positions of the major ocean currents such as the Gulf Stream and Kurushio.

Approximately 20% of the BT observations received at FNOC contain errors which cannot be corrected by a program known as Ocean ADP (OCNADP). OCNADP is a computer program which decodes and error checks BT JJXX reports. Examples of the errors which Ocean ADP cannot correct include: missing portions of reports, format errors which prevent OCNADP from locating BT parameters, improbable temperature values, future date-time-groups, and reports over land. OCNADP reports reject BT's to a statistical program which uses the ship's call sign for accounting and tracking purposes.

Global Spectral Ocean Wave Model (GSOWM)

Current quality control efforts emphasize the surface wind analysis input to the spectral winds planetary boundary layer (PBL) package which is in turn an input to the GSOWM analysis and prediction portion of the operational run. Watch personnel screen GSOWM output varians for unreasonable values, but the correction effort is aimed at catching problems at the wind analysis input stage.

II. SHPTRK

A System to Detect and Correct Ship Position Errors

At Fleet Numerical Oceanography Center (FLENUMOCEANCEN), world-wide synoptic weather and bathythermograph reports received from ships in real time are decoded by computer and the appropriate elements of the report are used in objective analyses of environmental parameters.

To minimize the impact of report errors on analyses (and hence on forecasts based on these analyses), a number of quality control checks are carried-out on observations. Gross errors in reported parameter values are detected and rejected by the objective analysis programs. In addition to gross errors, analysis systems reject parameter values which are in serious conflict with other observations in the same geographic area. A bogus capability also is available, for forcing out user-selected reports.

Most of these quality control procedures are based on determining how well the reported value of an environmental parameter fits its expected value at the reported location. However, there is no reason to suppose that reported locations are inherently more reliable than any other element of the report. Thus if a reported value of an environmental parameter does not reasonably agree with its expected value, the conflict may be due to a location error rather than an error in the parameter value.

If a position error does occur, in some instances the reported parameter values at the incorrect location may differ sufficiently from expected values to cause rejection by the analysis system. Thus the only adverse effect of such an error is the loss of a valid report at the correct location. A more serious problem arises when a report at an incorrect location passes the analysis system error checks. This introduces data into an analysis which is not correct for the reported location, and thereby can cause significant analysis error; it also prevents use of the report at the true location.

Since many ships take regular weather and/or bathythermograph observations along their tracks, ship-tracking techniques provide a capability for recognizing whether a reported position is in error. In some cases the error may be corrected by calculating the actual location of the report, using interpolation or extrapolation along the track defined by the other observations.

The Ship Tracking system at FLENUMOCEANCEN is a set of computer software designed to recognize position errors in marine synoptic weather and bathythermograph reports, and to correct these errors whenever feasible. The main program in this system, SHPTRK, performs the tracking calculations, error checks the ship positions and calculates corrected positions. Before SHPTRK is run, supporting software attempts to identify the reporting unit for each observation. After SHPTRK has completed its calculations, computer programs such as the surface pressure analysis use the information written by SHPTRK to reject or correct report positions.

(1) Ship identification

Observations are received at FLENUMOCEANCEN over both the Automated Weather Network (AWN) and the AUTODIN communications systems. Observations received via AWN are in bulletins, with the International Radio Call Sign (IRCS) included on each report if it was available at the collecting center. Reports received via AUTODIN are frequently sent directly from the ships which took the observations, so the message-originator line of an AUTODIN message header can be used to identify the report in case the IRCS is missing from the message text.

(2) Checking for Position Errors in Reports

The ship tracking program, SHPTRK, runs each time new observations are decoded and added to the data files to be used in analyses. SHPTRK extracts the IRCS, date-time-group (DTG), ship position and other parameters from each report, then sorts these entries by IRCS and DTG. The time-ordered reports from a particular ship are regarded as a ship track, and the program checks to see if all observations on the track are consistent with each other, assuming a maximum ship speed of 30 knots. Reports which are too far from the track are flagged as errors. SHPTRK consults a list of non-unique call signs, and does not perform tracking checks on reports with identifiers in this list. Entries in this list include generic terms such as SHIP, in addition to identifiers of collectives and aircraft.

(3) Correcting Ship Positions

SHPTRK attempts to correct each error by calculating a new position based on the other observations on the track. Since the actual error may be in the IRCS or the DTG, a careful check is included to ensure that the corrected position resembles the reported position. For example, if the original report is at 40.3N, 140.2W, and the calculated corrected position is at approximately 50.3N, 140.2W, SHPTRK will accept the correction, since the only error is a 10-degree difference in latitude. In the same example, if the calculated position is 36.5N, 157.2W, SHPTRK will not use the corrected position, since the latitudes and the longitudes both differ significantly. In this case, SHPTRK will flag the original report as an error, but will not provide a corrected position.

(4) Use of Position Rejection and Correction Information

When a report position is rejected or corrected, SHPTRK does not change the position entry in the original observation, since it is important to retain this information for future track checking and diagnostics. Instead, SHPTRK writes a record of the rejected and corrected positions on a disk file, to be used by analysis programs. SHPTRK also creates a diagnostic printer output, which is checked by Quality Control (QC) personnel. This printout displays each report that SHPTRK has identified as being suspect, in addition to the recent past history of the ship. QC personnel do not need to take any action concerning reports that SHPTRK has rejected or corrected, since all necessary processing of these reports is done automatically. However, in some cases SHPTRK cannot make a determination. For example, if there are only two reports from a ship and the two reports are inconsistent, SHPTRK cannot determine which one is incorrect. In these cases the QC personnel try to make a determination of validity. If a report is found to be incorrect, the QC personnel bogus the report out of the subsequent analysis. If a report is thought to be valid, it is left untouched, to be used in the analysis. The analysis programs ignore each report which was rejected by SHPTRK or bogussed out by the QC personnel, and use the corrected position for each report which SHPTRK corrected.

(5) Examples of SHPTRK Effect on Analysis

The following examples illustrate SHPTRK error detection and correction techniques as they affect the surface pressure analysis. The charts in Figures 2, 3, 4, 7, 8 and 9 consist of a display of contour lines of constant pressure at 4 millibar intervals, with each contour labeled with the tens and units digits of pressure. High and low center values are labeled with tens, units and tenths digits of pressure. For example, in Figure 7 the contour labeled +24 represents a pressure value of 1024 mb, and the high central value labeled +362 represents a pressure of 1036.2 mb. Pressure observations which were accepted by the analysis error checking and used in the analysis appear as tens, units and tenths values in small black figures. Pressure observations rejected by the analysis appear as small white figures within a black rectangle. Accepted wind observations appear as solid wind barbs, and rejected wind observations appear as dotted wind barbs.

EXAMPLE 1

For DTG 06Z 26 Oct 87, observations from a particular ship were received at two locations: (a) 17.3N, 130.7W and (b) 17.3N, 130.7E. The observation at the eastern longitude was consistent with the preceding observations from the same ship, and the observation at the western longitude was inconsistent. SHPTRK detected the error in the observation at 130.7W, and corrected it by changing the position to match that of the other observation at the same time. In this case, SHPTRK did not make any new data available to the analysis, since there was already a good report at the correct location. However, SHPTRK did flag the incorrect report so that the analysis would not use it. Figure 1 shows information concerning the ship track, adapted from SHPTRK printer output. Figure 2 shows output from a test run of the surface pressure analysis without SHPTRK, in which the report with the incorrect position was used. Both the reported surface pressure and the reported wind were accepted by the analysis program. Figure 3 is the output from the equivalent run in which SHPTRK preceded the analysis program. In this case the report at the incorrect location was ignored by the analysis, since SHPTRK flagged it for removal from the list of reports to be considered. Figure 4 shows an overplot of (a) the output from the analysis preceded by SHPTRK (solid lines) and (b) the output from the analysis without SHPTRK (dashed lines).

EXAMPLE 2

The 06Z 29 OCT 87 observation from a particular ship was reported at 40.4N, 48.4W. On the 06Z 29 run SHPTRK determined that this observation was inconsistent with the 00Z 29 Oct observation from the same ship. Extrapolating the track from the 12Z 28 and 00Z 29 observations gave a position very close to 40.4N, 40.4W. Since almost all characters in the corrected position matched the position as reported, SHPTRK accepted the corrected position. Thus SHPTRK changed the input data set available to the analysis program by (a) deleting the bad report at 40.4N, 48.4W and (b) inserting the good report at 40.4N, 40.4W. Figure 5 shows information concerning the ship track, adapted from SHPTRK printer output. Figure 6 is a plot of the track, with the actual track up to and including the 06Z 29 observation as a solid line and the track to the (incorrect) reported 06Z 29 position as a dashed line. The following observations, for 12Z 29 and 18Z 29 Oct, are plotted on the figure with a dotted line. Although these observations were not available to SHPTRK for evaluation of the 06Z 29 observation, due to the real-time nature of the data processing, they were hand-checked later to confirm that SHPTRK had functioned correctly. Figure 7 shows output from a test run of the surface pressure analysis without SHPTRK, in which the report with the incorrect position was used by the analysis. The analysis program rejected the wind report, since it differed significantly from the expected wind at the report location. However, the reported surface pressure was close enough to the expected value for the analysis to accept it. Figure 8 is the output from the equivalent run in which SHPTRK preceded the analysis program. In this case the report at the original (incorrect) location was ignored by the analysis, since SHPTRK flagged it for removal from the list of reports to be considered. The report at the corrected location was used in the analysis, and both the reported pressure value and the reported wind value were accepted by the analysis program. Figure 9 shows an overplot of (a) the output from the analysis preceded by SHPTRK (solid lines) with (b) the output from the analysis without SHPTRK (dashed lines).

III. NOGAPS 3.0 QUALITY CONTROL DESIGN

NOGAPS 3.0 consists of a multivariate optimum interpolation analysis, nonlinear normal mode initialization, and an 18 level, T47 spectral forecast model. The system has been designed with quality control in mind. Prior to the analysis, objective quality control of all observations is performed patterned after the methods outlined in ECMWF Technical Note 23.1. All observations are checked for internal consistency and against climatological limits. The rawinsonde observations are also subjected to extensive vertical consistency checks including a lapse rate check of the entire temperature profile, hydrostatic consistency checks of heights and temperatures, and vertical wind shear checks. Further quality control is performed within the analysis itself for observations flagged as suspicious during the pre-analysis quality control or for observations which deviate excessively from the background or first-guess field. Following Lorenc (1981) these observations are examined by systematically removing their effect from the analysis and are eliminated when their effect upon the analysis is unreasonably large.

Post-analysis quality control centers around the data records produced after each analysis which contain the differences between rawinsonde observations and the first guess field at the observation location. These records are maintained on-line for a one month period before being archived. They permit us to readily identify consistently unreliable stations for blacklisting and to monitor station performance. Systematic errors in the forecast model itself can be readily identified by plotting time-averaged differences. If all stations in a geographical area display similar biases it can be assumed that this is due to the first guess.

Lorenc, A., 1981: A global three-dimensional multivariate statistical interpolation scheme. Mon. Wea. Rev., 109, 701-721.

IV. MODEL VERIFICATION

Fleet Numerical Oceanography Center requires an atmospheric model forecast verification system which provides Navy Oceanography Command forecasters with information that helps them identify strengths and weaknesses of the FNOC products, and also provides statistical descriptions of the general performance of the atmospheric models. This Section describes the model verification system at FNOC. The techniques described here are used to verify 12 h through 120 h forecasts and do not pertain to short range verification used in the optimum interpolation analysis. Specific examples are given from a recent evaluation of the Navy Operational Global Atmospheric Prediction System (NOGAPS) global spectral model. However the same techniques are used for evaluating the Navy Operational Regional Atmospheric Prediction System (NORAPS).

Of obvious concern to the Navy forecaster is model performance regarding synoptic scale sea level pressure (SLP) cyclones, and associated wind and wave conditions. Unfortunately, traditional statistical measures of model performance identify few of the model tendencies concerning SLP cyclones. Therefore in addition to the standard types of statistical analyses of model forecasts a second automated system monitors analyzed and forecast SLP cyclones.

As stated above, a primary purpose of model verification, at FNOC, is to supply the forecasters with information to increase the current utility of the numerical products. This is accomplished by providing them with results of the verification process over the following time scales:

1) <u>DAILY</u> - Results of the model performance with respect to currently active SLP cyclones over the Northern Hemisphere are supplied daily in the QC Model Summary Bulletin (MSB);

2) <u>MONTHLY</u> - Summaries of all cyclones within each month over the Pacific and Atlantic Oceans are supplied to the Ocean Centers in the QC Monthly Summary.

3) <u>SEASONAL</u> - A combination of statistically derived model performance data and the SLP cyclone summaries valid for each season are summarized in the FNOC Quarterly Performance Summary. The expected model tendencies for the coming season are also supplied in the Quarterly Performance Summary.

The contents of the daily MSB and the Monthly Summary contain information regarding the model performance with respect to SLP cyclones. The MSB is subjectively derived from daily map discussions. The Monthly Summary is comprised totally of the results from the automated cyclone tracking system. The movement, deepening, and filling characteristics of all cyclones over the Pacific and Atlantic Oceans are continually monitored as they are depicted in the FNOC analyses and forecasts. The monitoring process investigates 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 groups of cyclones. Figure 9.1 illustrates a standard type of performance summary valid for the Navy Operational Global Atmospheric Prediction System (NOGAPS) 3.0 global spectral model. The tracks of cyclones occurring over the Pacific Ocean during the period 8 December - 25 December, 1985 are shown in Figure 9.1.a. The central pressure (CP) forecast errors during the deepening and filling stages of the cyclones are shown in Figures 9.1.a, and 9.1.b, respectively. The model performed well during the deepening of the cyclones, but was slightly slow to fill them. Position forecast errors are shown in Figures 9.1.d, and 9.1.e for the deepening and filling stages respectively. During deepening, position forecasts exhibited little bias at 24 h and 48 h. The forecast positions were slightly ahead of the analyzed position at 72 h. During filling, the 24 h and 48 h forecasts were positioned slightly ahead and to the left of the analyzed position.

Various types of summaries are readily available from the data produced by the storm tracking system. Cyclone deepening rate is one operationally relevant parameter which can be used to gauge model performance. Figure 9.2 shows a scatter diagram of the 72 h CP error versus the analyzed 24 h deepening rate of the cyclones in Figure 9.1.a. It is evident that the model generally over-predicts (negative CP error) the CP, but there is no dependence on deepening rate. The previous NOGAPS model exhibited a strong relationship between CP error and 24 h deepening rate, with rapidly deepening cyclones (negative 24 deepening rate) being severely under-forecast (positive CP error).

Model performance can further be examined with respect to deepening rate by examining how well the model predicts the initial development of a cyclone. Figure 9.3 shows the analyzed CP profile averaged over the first 6 days of each cyclone in Figure 9.1.a. Day zero defines the very first time the cyclone appeared in the analysis (i.e., cyclogenesis). The average predicted CP profile from forecasts initiated 24 h prior to cyclogenesis is also shown in Figure 9.3. The 24 h forecasts verifying on day zero slightly under-forecast cyclone development, but 48 h and 72 h forecasts are very accurate.

These examples illustrate the capability to present operationally relevant QC data which identify model tendencies concerning synoptic scale SLP cyclones. Various types of summaries can easily be produced by accessing the growing data base being maintained by the storm tracking system.

In addition to the above approach to model verification as a QC function, at FNOC, more traditional verification data are produced. These include the following measures;

1) Height bias, Root mean Square error (RMSE), and standard deviation;

2) Height anomaly correlation;

3) Mean vector wind error (VWE), and RMS VWE.

4) Temperature bias, RMSE, and standard deviation.

These measures are computed at various levels, and integrated over several geographic regions which include the major ocean basins and various latitude bands.

The NOGAPS 3.0 height bias and standard deviation during the 11 December - 25 December 1985 evaluation period are shown for the Northern Hemisphere (20 N - 90 n) in Figures 9.4.a and 9.4.b respectively. The bias pattern shows that the forecast heights became too high as both the forecast interval and vertical level increase. The NOGAPS 3.0 height anomaly correlations are shown in Figure 9.5 for the same time period and area. Correlation values above 0.6 are indicative of useful forecasts. The scores in Figure 9.5 are all well above 0.6 indicating considerable forecast skill through 72 h.

In summary, FNOC uses forecast verification statistics in a QC type of environment to supply information to the forecasters which may help them better utilize the numerical products. Also various statistical analyses of model performance are used to meet other requirements such as evaluation of overall model fit to verifying analyses and observations, measurement of model improvements, and comparison to other operational models.

```
date-time-group          26/06Z----26/06Z     26/03Z     26/00Z
reported latitude         17.3N      17.3N     18.0N      18.7N
reported longitude       130.7W     130.7E    131.0E     131.3E
calculated speed (kts)        large        15         15

reported pressure        1011.2     1011.2    1013.4     1014.0

corrected latitude        17.3N
corrected longitude      130.7E
corrected speed (kts)           0
```

Figure 1

Diagnostic Printout for SHPTRK Example 1

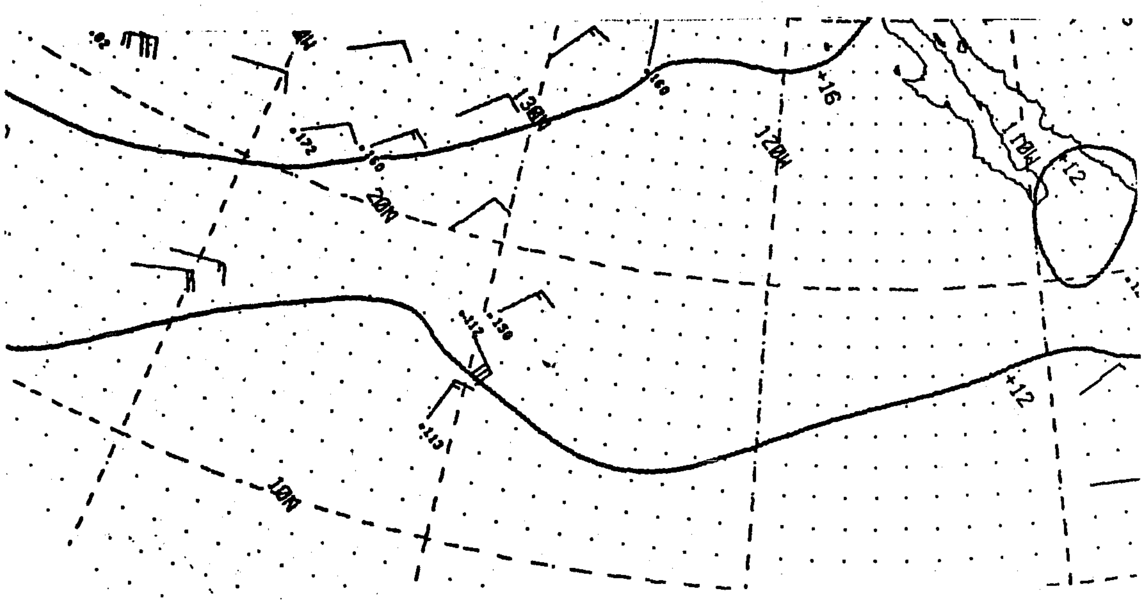


Figure 2

Analysis Output for Example 1 <u>without</u> SHPTRK

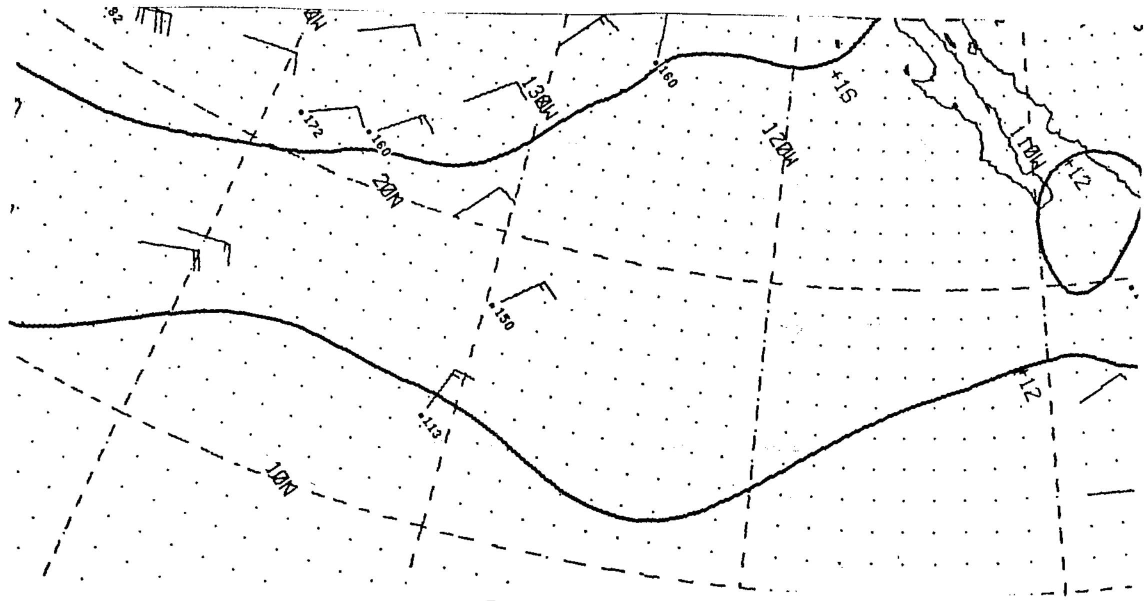


Figure 3

Analysis Output for Example 1 with SHPTRK

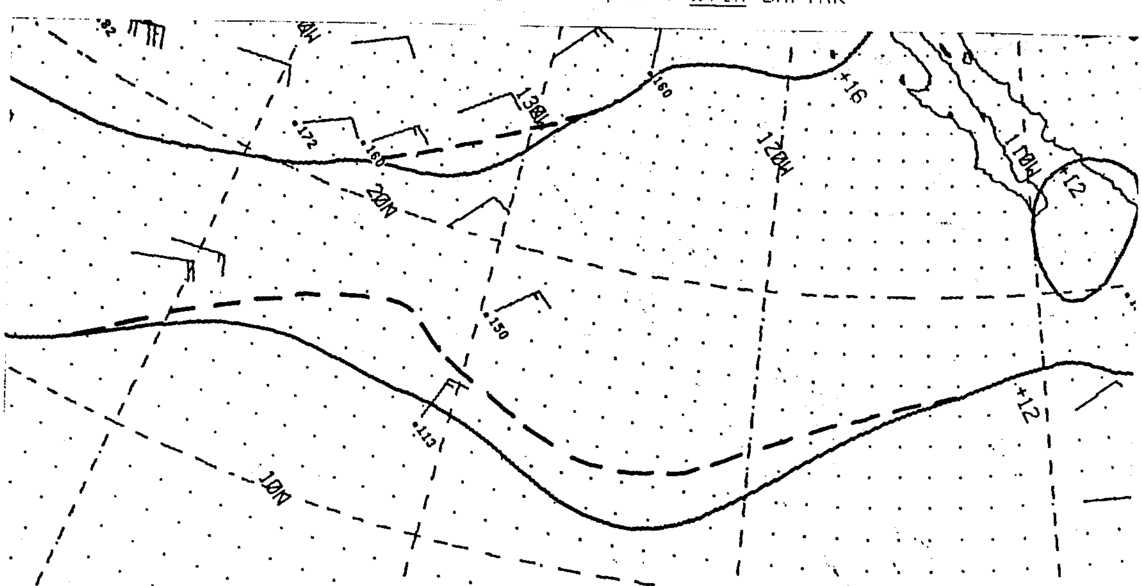


Figure 4

Analysis Output for Example 1 without SHPTRK (Dashed Lines) and with SHPTRK (Solid Lines)

date-time-group	29/06Z		29/00Z		28/12Z
reported latitude	40.4N		40.2N		40.0N
reported longitude	048.4W		039.0W		035.9W
calculated speed (kts)		72		12	
reported pressure	1027.2		1026.4		1019.0
corrected latitude	40.4N				
corrected longitude	040.4W				
corrected speed (kts)		11			

Figure 5

Diagnostic Printout for SHPTRK Example 2

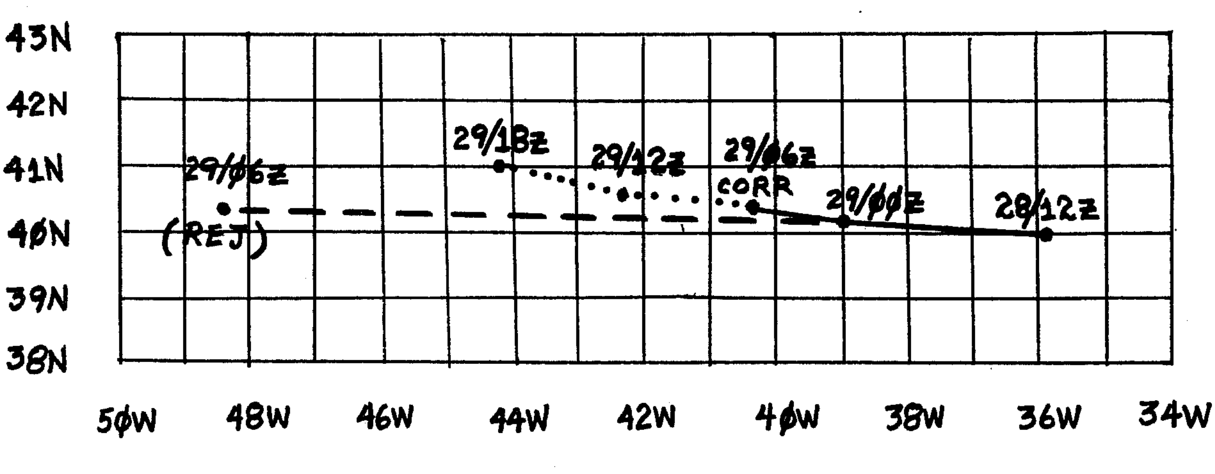


Figure 6

Plot of Ship Track for Example 2

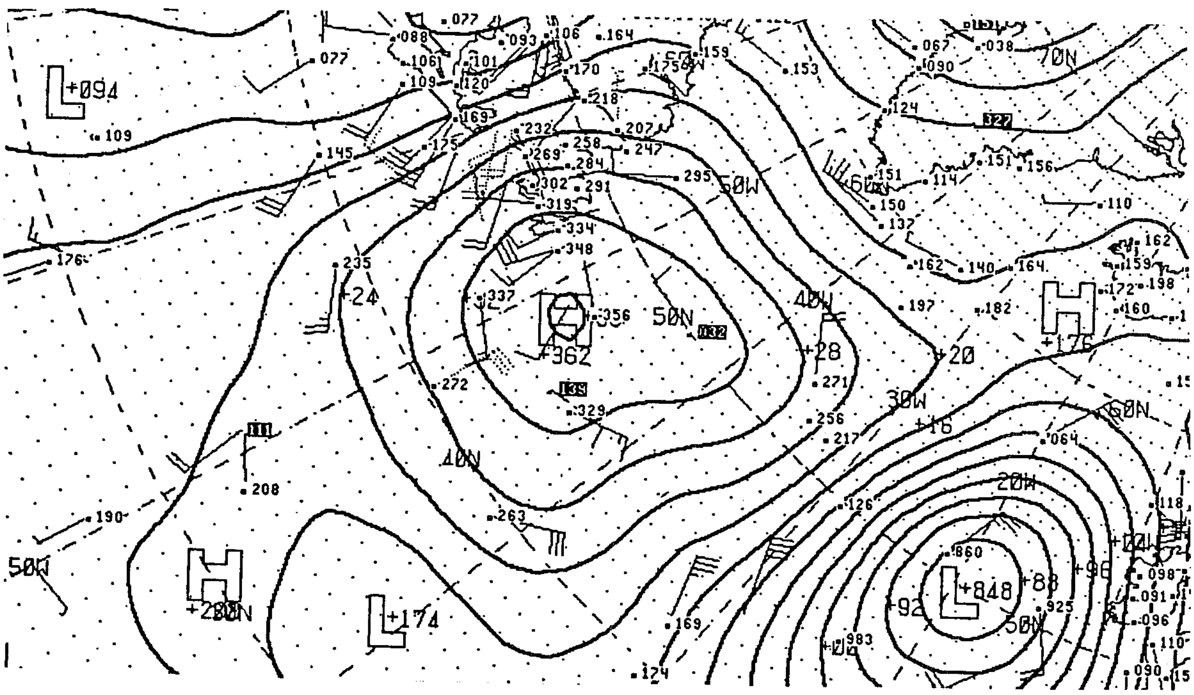


Figure 7

Analysis Output for Example 2 <u>without</u> SHPTRK

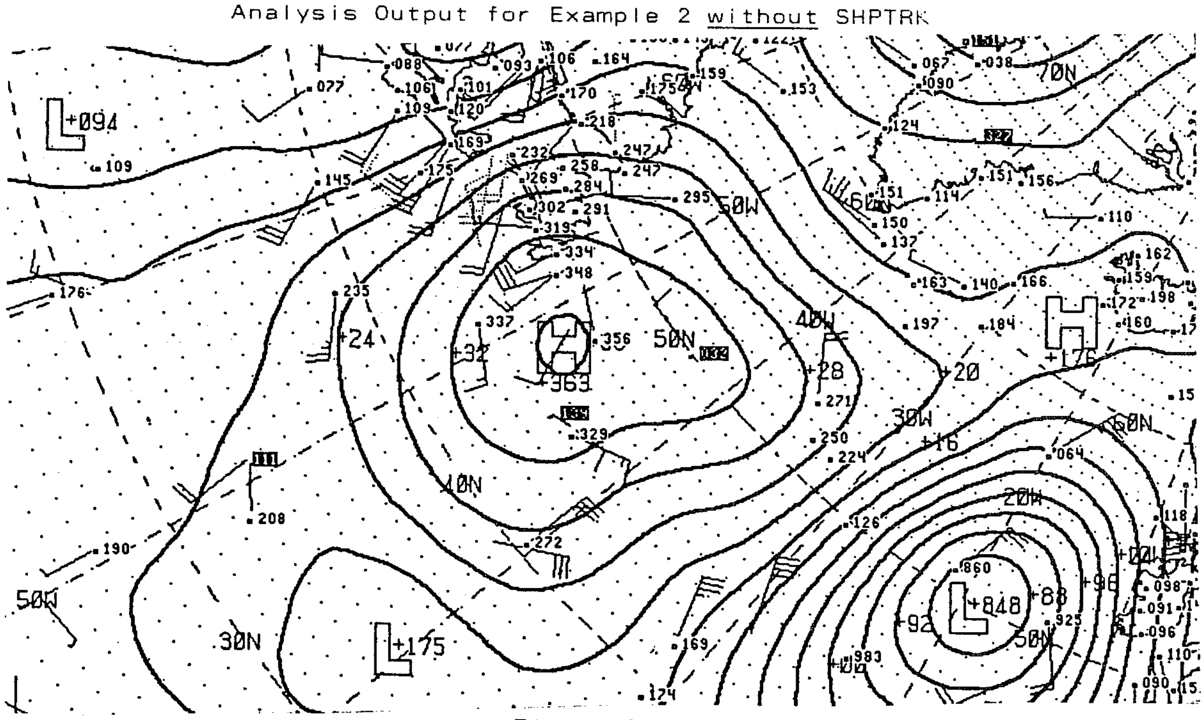


Figure 8

Analysis Output for Example 2 <u>with</u> SHPTRK

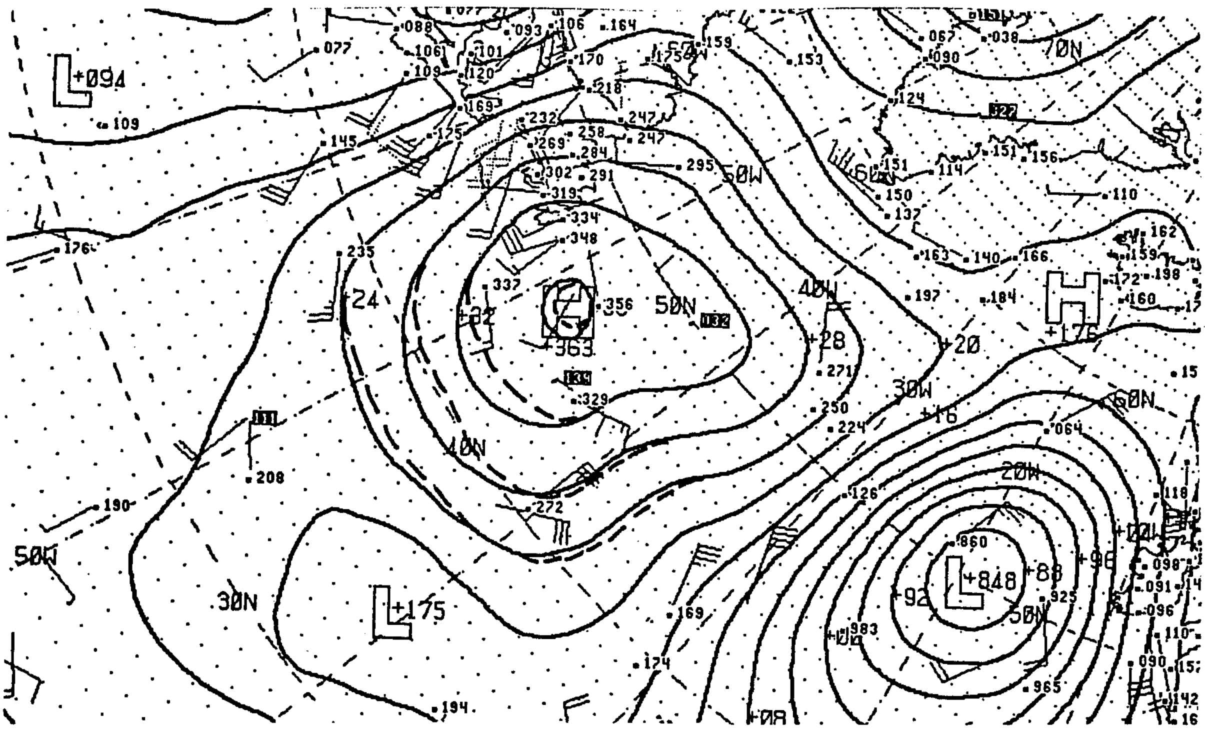
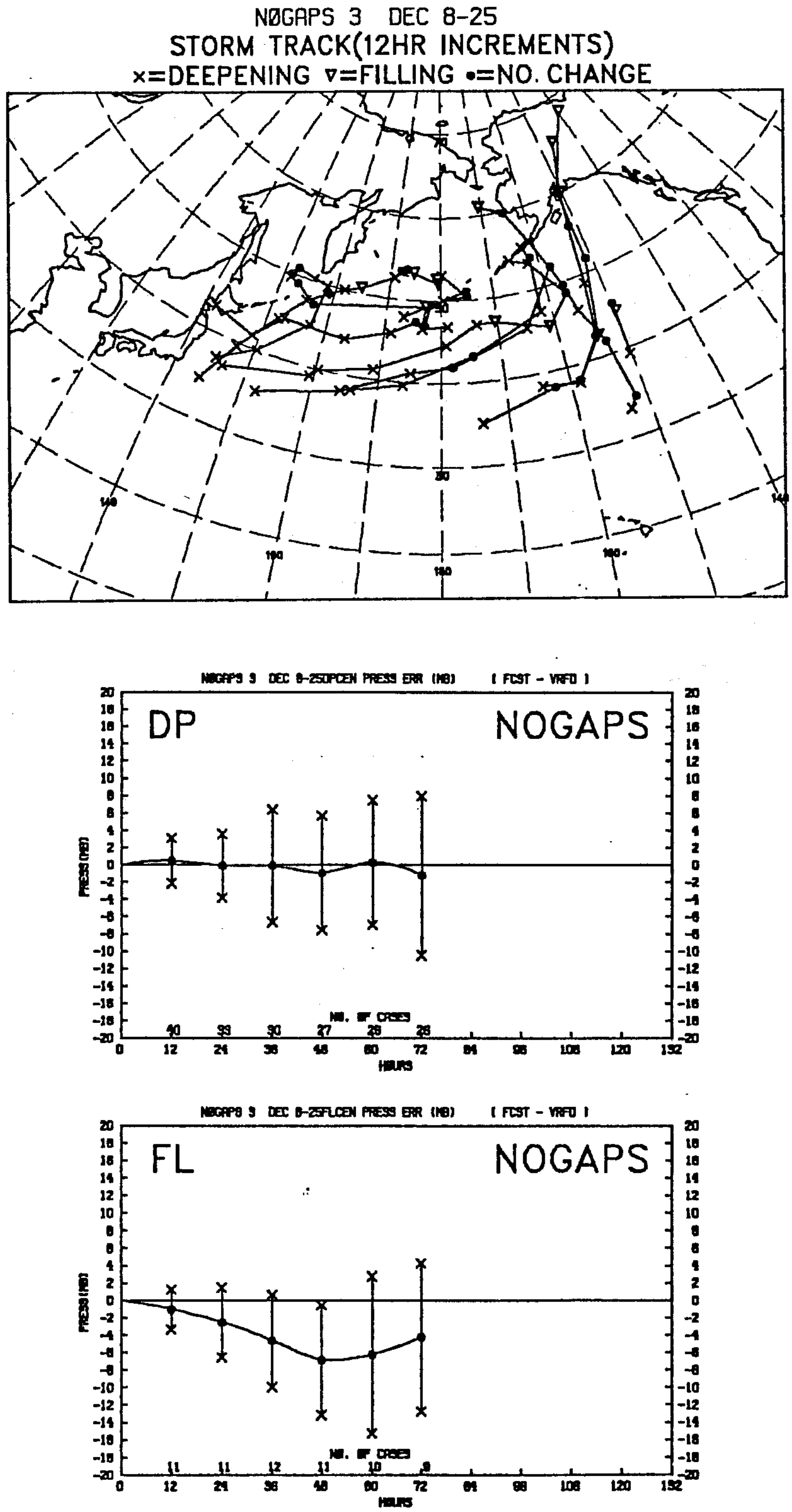


Figure 9

Analysis Output for Example 2 <u>without</u> SHPTRK (Dashed Lines) and <u>with</u> SHPTRK (Solid Lines)

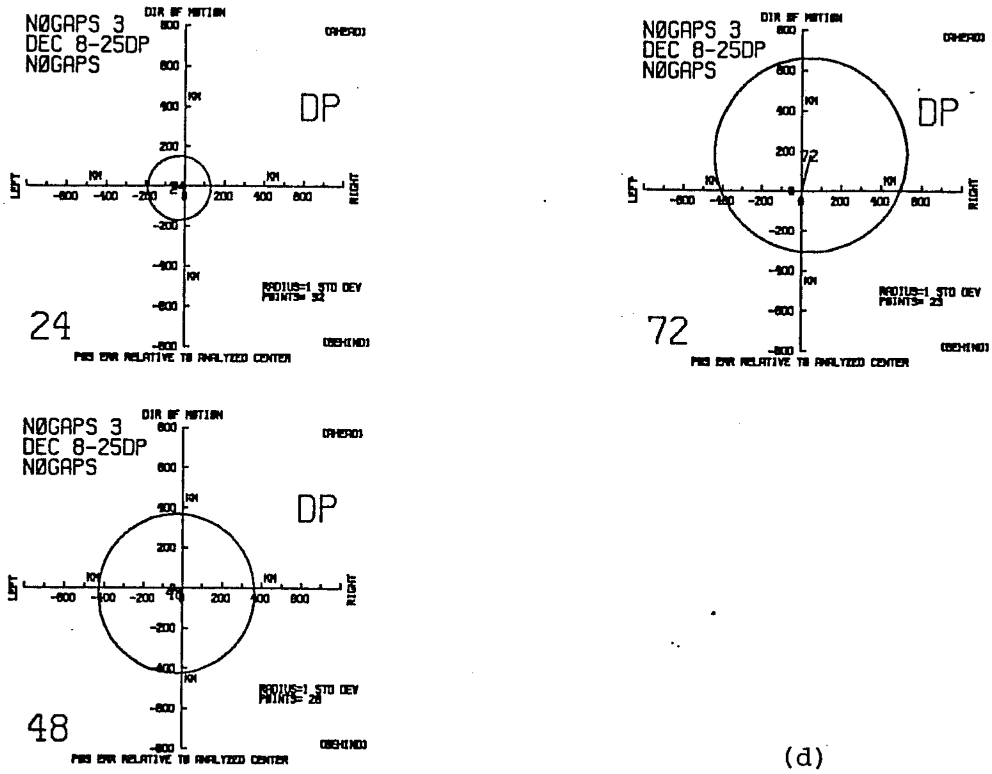


(a)

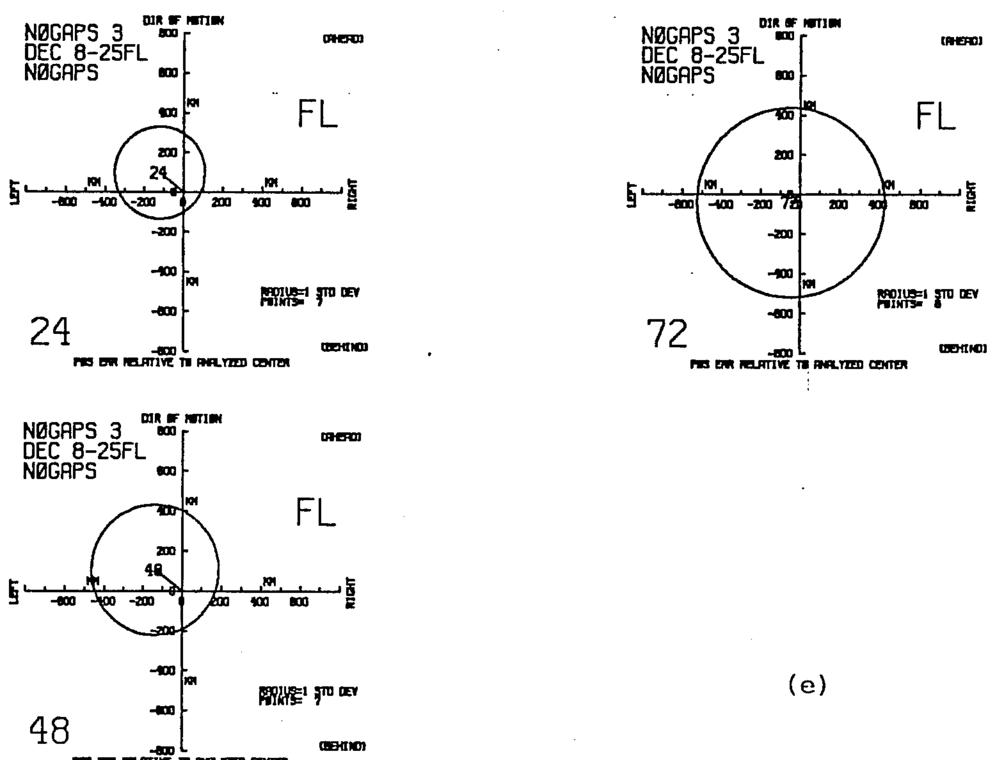
(b)

(c)

Figure 9.1. NOGAPS 3.0; (a) Analyzed tracks of sea level pressure cyclones occurring during 8 December - 25 December 1985; (b) Central Pressure (CP) errors during the deepening stages of the cyclones; (c) CP errors during the filling stages of the cyclones. Deepening is defined as at least a decrease of 3 mb in successive 12 h analyses, and filling is defined by at least a 3 mb increase between successive 12 h analyses. The vertical lines represent the standard deviation about each mean error. Positive errors indicate that the forecast CP was too high.



(d)



(e)

Figure 9.1 (continued). (d) Position errors during the deepening stages of the cyclones; (e) Position errors during the filling stages of the cyclones. The analyzed center is represented by the origin of the axes, and the cyclone direction is along the positive y axis. The circle radius around the mean error position represents the standard deviation about the mean error.

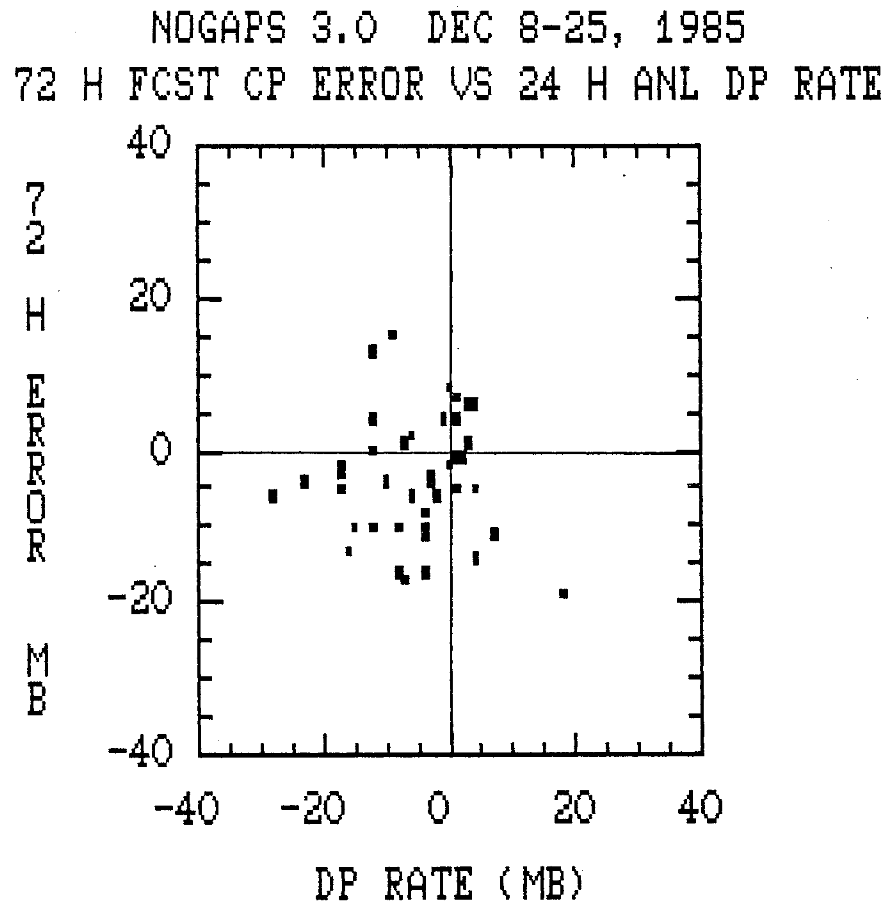


Figure 9.2. A scatter diagram of NOGAPS 3.0 72 h CP forecasts versus the 24 h analyzed cyclone deepening rate. Errors are computed as forecast - verifying analysis, and positive errors mean that the forecast CP was too high.

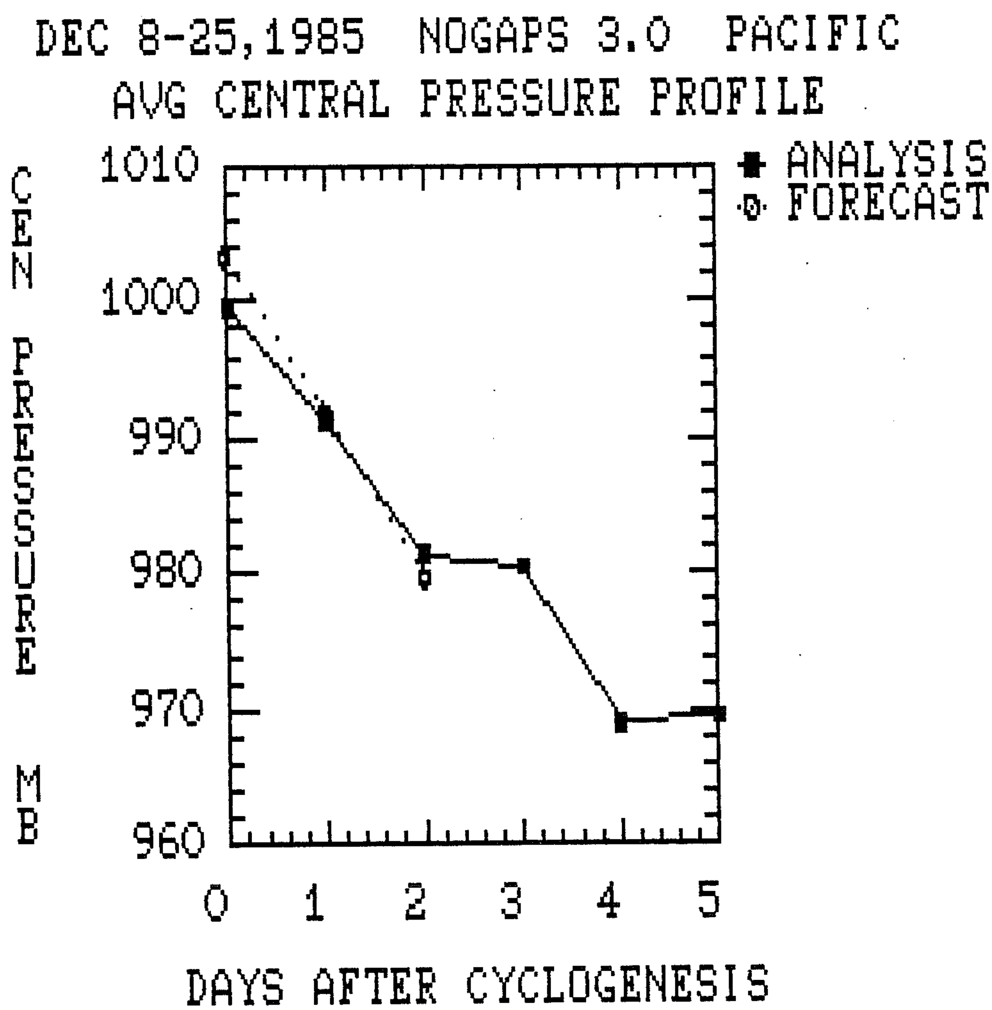


Figure 9.3. The solid line is the analyzed cyclone CP profile averaged over the first 6 days of the cyclones in Figure 9.1.a. The dotted line is the forecast CP profile averaged over all forecasts which were initiated 24 h prior to the first appearance of the cyclone in the analysis (DAY 0).

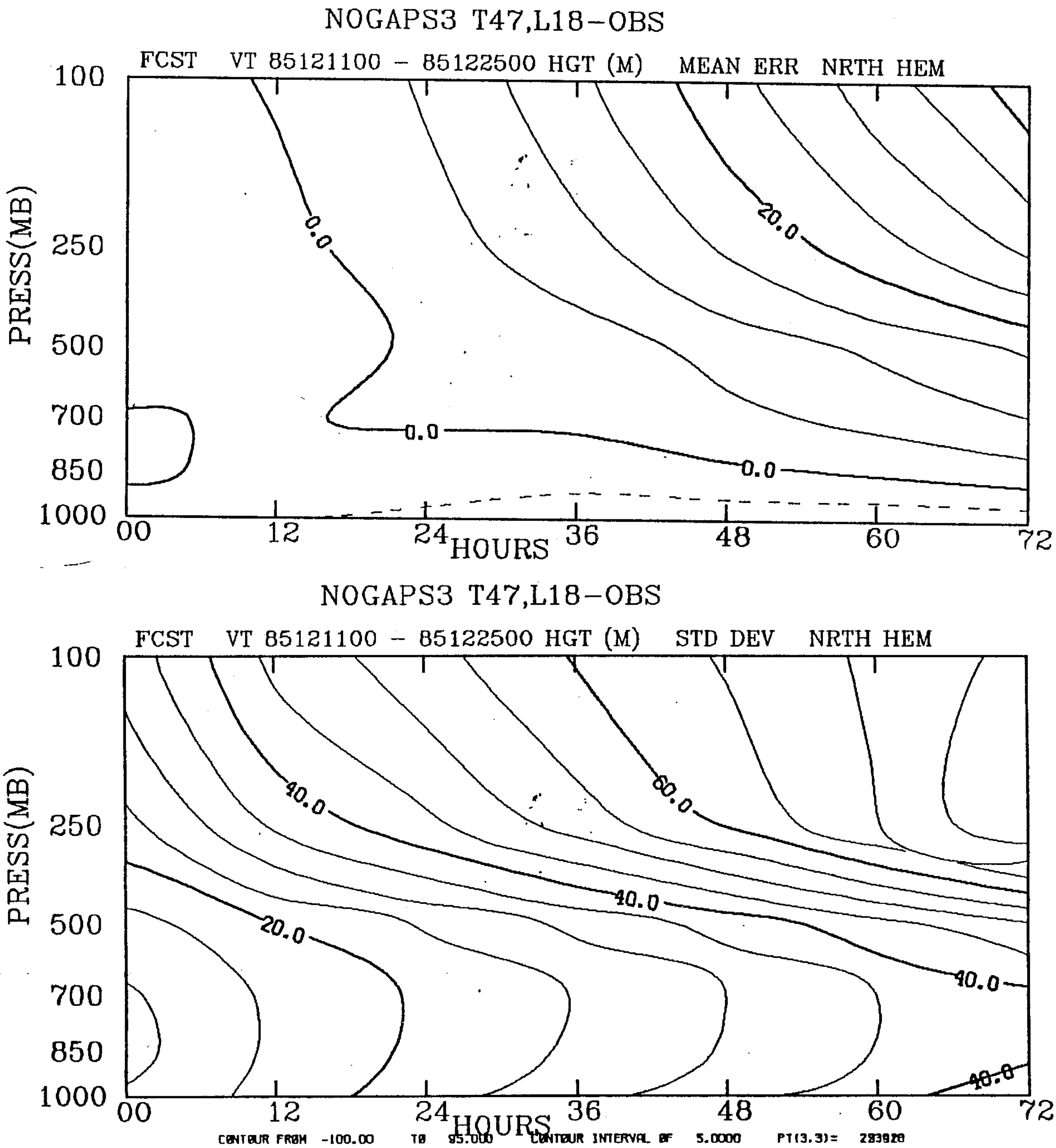


Figure 9.4. (a) The time/height cross section of the NOGAPS 3.0 height error over the Northern Hemisphere during 11 December - 25 December 1985. The errors are computed using verifying radiosonde observations. (b) The standard deviation of the height error shown in (a). Units are meters.

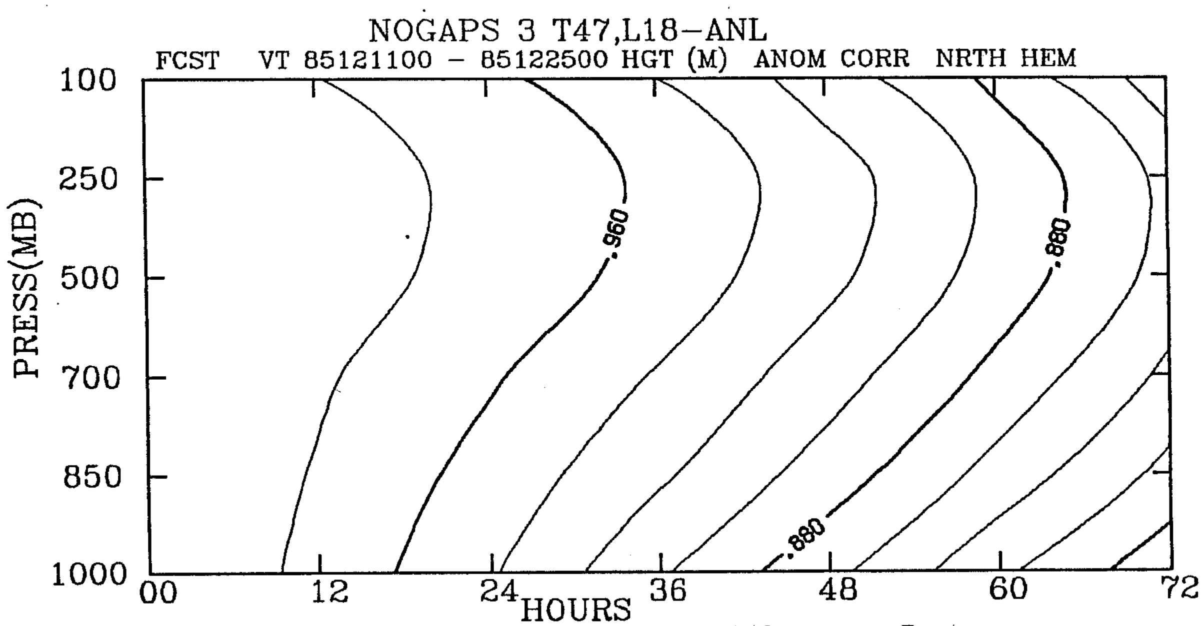


Figure 9.5. The time/height cross section of the NOGAPS 3.0 height anomaly correlation over the Northern Hemisphere during 11 December - 25 December 1985.