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THE EVOLUTION OF DAILY FORECAST VERIFICATION FOR SHUTTLE LANDING SITES

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1. INTRODUCTION

After the 1986 *Challenger* accident, the NWS Spaceflight Meteorology Group (SMG) at the Johnson Space Center (JSC) began issuing daily forecasts and collecting verification data for shuttle landing sites in the Continental United States, Spain, Morocco, and The Gambia (Brody et al., 1997) (See Table 1). Specifically, these sites are: 1) the Kennedy Space Center Shuttle Landing Facility, Florida, 2) Edwards AFB, California, 3) White Sands Space Harbor, New Mexico, 4) Zaragoza, Spain, 5) Moron, Spain, 6) Ben Guerir, Morocco, and 7) Banjul, The Gambia. This effort was done in order to maintain forecast proficiency while preparing for the Shuttle's Return to Flight. SMG continues to issue daily Shuttle landing site forecasts. More recently SMG no longer issues forecasts for Banjul, The Gambia, but has begun issuing forecasts for Le Tube (Istres), France at the request of the JSC **Ascent/Entry Flight Techniques Panel (AEFTP). Figure 1 depicts a timeline of these events. Daily forecast verification times are dependent on the launch and landing times of the next scheduled shuttle mission. Since the launch time of the next flight has not been determined, SMG has arbitrarily begun verifying forecasts at 1600 UTC each day.

Daily SMG forecast verification statistics have been maintained since 1987 and are periodically reviewed and used to help develop or refine shuttle weather flight rules. Bellue and Cunningham (1990) first described this effort and subsequent developments have been described by Bellue (1993). Garner (1999, 2000) utilized actual Shuttle mission forecasts from STS-60 (February, 1994) to the present to generate Mission Forecast Statistics to further refine Shuttle weather flight rules. Changes in forecast codes, e.g. the addition of the FEW cloud amount category and the cloud height placement following the cloud amount, have prompted changes to the SMG forecast data collection and verification decoding scheme. The migration from one computer system to another has prompted updates, for example from the Meteorological Interactive Data Display System (MIDDS) (Rotzoll, 1991) mainframe computer to the MIDDS distributed system and then to AWIPS. Reformatting of the data collected before these changes were made became a prerequisite to generating a standardized database (Bellue, 1998). Forecast data older than 1997 have been reformatted to appear as existing data to create a standardized SMG verification database. Some fields,

TABLE 1. SMG DAILY FORECAST SUITE
times vary with planned landing of next upcoming shuttle mission

SITE	FORECAST LEAD TIME	VERIFIES AT
TTS (KSC) Shuttle Landing Facility, FL	90 min 30 min 90 min 90 min 15 hr 24 hr 72 hr	12Z 16Z 16Z 20Z 16Z 16Z 16Z
E28 (NOR) White Sands Space Harbor, NM	90 min 90 min 15 hr 24 hr 72 hr	16Z 20Z 16Z 16Z 16Z
EDW Edwards AFB, CA	90 min 90 min 15 hr 24 hr 72 hr	16Z 20Z 16Z 16Z 16Z
ZZA Zaragoza, Spain	30 min 15 hr 24 h 72 hr	16Z 16Z 16Z 16Z
MRN Moron, Spain	30 min 15 hr 24 hr 72 hr	16Z 16Z 16Z 16Z
BEN Ben Guerir, Morocco	30 min 15 hr 24 hr 72 hr	16Z 16Z 16Z 16Z
BYD*** Banjul, The Gambia	30 min 15 hr 24 hr 72 hr	16Z 16Z 16Z 16Z
FMI**** Le Tube (Istres), France	30 min 15 hr 24 hr 72 hr	16Z 16Z 16Z 16Z

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** The JSC Ascent / Entry Flight Techniques Panel is chaired by the Flight Directors' Office and is comprised of Flight Controllers from various disciplines. Its purpose is to review all aspects of Shuttle flight and advise the Shuttle Program of any changes in equipment and procedures necessary to accomplish human spaceflight safely and efficiently.

*** BYD was dropped as a TAL site in 2002. Consequently, SMG forecasting ceased for that site then.

**** LFI was added to SMG forecast suite in 2003 resulting from a request of the AEFTP 10/10/03.

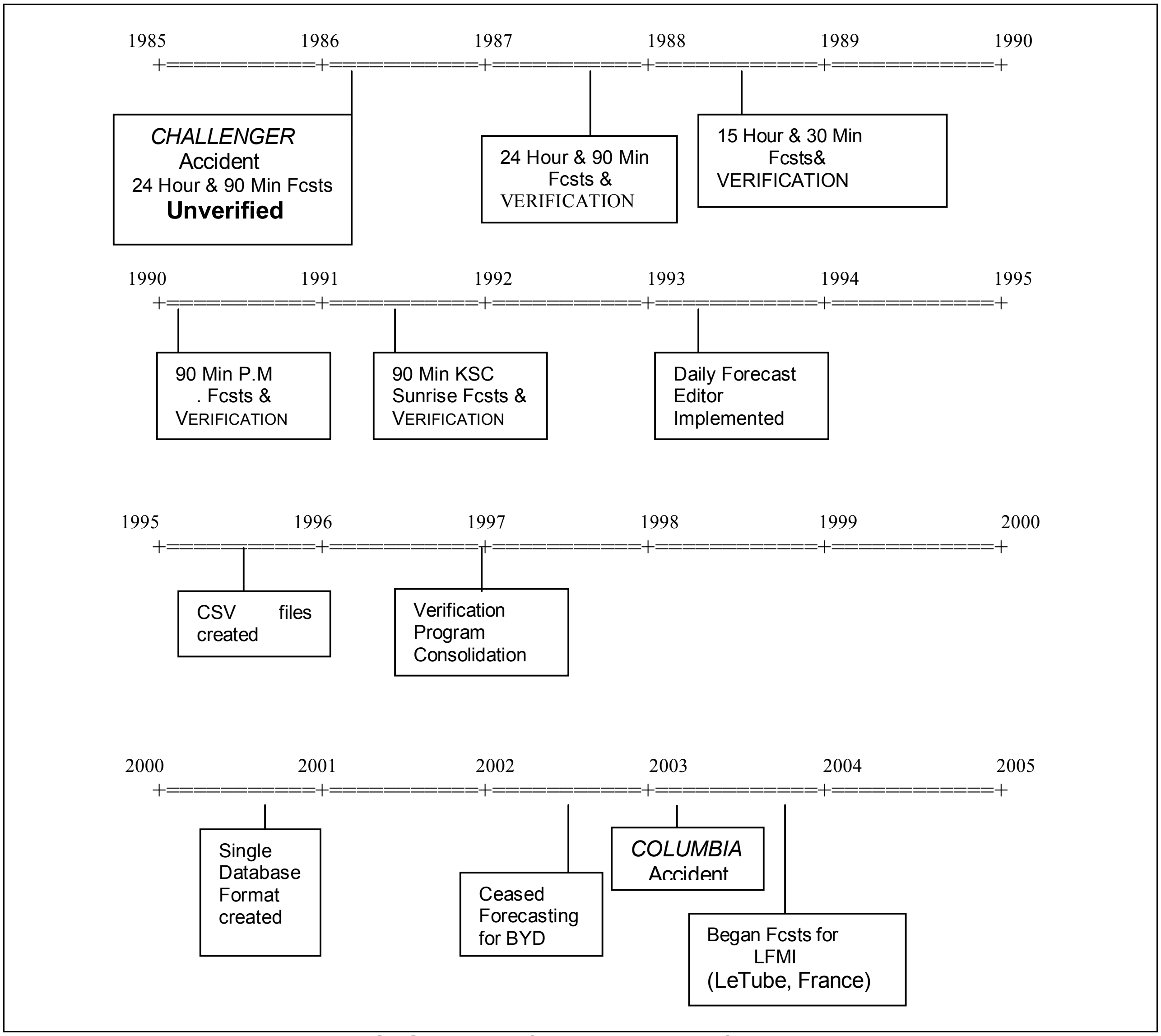

Figure 1. SMG Timeline of Daily Forecast Verification Evolution

for example forecaster ID, altimeter, and temperatures, from these earlier data are not available since the information was never recorded. It was found during the process of reformatting the older data that some original 1989 data are missing; however, the tabulated forecast accuracy statistics, created from the original data, were available and are now combined with existing data to obtain an overall forecast accuracy statistic for the period of September 1987 to October 2003. Development of a standardized database described by Bellue (2001) has been achieved and is another enhancement to the verification effort.

2. METHODOLOGY

SMG verifies forecasts based on a generic set of Shuttle Weather Flight Rules (NASA, 2002) (See Table 2), which has been simplified for the ease of verification. For example, night time and extended mission Flight Rule limits are not verified. Elements dealing with cloud height and amount, visibility, precipitation, and wind are verified. A fifth element, the "Overall" category, is a combination of the first four elements. All elements must be observed or forecast "GO" (i.e. not exceeding the flight rule limit) to have the Overall category element be "GO". Any one element that is "NO GO" (i.e. exceeding the flight rule limit) makes the Overall category "NO GO".

Initially, each of these elements was evaluated using the contingency table in Table 3. At the outset of the verification effort SMG followed the direction of the AEFTP to provide a reasonable estimate of forecast accuracy. Specifically, the AEFTP requested that SMG demonstrate a 95 percent forecast accuracy rate in "GO" forecasts prior to "Return to Flight" in 1988.

TABLE 2. WEATHER FLIGHT RULE LIMITS ***

*** *RULES VARY BETWEEN NIGHT AND DAY AND FROM SITE TO SITE. THESE REFLECT SIMPLIFIED LIMITS FOR VERIFICATION ONLY.*

Generic Weather Flight Rules	
CEILING	"GO" = 8000 ft AGL or greater
VISIBILITY	"GO" = 5 statute miles or greater
PRECIPITATION	"GO" = none within 30 nmi (including VIRGA)
CROSSWIND	"GO" = 15 kts or less
HEADWIND	"GO" = 25 kts or less
TAILWIND	"GO" = 10 kts or less
GUST SPREAD	"GO" = 10 kts or less between steady state and peak

Statistics were gathered with emphasis on the percent "Correct GO" Forecasts. The idea was to maximize the percent correct "GO" forecasts and minimize what was termed a "categorical" busted forecast, a forecast of "GO" condition and an observed "NO GO" condition. This is somewhat different than overall forecast accuracy. Forecasts that were issued as "NO GO" and verified as "GO", though in error, were not considered as bad as the forecasts that were "GO" and verified as "NO GO". Reports to the AEFTP continued through the early 90s concentrating only on Percent "Correct GO" forecasts. As more data were collected and false alarm forecasts occurred, SMG was requested to identify the cause of the error and quantify the extent. The forecasts of cloud ceilings were the cause of most forecast errors. This knowledge brought about changes in the Weather Flight Rules that addressed the observed cloud amount prior to the de-orbit burn decision time, which about 90 minutes prior to the Shuttle's landing time.

Table 3. SMG's Contingency Table for the Evaluation of Weather Flight Rules

Forecast GO Observed GO **Correct GO**	Forecast GO Observed NO GO **Busts**
Forecasts NO GO Observed GO **Missed Opportunities**	Forecast NO GO Observed NO GO **Correct NO GO**

Table 4 is a generic 2 X 2 contingency table used in the evaluation of forecast elements as a means to calculate categorical and skill scores as defined in Shaefer (1990) and Doswell et al. (1990). Thus, the Success Ratio (SR), the False Alarm Rate (FAR), Probability of Detection (POD), Bias, Critical Success Index (CSI), and Heidke Skill Score (HSS) can be identified. Garner (1999) developed mission forecast

Table 4. Generic 2 x 2 Contingency table for the evaluation of a forecast element. (see text)

	Observed GO	Observed NO GO
Forecast GO	x	z
Forecast NO GO	y	w

scores based on NO GO conditions. These are as follows:

$$\text{Correct Forecasts} = x + w \quad (4.1)$$

$$\text{Correct GO Forecasts} = x \quad (4.2)$$

$$SR = x / (x + z) \quad (4.3)$$

$$\text{Busts} = z \quad (4.4)$$

$$\text{Missed Opportunities} = y \quad (4.5)$$

$$\text{FAR of GO} = z / (x + z) \quad (4.6)$$

$$\text{FAR of NO GO} = y / (y + w) \quad (4.7)$$

$$\text{POD of GO} = x / (x + y) \quad (4.8)$$

$$\text{POD of NO GO} = w / (z + w) \quad (4.9)$$

$$\text{Bias} = (x + z) / (x + y) \quad (4.10)$$

$$CSI = x / (x + y + z) \quad (4.11)$$

$$HSS = 2(xw - yz) / ((y^2 + z^2 + 2(y + z)(x + w)) \quad (4.12)$$

As concern grew for launch availability due to short launch windows in International Space Station (ISS) rendezvous flights, more emphasis was given to the understanding of the percent of missed "NO GO" forecasts. Therefore in addition to identifying the percent "Correct "GO" forecasts (or Success Ratio), SMG proceeded to calculate percentages for all Correct Forecasts, POD, FAR, HSS, BIAS, and CSI. More recently, some individual flight rule limit parameters have been varied to determine if an increase in launch and landing probabilities could be achieved, if new limits were applied. Specifically, ceiling limits have been varied from 8 000 ft to 5 000 ft to 3 000 ft and analyzed to determine if lowering the limits contributed to any increased launch and landing probabilities. Garner (1999 and 2000) described statistics generated from actual Shuttle mission forecasts back to STS-60 (February, 1994) to determine weather impacts on shuttle operations. Now SMG has two consistent, though not identical databases, of forecast data. Both the mission and daily forecast databases, provide a sound basis for assessing SMG's forecasting capabilities.

Daily forecasts for each site and each forecast time are entered using the Daily Forecast Editor (Myers, 1993). The current Forecast Editor has evolved from the original one due to SMG equipment changes, but its function remains as an interface to write forecasts to a daily file. Forecasts are written each day Monday through Friday. The first written forecast of the day is a "Sunrise" 90 Minute KSC forecast, attempting to simulate the Shuttle de-orbit decision made in darkness and landing in daylight. Next, the 90 Minute AM forecasts and the 30 Minute Forecasts verifying at *1600 UTC are written. These simulate forecasts for End of Mission and the Return To Launch Site (RTLS) landing, respectively. Then the 1600 UTC verification data for the current day is collected and entered. Next, the 24 hour forecasts for the following day are written followed by the afternoon 90 minute forecasts verifying at 2000 UTC. After 2000 UTC, the verifying 2000 UTC observations are collected and entered. Finally, the 15 Hour Forecasts are written just before the office closes for the day. On Fridays, no 24 hour forecasts are written, instead, a 72 hour forecast is written for the following Monday. All forecasts are saved in a file identified by the Julian Date.

** The verification time varies from mission to mission. The current verification time is 1600 UTC.*

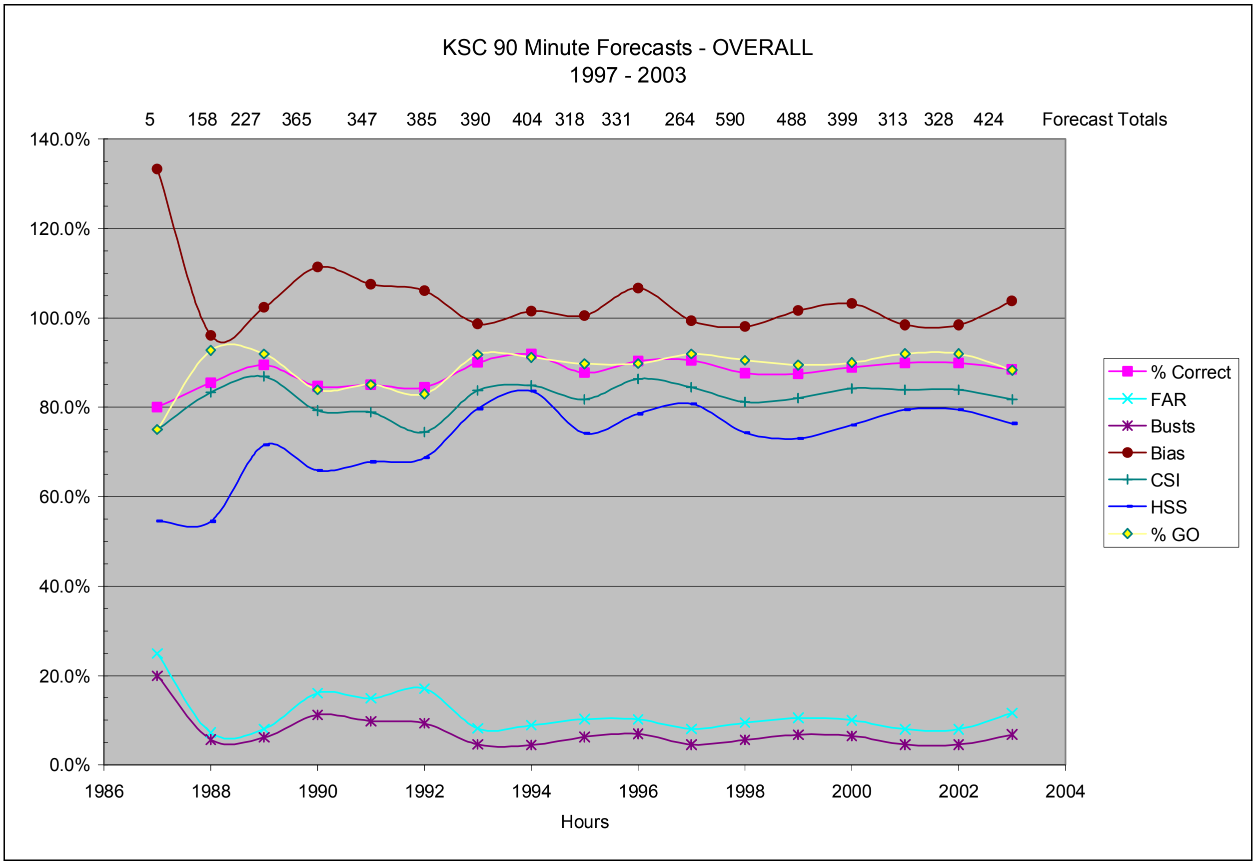

Figure 2. Graph of Forecast Accuracy Parameters for the Shuttle Landing Facility, Florida since 1997
(Numbers listed above graph are actual number of forecasts for all 90 minute KSC forecasts.)

3. Forecast Database and Product Output

One forecast file per day is created. These files are manually transferred from the Advanced Interactive Weather Processing System (AWIPS) to the MIDDS before being downloaded manually to a compact disk. Data are then collected and saved into a "year" file on an office PC. Various macros are used to parse data and evaluate results based on the sites, the forecast times, and the individual forecasters. Results from each "year" file are collected and posted to a master forecast verification file. Table 5 lists the data header IDs for the elements of the SMG verification database. Daily files are imported directly into the "year" file, where quality control of the data is exercised whenever obvious errors occur. Once data are moved into the "year" file, various macros are employed to evaluate conditions and parse that information into appropriate worksheets. Forecast statistics are created using the decoded data and each site is evaluated based on forecast accuracy, POD, FAR, Bias, CSI, and HSS. Figure 2 shows 90 Minute Forecast statistics for the OVERALL Category for the KSC Shuttle Landing Facility, Florida for the period from September 1987 through October 2003. The FAR is for NO GO conditions. Figures 3 and 4 show the forecast accuracy for the Ceiling and Winds category of KSC 90 Minute Forecasts generated for the same period.

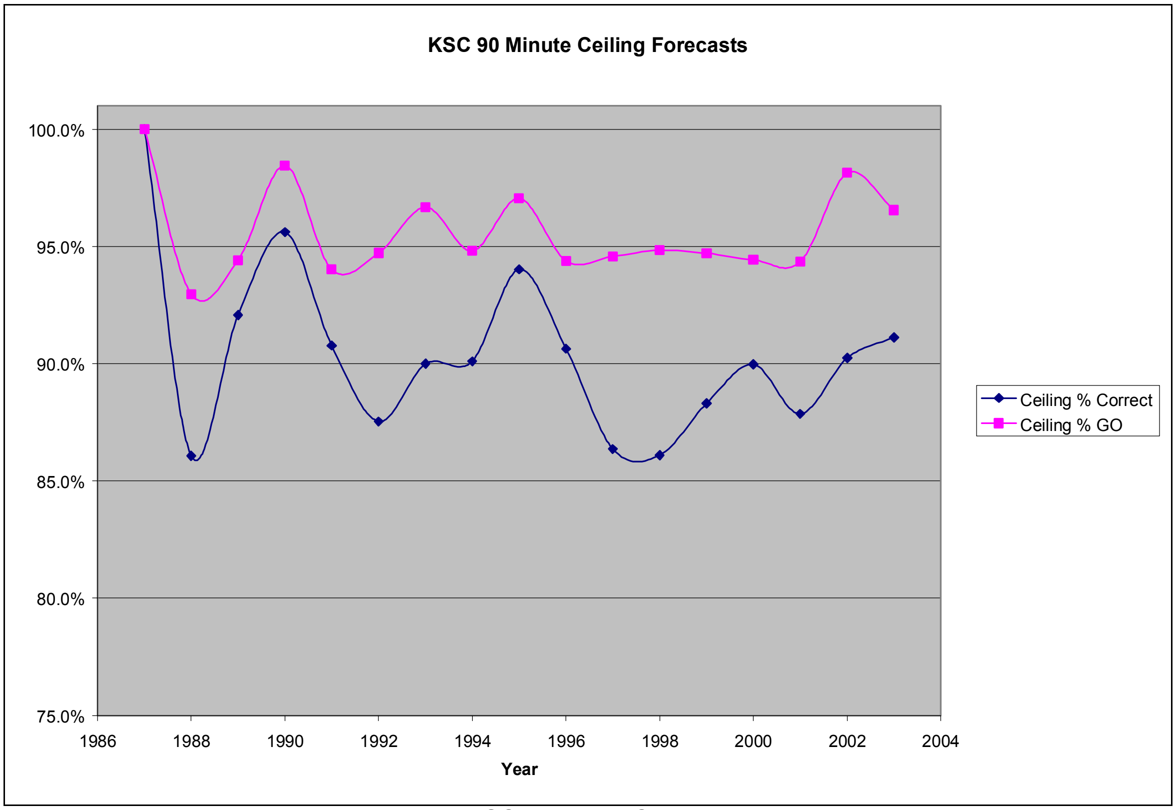

Figure 3. KSC 90 Minute Ceiling Forecasts

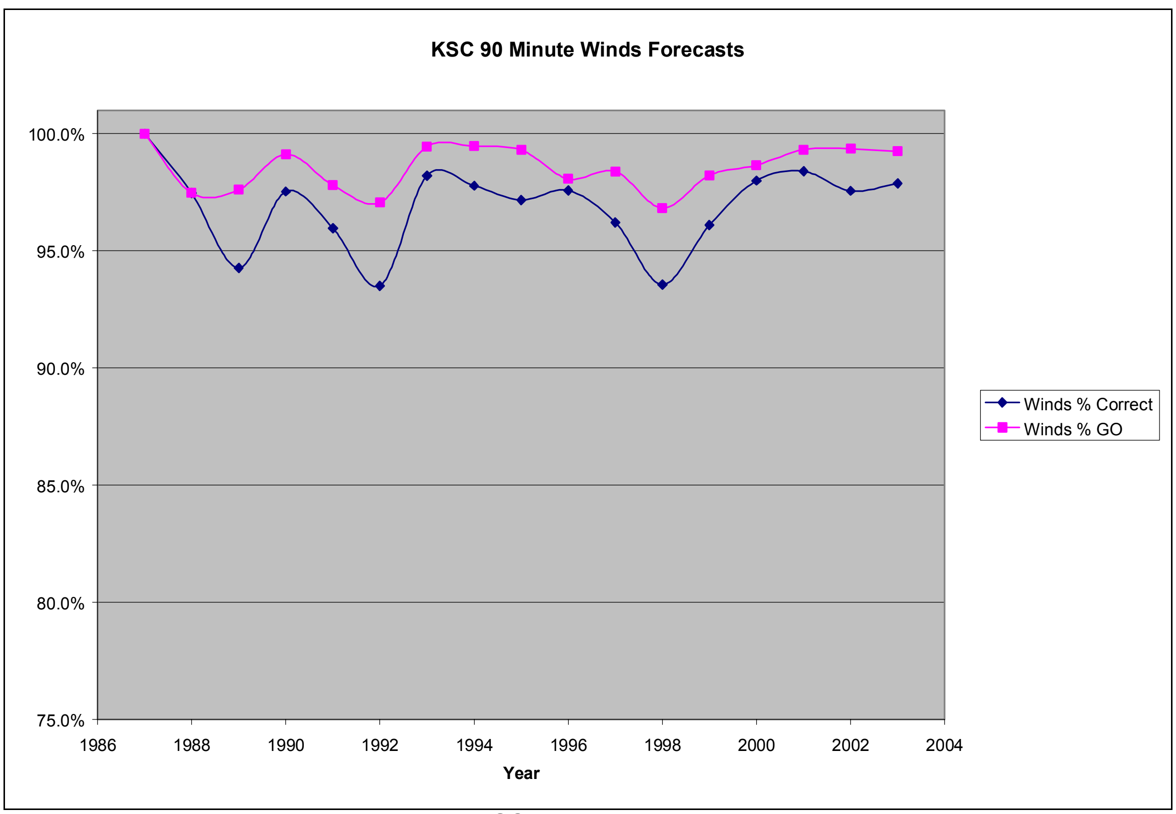

Figure 4. KSC 90 Minute Wind Forecasts

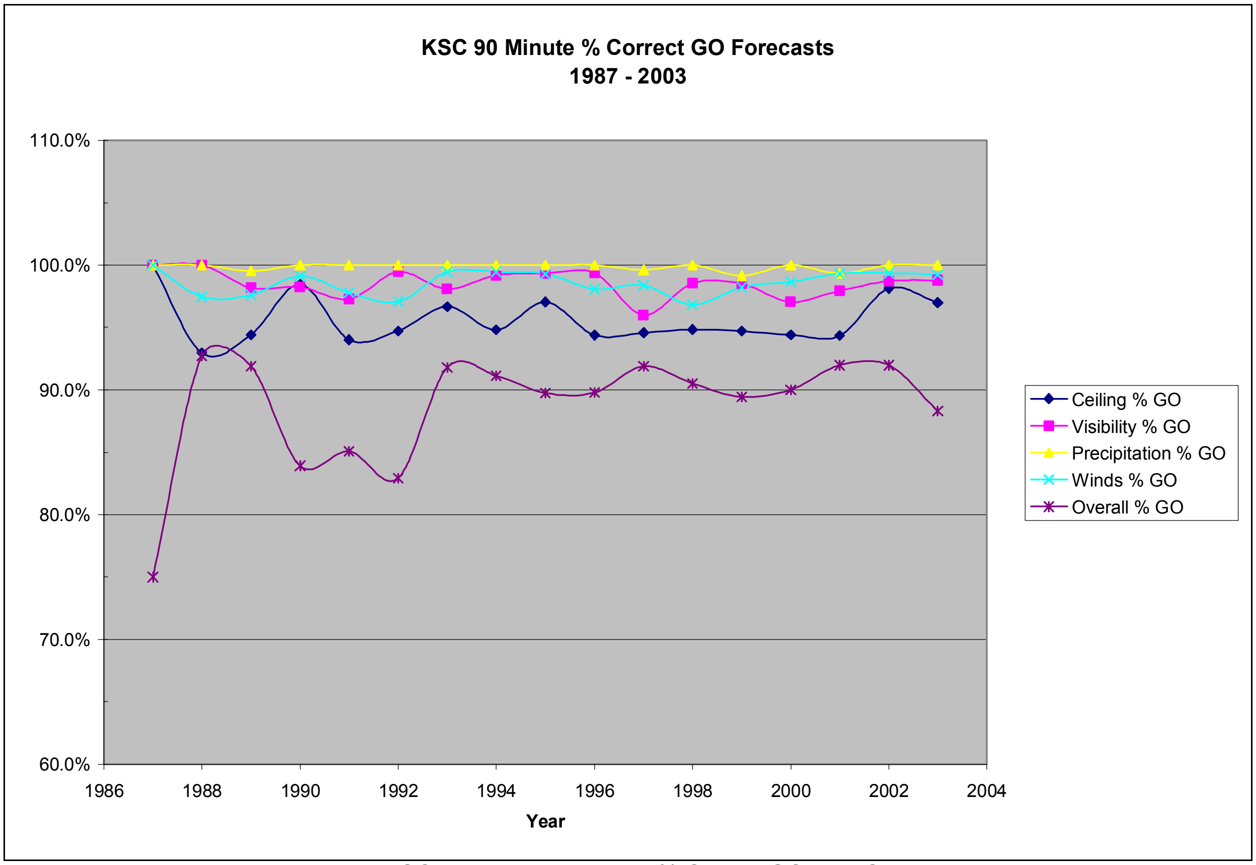

Figure 5. KSC 90 Minute Forecasts % Correct GO – All Categories

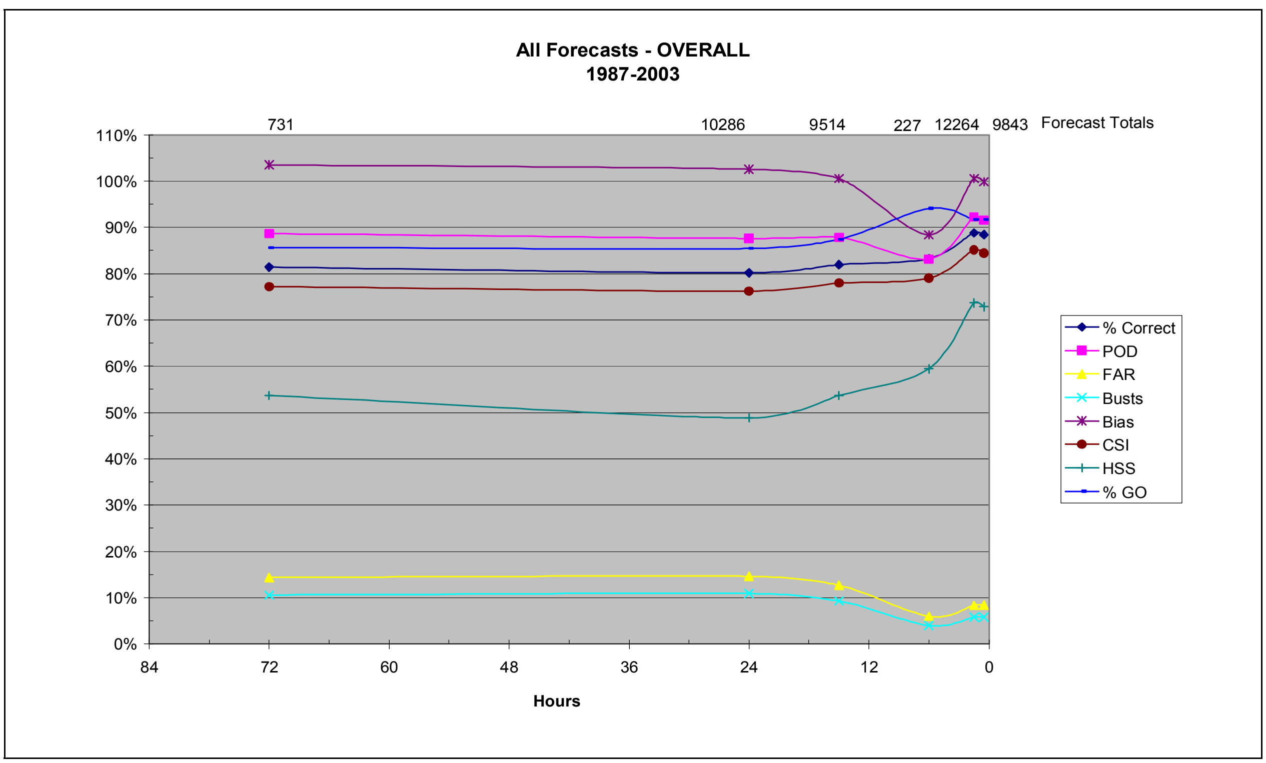

Figure 6. Graph of Forecast Accuracy Parameters for the SMG Forecasts generated from 1987 to Present.
(Numbers listed above graph are actual number of forecasts for 72 hours, 24 hours, 15 hours, 6 hours, 90 minutes and 30 minutes.)

Of the Ceiling forecasts note that the percent Correct forecasts average about 90 % and the percent "Correct GO" forecasts average about 95 %, though there is some variability from year to year. The wind forecasts show slightly higher forecast accuracies. Figure 5 shows all the percent Correct 90 Minute KSC forecasts for all categories. Ceiling forecasts have provided the greatest challenge. Figure 6 is a graph of all forecasts for all times and is another example of output created from the master file. This may account for some lack of variation from 1993 to present. It may be interesting to note that SMG's current group of forecasters has been in place since 1994. These graphs show at slightly more consistent pattern after this time.

4. CONCLUSIONS

Analysis of the SMG Daily Forecast Database show similar results to those found in the Mission Forecast Database. Specifically, while there is increased improvement in forecast accuracy from 72 hours to 30 minutes, there remains a minor downward decline from earlier forecasts in the 15-hour and 6 hour forecasts. This feature shows up at most all sites. The standardized Daily Forecast Database allows for a variety of comparisons. Also, Flight Rule parameter limits can be varied to determine if lowering or raising the limits changes any forecast scores.

5. FUTURE ENHANCEMENTS

Initial automatic entry of verifying observations into the database is in work and should be a significant time-saver once accomplished. The initial entry is meant to be a starting point and not an end unto itself. Forecasters will have to evaluate each observation using a variety of tools to fully document what occurred. Also, incorporation of updated flight rules for each site, e.g. cloud ceilings and visibility limits of 8000 ft and 5 miles to 5000 feet and 4 miles, will be done to the 30 minute forecasts. The "master" database file is available on CD and will be updated annually. Additionally, retrieval of past observations not entered as a result of simulation and mission support has not been attempted, but will be given consideration as time permits.

6. ACKNOWLEDGMENTS

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