The Automated Tropical Cyclone Forecasting System (Version 3.2)

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ABSTRACT

The Automated Tropical Cyclone Forecasting System (ATCF) is software intended to automate and optimize much of the tropical cyclone forecasting process. The system features global tracking capability, a suite of objective aids, and a user interface that allows simultaneous tracking of multiple tropical cyclones. The version discussed in this article, ATCF 3.2, runs on UNIX workstations. The Joint Typhoon Warning Center in Guam, the Naval Pacific Meteorology and Oceanography Center in Pearl Harbor, and the Naval Atlantic Meteorology and Oceanography Center in Norfolk successfully used ATCF 3.2 during the 1998 tropical cyclone season.

1. Introduction

The Automated Tropical Cyclone Forecasting System (ATCF), developed by the Naval Research Laboratory (NRL) in Monterey, California, is a computer-based application intended to automate and optimize much of the tropical cyclone forecasting process. It provides capabilities to track, forecast, construct messages, and disseminate warnings. A graphical user interface allows rapid access to current and past cyclone data, numerical weather prediction (NWP) model fields, objective forecast guidance, and many types of observations. The interface is mouse-driven but requires limited keyboard entry. ATCF does not replace the forecaster; rather, it provides the forecaster with an organized framework of tools to use in the forecasting process.

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In final form 11 November 1999.

2. History

Prior to 1988, the typical tools for forecasting at U.S. Department of Defense (DOD) tropical cyclone warning centers were grease pencils, acetates, and a number of separate computer programs. In 1988, ATCF was installed on DOS-based personal computers at the Joint Typhoon Warning Center (JTWC) in Guam as described in Miller et al. (1990) and has served as the primary forecasting tool since that time. ATCF was also installed at the Naval Pacific Meteorology and Oceanography Center in Pearl Harbor and the Naval Atlantic Meteorology and Oceanography Center in Norfolk, Virginia. In the early 1990s, the National Hurricane Center (NHC) in Miami modified ATCF for operational tracking and forecasting at NHC, the National Centers for Environmental Prediction (NCEP), and the Central Pacific Hurricane Center (CPHC) in Honolulu.[1] The Central Weather Bureau in Taiwan also modified and installed ATCF.

[1]NHC, NCEP (a backup for NHC), and CPHC issue official U.S. tropical cyclone forecasts for the Northern Hemisphere east of the date line. DOD forecast centers reissue these forecasts to DOD customers and make their own forecasts for tropical cyclones west of the date line or in the Southern Hemisphere.

Throughout the 1990s, other tropical cyclone warning agencies have developed tropical cyclone forecasting software similar to ATCF. For example, the Australian Tropical Cyclone Workstation, developed by the Bureau of Meteorology in Australia, is used in operations at the Western Australia regional office in Perth and in New Caledonia (F. Woodcock 1997, personal communication). The Canadian Hurricane Centre Forecaster's Workstation (MacAfee 1997), developed for Canadian tropical cyclone forecasting, is used in operations at the Canadian Hurricane Centre.

In 1996, NRL developed ATCF 3.0, a major upgrade to the DOS version, and installed it in DOD tropical cyclone warning centers. The upgrade is for UNIX workstations and has a graphical user interface similar to what is seen in Windows applications. The graphical user interface is written in C, while the objective aid and statistical software is written in FORTRAN. All graphics employ the XVT Portability Toolkit™, which will allow for an easy transition of graphics software to other platforms (such as Windows™ or Windows NT™). The version described here, ATCF 3.2, was installed prior to the 1998 season and resides on Hewlett Packard workstations with a HPUX 10.2 operating system.

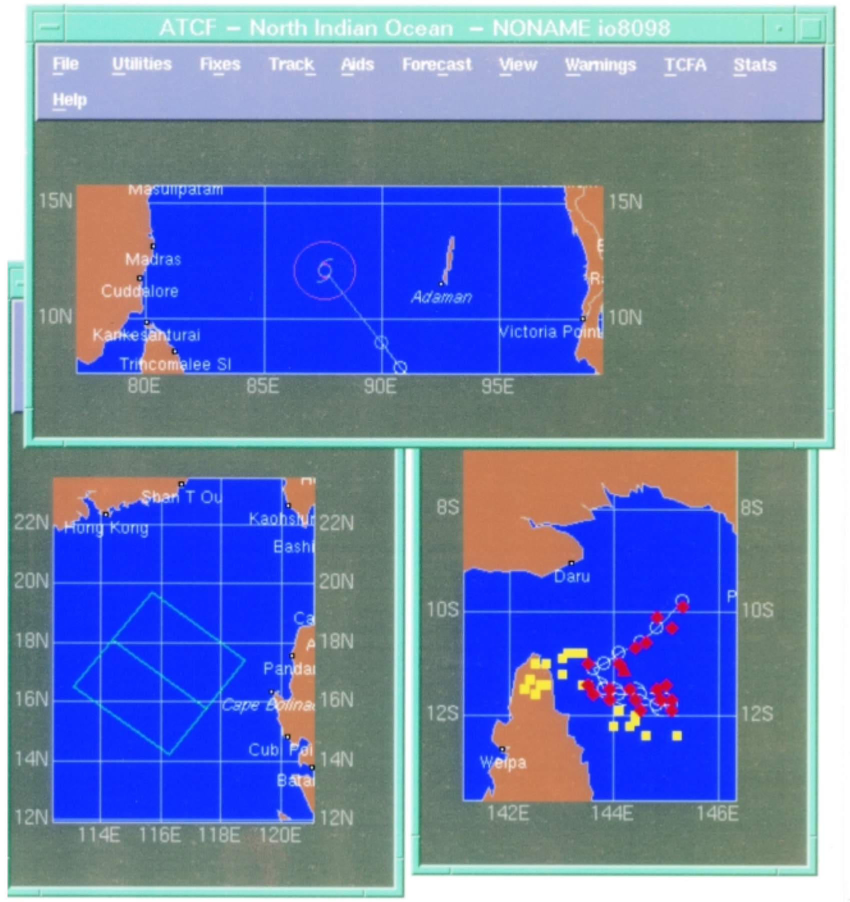

FIG. 1. Three ATCF map windows on a single monitor. A 12-h forecast track (light blue line with blue tropical cyclone symbol) and forecast wind radius (purple circle encompassing the blue tropical cyclone symbol) is shown in the top window. A tropical cyclone formation alert (TCFA) in the South China Sea is shown as a green box in the lower left window. An Australian region tropical cyclone track (white typhoon symbols) with satellite center position fixes (red and yellow squares, diamonds and triangles) is shown in the lower right window. The title on the top window indicates the application name (ATCF), geographic area of interest (North Indian Ocean), storm name (NONAME), and storm ID. The storm ID (e.g., wp8098) uniquely defines a tropical cyclone and is a combination of a two-character basin name, a two-digit storm number, and a two-digit storm year. Menu items (File, Utilities, etc.) define major functional areas of the application.

3. ATCF 3.2 highlights

The intention in this section is to highlight major improvements of the UNIX ATCF as compared with the original DOS version. For more information about ATCF, see Miller et al. (1990), which has a slightly outdated but still relevant description of ATCF use in tropical cyclone forecasting. A comprehensive description of ATCF functions is included in A&T (1996) and documentation for key ATCF data files (i.e., tracks, position fixes, objective aid forecasts, and forecasted wind radii) can be obtained from the authors or alternatively from the ATCF Web page at NRL.[2] Finally,Guard et al. (1992) contains an overview of DOD tropical cyclone forecasting at JTWC. The forecasting described within this section demonstrates how functions within the UNIX ATCF can be used in forecasting and is not intended to represent forecast processes at the official U.S. forecast agencies.

[2]Available online at http://www.nrlmry.navy.mil/

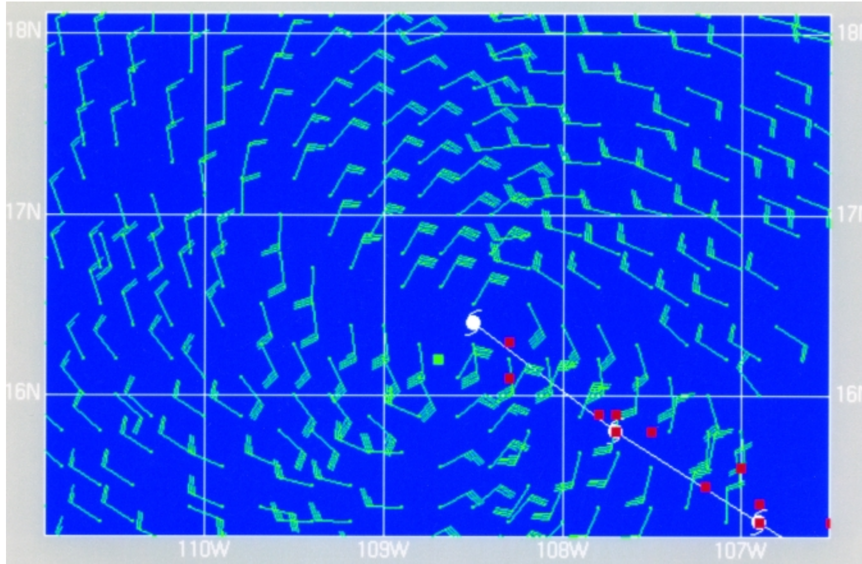

FIG. 2. Six-hour tropical cyclone positions (white tropical cyclone symbols) of Hurricane Blas with satellite position fixes (red squares) and *ERS-2* Fast Delivery Product winds at approximately 1730 UTC 25 June 1998 (green wind barbs) superimposed. The northernmost white tropical cyclone symbol represents the forecaster's estimated 1800 UTC 25 June 1998 tropical cyclone location, while the green square indicates a synoptic fix using the 1730 UTC scatterometer pass and the northernmost red square indicates a 1630 UTC *GOES-9* visible image position fix.

a. User interface

The single most important improvement of the UNIX ATCF is the new graphical user interface, which has been simplified when compared with the arcane user interface of the DOS version. Hence, navigation through ATCF is much easier. The new version permits multiple windows on a single screen, multitasking, and window icons—all of which promote efficiency, especially when forecasting for two or more tropical cyclones in a single six-hour warning period.

For example, consider a situation in which a forecaster is confronted with tracking three tropical systems at once: a tropical storm in the Australian region, a tropical storm in the North Indian Ocean, and an area of possible tropical cyclone formation in the South China Sea. The forecaster is able to open three windows—one for each of the three tropical systems currently tracked (Fig. 1). Navigation between the three windows is accomplished by setting the cursor in the desired window and clicking the left mouse button, thus setting the focus on that window. When windows are revisited, they are found in the same state as when they were last visited. As shown in Fig. 1, the forecaster can concurrently complete a forecast for a North Indian Ocean tropical cyclone, enter a new track position for an Australian tropical cyclone, and create a tropical cyclone formation alert (TCFA) for the South China Sea. In the DOS version of ATCF, switching from one tropical cyclone to another required navigation through a series of disparate user interfaces because individual storms had to be processed sequentially.

b. Data ingest and display capability

ATCF has access to NWP model grid point data from the navy, NCEP, and the European Centre for Medium-Range Weather Forecasts. Observations from conventional sources (surface stations, buoys, and ships), and scatterometer and cloud-tracked winds are also available. All these data are stored on an ATCF workstation and are managed by a relational database—the Tactical Environmental Data Server (TEDS).[3] Wind barbs, streamlines and contours of the gridpoint data can be displayed or looped in conjunction with tropical cyclone tracks and forecasts, providing comparisons between NWP models and official forecasts. Recently retrieved scatterometer winds, conventional surface reports and cloud and water vapor tracked winds can also be displayed. For example, Fig. 2 shows *European Remote Sensing Satellite-2 (ERS-2)* Fast Delivery Product (FDP) winds for a swath passing directly over Hurricane Blas at approximately 1730 UTC 25 June 1998. In this case, the FDP winds could be used to estimate near surface 15 m s^{-1} wind radii of Blas. Additionally, a tropical cyclone center fix could be estimated from these data by experienced forecasters (even though many of the wind directions are reversed) by using the synoptic fixing method described in the Australian Tropical Cyclone Forecasting Manual (Bureau of Meteorology 1978). Dozens of the JTWC center fixes and wind radius estimates were based on data from scatterometer passes during the 1998 season.

[3]For the latest description of TEDS, contact the authors or see the Web site at http://c4iweb.nosc.mil/185/.

TABLE 1. Suite of objective forecast aids that reside on the ATCF 3.2 workstations.

Model ID	Model name and/or description	Key references
CLIP	WPCLIPER (western N. Pacific)	Neumann (1992)
CLIP	OCLIPER (Indian Ocean) OCLIPER (Southern Hemisphere)	Neumann and Mandal (1978) Neumann and Randrianarison (1976)
CLIP	STIFOR (intensity)	Chu (1994)
CSUM	Colorado State University model	Matsumoto (1984)
FBAM, MBAM, and SBAM	Beta and advection models	Marks (1992)
GLAV and RGAV	Global and regional model ensembles	Goerss (2000)
JT92	JTWC92	Neumann (1992)
NGPR	NOGAPS Vortex Tracker on ATCF workstation	Hamilton (1996) Goerss and Jeffries (1994) Hogan and Rosmond (1991)
OTCR	OTCM on the ATCF workstation	Hamilton (1996) Hodur and Burk (1978)
STRT and RECR	Tyan93	Hamilton (1996)
WGTD and BLND	Weighted averages	Mundell and Rupp (1995)
XTRP, CLIM, and HPAC	Extrapolation, climatology, and ½ persistence ½ climatology	Sampson et al. (1990)

TABLE 2. Suite of objective forecast aids run at FNMOC and distributed to ATCF 3.2 workstations.

Model ID	Model name or description	Key references
GFDN and GFDE	Navy GFDL model N = 0–72-h forecasts E = older forecasts relabeled to appear current	Rennick (1999) Kurihara et al. (1995)
NGPS, NGPX, and NGPE	NOGAPS Vortex Tracker S = 0–72-h forecasts X = 84–120-h forecasts E = older forecasts relabeled to appear current	Hamilton (1996) Goerss and Jeffries (1994) Hogan and Rosmond (1991)
NRPP	NORAPS Vortex Tracker	Hamilton (1996) Liou et al. (1994)
OTCM	OTCM	Hamilton (1996) Hodur and Burk (1978)

Satellite and radar imagery ingest, display, and the majority of the tropical cyclone fix determination are done on separate equipment at the forecast center or by outside tropical cyclone fixing agencies. These fixes are then entered into the ATCF via a fix entry dialog. The fix entry function includes capability to enter fixes from visible, infrared, Special Sensor Microwave/ Imager and radar imagery, aircraft, scatterometer winds, and conventional surface reports.

c. Objective aids

A large suite of tropical cyclone objectives aids is run on the ATCF workstation (Table 1). Many of the objective aids require NWP model data that are maintained in the TEDS relational database mentioned in the previous section. Other objective aids are initiated by transmission of a synthetic tropical cyclone observation or warning message over the Internet to Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California. These objective aid forecasts are computed at FNMOC and transmitted back to ATCF workstations. The suite of objective aid forecasts computed at FNMOC is shown in Table 2. Finally, forecasts from objective aids not listed in either Tables 1 or 2 can be manually entered into ATCF via an objective aid entry dialog. Objective aid forecasts are then displayed on the storm window (Fig. 3).

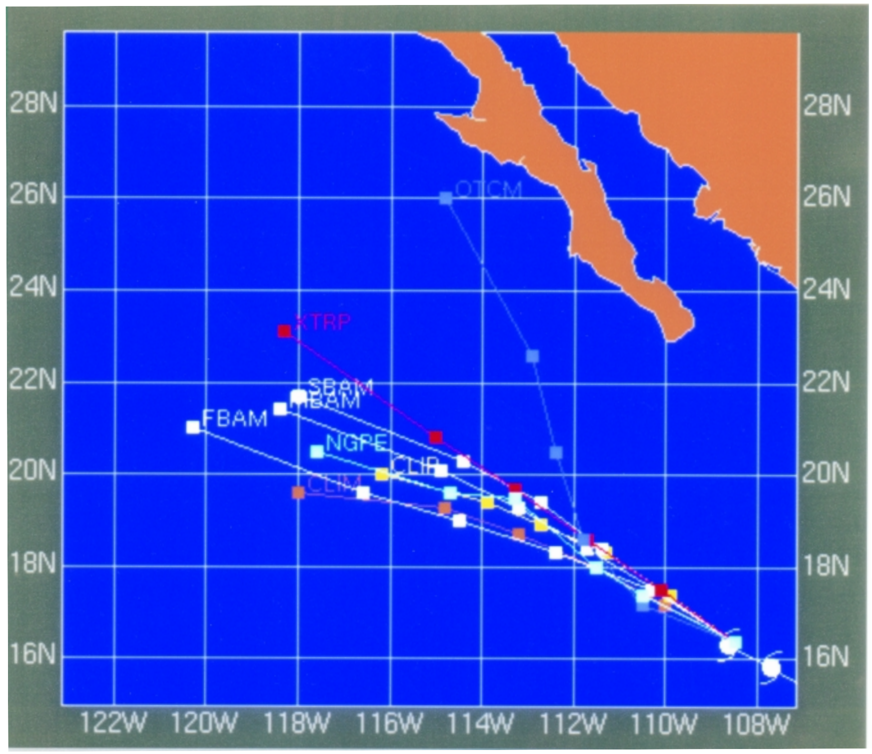

FIG. 3. Objective aid display for Hurricane Blas at 1800 UTC 25 June 1998. Tropical cyclone symbol near 16°N, 108°W represents track position at 1800 UTC. Multicolored lines represent track forecasts for many objective aids listed in Tables 1 and 2. Squares along forecast tracks indicate 12-, 24-, 36-, and 72-h track positions. The light blue square superimposed on tropical cyclone symbol indicates track position at time of objective aid computation.

Performance of objective aids can be monitored qualitatively by overlaying old forecasts on the track or quantitatively through use of two online statistical routines. The first statistical routine computes historical forecast errors for one objective aid and for a single storm. The second statistical routine computes head-to-head forecast errors of selected objective aids for a single storm. Based on output from the statistical routines, forecasters can focus attention on exceptional performers in the objective aid suite and ignore poor performers. The two statistical routines can also be used to compute an objective aid's performance over the entire season. A look at mean forecast errors (Table 3) indicates that the One-Way Influence Tropical Cyclone Model (OTCM) performed poorly in the eastern North Pacific during the 1997 season (a mean forecast error of 394 nm for 61 cases). In 1997 head-to-head comparisons, forecast error is higher for OTCM than for any of the other objective aids included in Table 3. It is difficult to prove inferior or superior performance of objective aids, but routinely monitoring mean forecast errors can bring attention to objective aid coding problems and provide quantitative feedback for objective aid developers. OTCM was rarely used in operational forecasting at U.S. DOD forecast centers during the 1998 season.

Forecasters can view loops or static overlays of NWP model forecast data to check consistency of objective aid forecasts with synoptic conditions. For example, the most current Navy Operational Global Atmosphere Prediction System (NOGAPS) surface pressure analysis (Fig. 4a) shows a high center northwest of Hurricane Blas (the third tropical cyclone of the 1998 eastern North Pacific season). This high pres-

TABLE 3. Head to head comparisons of 1997 72-h mean forecast error (nm) for objective aids shown in Fig. 3 (NGPE not included). Objective aids are listed along each axis; intersections of rows and columns indicate head-to-head comparisons between the column objective aid and the row objective aid. Each box contains the number of cases (upper left), column (upper right) and row (lower left) mean forecast errors and difference between row and column errors (lower right). A positive value in the lower right corner indicates that row objective aid mean error is larger than that of the column.

	FBAM	MBAM	SBAM	OTCM	CLIM	CLIP	XTRP
FBAM	166 313 313 0						
MBAM	166 313 311 –2	166 311 311 0					
SBAM	166 313 328 15	166 311 328 17	166 328 328 0				
OTCM	44 278 368 90	44 259 368 109	44 277 368 91	61 394 394 0			
CLIM	163 314 348 34	163 314 348 34	163 331 348 17	49 382 310 –72	181 342 342 0		
CLIP	162 313 288 –25	162 310 288 –22	162 328 288 –40	57 391 264 –127	175 347 286 –61	218 285 285 0	
XTRP	166 313 326 13	166 311 326 15	166 328 326 –2	57 391 282 –109	179 344 317 –27	218 285 321 36	222 322 322 0

sure, which remains in place throughout the 48-h forecast period (Fig. 4b), should inhibit northward movement. The most current NOGAPS 500-mb streamline and isotach analysis (Fig. 4c) and 48-h forecast (Fig. 4d) reinforce a westward motion forecast, although a midlatitude trough passing north of the tropical cyclone within the first 24 hours of the forecast period could affect the motion of Blas. It is decided that the midlatitude trough passage appears to be quite far north and probably will not alter the west–northwest course of the tropical cyclone.

The Blas 1200 UTC location in the NOGAPS surface pressure analysis is close to the 1200 UTC location in ATCF. This indicates that synthetic tropical cyclone observations (Goerss and Jeffries 1994) were used in the analysis and that NOGAPS was initialized properly to include the tropical cyclone circulation. Blas is represented as a closed circulation in the 1000-mb wind analysis (not shown), which is a requirement for successful execution of the NOGAPS vortex tracker (Hamilton 1996). NOGAPS 1000-mb wind forecasts are looped to ensure that the vortex tracker follows the tropical cyclone circulation center through time.

Given that the synoptic conditions shown in analysis and forecast charts are thought to be those associated with a west–northwest moving tropical cyclone and that the majority of the objective aid forecast tracks indicate such, a west–northwest motion is forecast.

d. Forecasts

Track, intensity (maximum wind speed), and wind radii forecasts are all constructed on the ATCF (Fig. 5). Track forecast positions are constructed first by clicking the mouse in the desired location on the map background. Then, intensity and wind radii forecasts are entered using a series of dialogs. Track and wind radii are displayed or refreshed on the map instantaneously so that forecasted winds can be viewed as they are being constructed. In ATCF 3.2, track forecasts can be defined in 12-h increments out to 72 hours, and intensity and wind radii forecasts are constructed for each track position. The intensity forecasts are defined in increments of 2.5 m s^{-1} (5 knots) while the wind radii can be defined in increments of 9.26 km (5 nautical miles) for winds greater than 18, 25, 33, and 51 m s^{-1} (35, 50, 65, and 100 kt, respectively). Shapes for the wind radii include combinations of circles, semicircles, and quadrants. Intensity forecast guidance within ATCF is currently limited to a few objective aids (model IDs CLIP, CLIM, HPAC, XTRP, RECR, and STRT in Table 1). Wind radii forecast guidance is limited to two routines described in Miller et al. (1990). The authors anticipate adding tools to view intensity and wind radius guidance in the coming years.

e. Warning products

Forecasters generate textual warning products for each forecast. In ATCF 3.2, there are four different textual representations of the warning—the warning that is disseminated to the public and three products specific to U.S. Navy computer systems. Forecasters interact with ATCF to generate the warning described in the U.S. Commander in Chief, Pacific Command Instruction (3140.W), and then the three other textual warning products are generated automatically.

In the last few years, great emphasis has been placed on World Wide Web technology. DOD tropical cyclone forecasters now use the Web in both forecast preparation and warning dissemination. After a warning is generated, forecasters post a graphical display of the warning on the command Web page (Fig. 6). These graphical displays are generated manually through a series of mouse

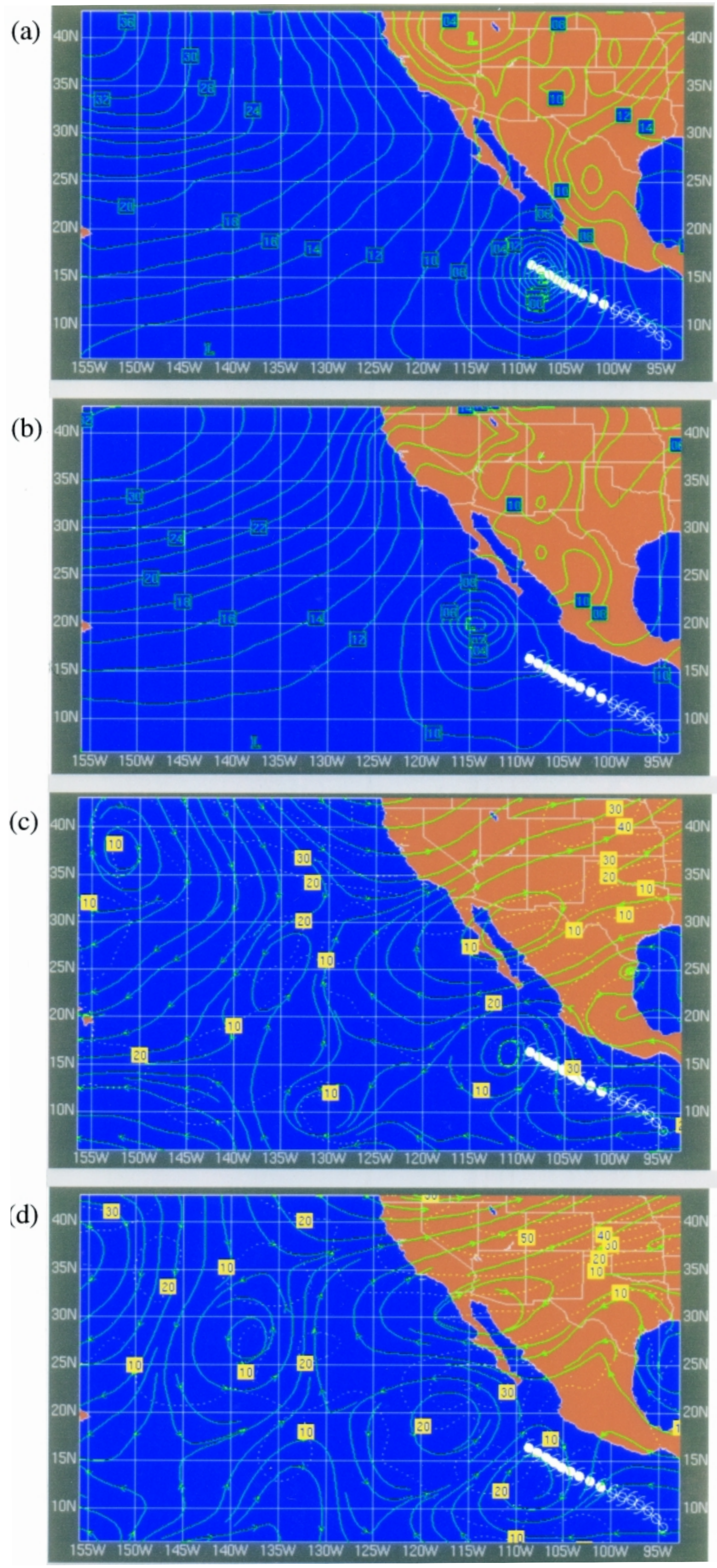

FIG. 4. (a) NOGAPS surface pressure analysis for 1200 UTC 25 June 1998 superimposed on the Hurricane Blas historical track. Westernmost tropical cyclone symbol indicates the 1800 UTC 25 June 1998 position of Blas. Isobars are drawn in increments of 2 mb. (b) NOGAPS 48-h surface pressure forecast for 1200 UTC 27 June 1998. (c) NOGAPS 500-mb streamline and isotach analysis for 1200 UTC 25 June 1998. Isotachs are in increments of 10 kt. (d) NOGAPS 48-h forecasted 500-mb streamlines for 1200 UTC 27 June 1998.

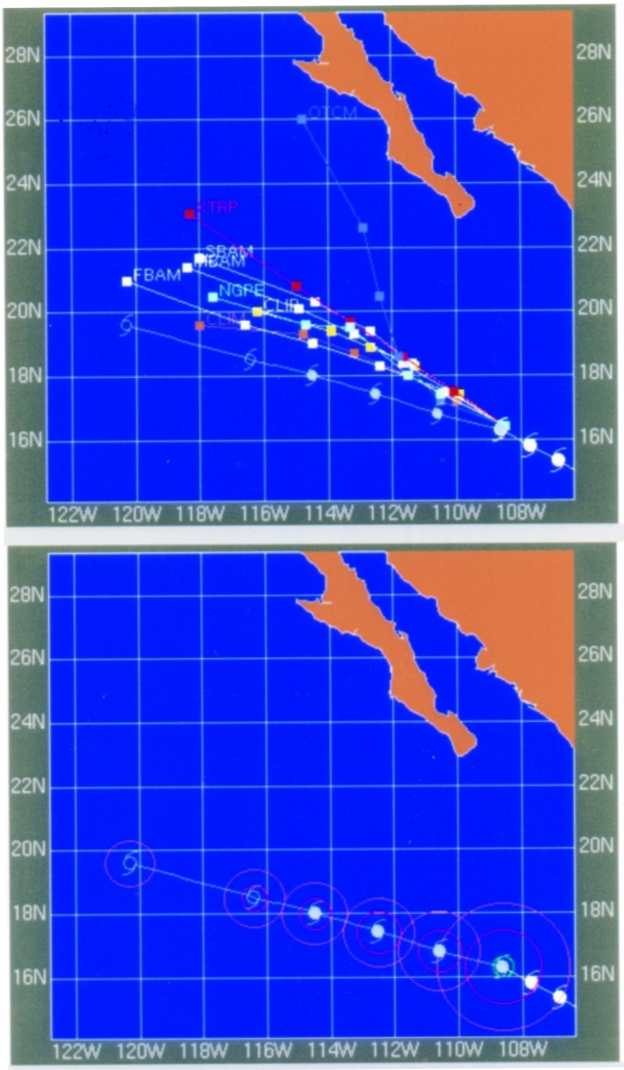

FIG. 5. (top) Objective aid display for Hurricane Blas at 1800 UTC 25 June 1998 with graphical display of user 12-, 24-, 36-, 48-, and 72-h forecast track (purple) south of other objective aid tracks shown. Six-hourly historical track positions are shown as white tropical cyclone symbols. (bottom) Hurricane Blas forecast track for 1800 UTC 25 June 1998 with estimated and forecast wind radii. From the outside in, radii encompassing tropical cyclone symbols indicate locations of the 18, 25, and 50 m s^{-1} winds, respectively. In this figure, the only 50 m s^{-1} wind radius is for the 0-h position.

clicks. Included on the display are graphical representations of the past, present, and future tropical cyclone positions; present and future wind radii; a text label with information about the warning; and another label defining closest points of approach to geographical locations.

f. Operational support and backup

ATCF has evolved into an integral part of U.S. DOD tropical cyclone forecast center operations. As such, it is expected that the system function robustly on demand throughout the year. In order for this to occur, special provisions have been developed to support the system. The first phase of support is one or more experienced on-site ATCF users who train other users and troubleshoot problems. These on-site individuals handle the bulk of users' problems with the software. Even though the great majority of them are not formally trained system administrators, nor have much experience with UNIX, they do an outstanding job of solving most problems on site. The second phase of support is a Web-based support system, which includes an electronic log for reporting software bugs, a 6-hourly storm file backup, and system performance reports. The electronic bug log plays an important role in support because it allows users to note problems and ask questions while working shifts. Responses from ATCF developers provide answers and corrective solutions to users within days. The electronic bug log and system performance reports are monitored daily by developers at NRL. Developers use data from the 6-hourly storm file backup to debug software problems. Storm data files are retrieved from the Web-based storm file backup to recreate problems reported in the electronic bug log. Solutions are developed at NRL, code and/or data are transferred to the operational centers, and solutions are reported back to users via the bug log. The third phase of support is the telephone, which is usually reserved for critical problems. Problems reported by telephone tend to get higher priority support than those listed in the bug log, but use of the bug log ensures that problems are formally recorded and that assets are assigned to fix them. Most problems are fixed within days, if not within hours, of when they are reported. This rapid response is possible because the same small cadre of programmers is charged with both development and support. Hence, bugs are isolated, fixed, and delivered to operations with minimal bureaucracy and efficient coordination.

Replacement equipment and manpower are also available in the event of catastrophic software and/or equipment failure. Each forecast center has a backup ATCF installed on site that can be pressed into service if the primary ATCF fails. Storm data on the backup system are updated daily and are ready for immediate use. In the event that a forecast center is unable to create or disseminate a warning, a previously designated backup center will assume forecast responsibility while the primary center recovers its capabilities.

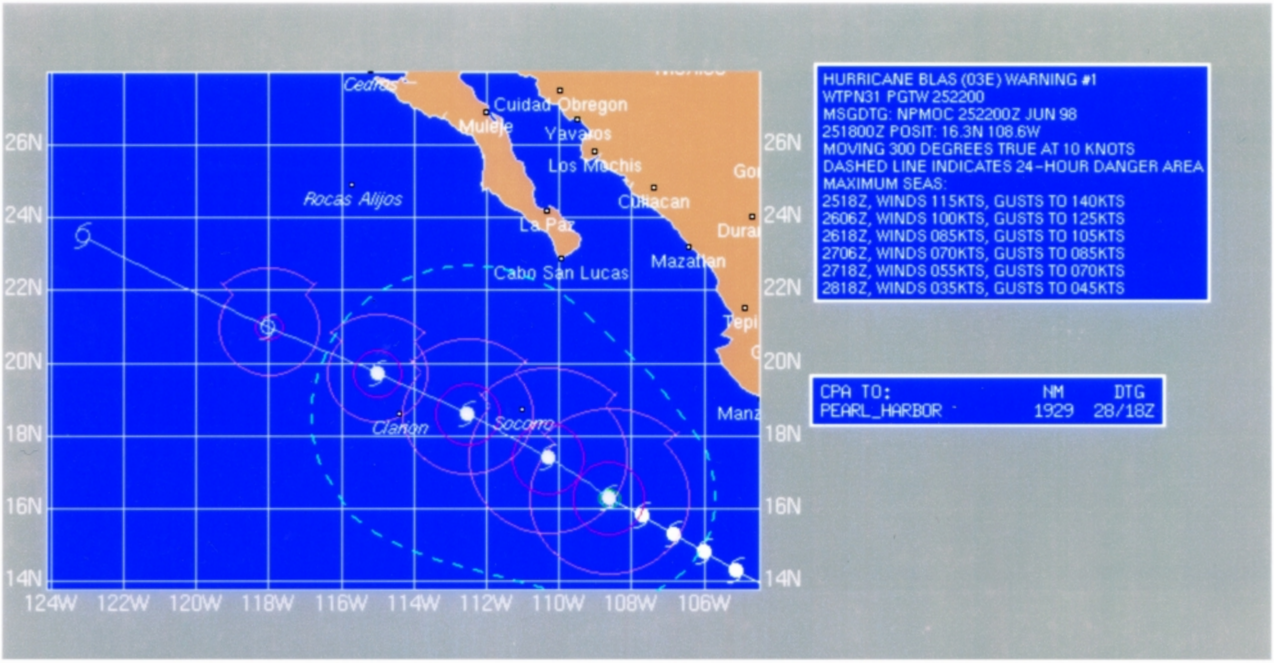

FIG. 6. Warning graphic depicting an official warning produced by the Naval Pacific Meteorology and Oceanography Center, Pearl Harbor, at 2200 UTC 25 June 1998. The graphic includes 6-hourly historical track positions (white tropical cyclone symbols), and the 0-, 12-, 24-, 36-, 48-, and 72-h forecast positions (purple tropical cyclone symbols). From the outside in, radii encompassing tropical cyclone symbols indicate the locations of the 18, 25, and 50 m s^{-1} winds, respectively. Also included is a danger area (dashed line), which is an exclusion area for U.S. Navy ships at sea. In ATCF, the danger area is computed by adding an average position error for the forecast agency to the maximum 18 m s^{-1} wind radius. The danger area shown here is a sum of individual 0-, 12- and 24-h areas. Upper box on the right is a summary of the warning message, while the lower box indicates closest point of approach (CPA) to different geographical points.

4. Conclusions

It is difficult to demonstrate quantitatively that improvements to ATCF have increased forecaster efficiency or forecast quality. User feedback, which is much easier to obtain, is often solicited and used as a measure of performance. Recent correspondence from JTWC states that ATCF "has developed into a robust and reliable tool which is used by the Joint Typhoon Warning Center (JTWC) for all phases of forecast development and warning dissemination. All of the mission essential and mission enhancing requirements originally identified . . . have been met."

While ATCF performs many of the menial tasks of forecasting admirably, there is plenty of room for improvement. Lists of user requirements are gathered from users and prioritized annually. A few of the major requirements that will be addressed in the next release include: forecasting beyond 72 hours, ensuring Y2K compliance, and internal storage of an expanded list of tropical cyclone parameters such as central pressure and outermost closed isobar.

Acknowledgments. Thanks are in order to the many unheralded programmers who have worked on the UNIX version of ATCF, among them Ron Miller, Ted Tsui, Kent Dolan, Mike Frost, Sally Calvert, Daren Grant, Doug Roesser, Harry Hamilton, Mary Clifford, Earl Ravid, and Mugur Georgescu. The hardworking employees of JTWC, NPMOC, and NLMOC are also acknowledged forconstructive suggestions that helps us improve ATCF. Thanks are also in order for the insightful comments of our NRL colleagues, James Gross of NHC, Ed Fukada of NPMOC/JTWC, and two anonymous reviewers. Finally, we gratefully acknowledge the support of the Oceanographer of the Navy through the program office at the Space and Naval Warfare Systems Command (PMW-185), Program Element 0603207N.

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