NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

VALUE OF FORECASTER IN THE LOOP

by

Michael J. Harris

September 2014

Thesis Advisor:	Patrick A. Harr
Second Reader:	Wendell A. Nuss

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704–0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 2014

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE
VALUE OF FORECASTER IN THE LOOP

5. FUNDING NUMBERS

6. AUTHOR(S) Michael J. Harris

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB Protocol number ____N/A____.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words)

Over the past 20 years, there have been many advancements in the process of weather. Specific contributions to improvements in the forecast process come from improvements in numerical model forecast guidance and the timely availability of many new observational data types. As numerical forecasts guidance improves, it has become important to document the value a human forecaster adds to the forecast process. Because of collateral duties and career requirements, United States Navy forecasters often find it difficult to become proficient at forecasting. In this study, a basic forecast process was used to identify the skill in forecasts of ceiling and visibility made by human forecasters and produced by a statistical modification to numerical model fields. Terminal Aerodrome Forecasts (TAF) were collected for eight military air stations and compared to the performance of the Localized Aviation Model Output Statistics Program (LAMP). Hit rates and critical success indices were used to identify forecast skill. Using various timelines and categorical partitions, all results showed that there were little to no statistical differences between the TAF and LAMP in 2013. Finally, a case study was examined to highlight the capability of probability forecasting as an improvement to the forecast process.

14. SUBJECT TERMS
numerical model , forecaster in the loop, Human Forecaster, forecast skill

15. NUMBER OF PAGES
77

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540–01-280-5500

Standard Form 298 (Rev. 2–89)
Prescribed by ANSI Std. 239–18

THIS PAGE INTENTIONALLY LEFT BLANK

VALUE OF FORECASTER IN THE LOOP

Michael J. Harris
Lieutenant Commander, United States Navy
B.A., Thomas Edison State College, 2010

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND PHYSICAL OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
September 2014

Author:	Michael J. Harris
Approved by:	Patrick A. Harr Thesis Advisor
	Wendell A. Nuss Second Reader
	Wendell A. Nuss Chair, Department of Meteorology

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Over the past 20 years, there have been many advancements in the process of weather. Specific contributions to improvements in the forecast process come from improvements in numerical model forecast guidance and the timely availability of many new observational data types. As numerical forecasts guidance improves, it has become important to document the value a human forecaster adds to the forecast process. Because of collateral duties and career requirements, United States Navy forecasters often find it difficult to become proficient at forecasting. In this study, a basic forecast process was used to identify the skill in forecasts of ceiling and visibility made by human forecasters and produced by a statistical modification to numerical model fields. Terminal Aerodrome Forecasts (TAF) were collected for eight military air stations and compared to the performance of the Localized Aviation Model Output Statistics Program (LAMP). Hit rates and critical success indices were used to identify forecast skill. Using various timelines and categorical partitions, all results showed that there were little to no statistical differences between the TAF and LAMP in 2013. Finally, a case study was examined to highlight the capability of probability forecasting as an improvement to the forecast process.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

AC	anomaly correlation
CNMOC	Commander Naval Meteorology and Oceanography Command
COAMPS	Coupled Ocean Atmosphere Mesoscale Prediction System
CSI	critical success index
FAR	false alarm rate
FITL	forecaster in the loop
FWC	fleet weather centers
GFS	global forecast system
IFR	instrument flight rules
IMC	instrument meteorological conditions
LAMP	Localized Aviation Model Output Statistics Program
METOC	Meteorology and Oceanography
MOS	model output statistics
MVMC	marginal visual meteorological conditions
NAS	naval air station
NAVGEM	Naval Global Environmental Model
NCEP	National Center for Environmental Prediction
NEDN	Naval Environmental Data Network
NOGAPS	Naval Operational Global Atmospheric Prediction System
NTSB	National Transportation Safety Board
NWP	numerical weather prediction
RUC20	20 km rapid update cycle
TAF	terminal aerodrome forecast
VFR	visual flight rules
VMC	visual meteorological conditions
WRF-NMM	Weather Research and Forecasting Nonhydrostatic Mesoscale Model

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

Many thanks to Professor Patrick Harr for his guidance and patience; Judy Ghirardelli at NOAA for her quick turnaround of my LAMP requests; TJ Long for his long hours on the Excel set up; and Kate Hermsdorfer and William Sauer for their critical tutoring skills.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. MOTIVATION

Over time, the process of weather forecasting has evolved along several fronts. Initially, a weather forecaster had access to a relatively small amount of information upon which a complete analysis of the current weather conditions and prediction of future conditions were to be based. This analysis had to be equally valid for a forecaster's region and remote regions. Because information was scarce and its accuracy may have been suspect, the analysis was often based on the forecaster's subjective interpretation of the data and a persistence factor based on an earlier interpretation of limited data. Therefore, accurate forecasts were very dependent on knowledge that the forecaster possessed with respect to basic meteorological principles, the regional locations, the accuracy of information being provided.

Today, the forecast process remains largely one in which information is continually made available for interpretation by the forecaster. However, there is now an often overwhelming amount of information available. The increase in information is due to two factors. One is the vast number of products made available to provide forecast aids. These may be output from extremely complex numerical weather prediction (NWP) models, statistical models that modify or blend observations and output and NWP models, or software that displays observations from a very large number of sources.

The second factor is the capability to deliver large amounts of information to the forecast in a timely manner. The forecast process is often strictly controlled by time in which a number of forecast products must be delivered to a variety of customers. Today, the electronic transfer and display of products can be accomplished rapidly to meet the constraints of the forecast release schedule.

The value of humans as forecaster in the loop (FITL) during the forecasting process has been in debate since the advent of NWP models in the 1960s (Stuart et al. 2006). Like their civilian counterparts, Navy forecasters draw from several numerical models, forecasting rules of thumb, and personal knowledge when building their forecast.

In the early 1990s, forecasters started the forecasting process by hand drawing a surface analysis and identifying bogus observations to be deleted from the model run. Today, the numerical model is operating mostly autonomously and arguably has become the primary consideration of today's Navy forecasters.

Over the past 20 years, the accuracy of NWP forecasts has improved considerably (Figure 1) Here, forecast skill is expressed in terms of the anomaly correlation (AC), which is a measure of forecast skill score relative to climatology. The AC of the five day forecasts from the Global Forecast System (GFS) from the National Centers for Environmental Prediction (NCEP) has improved from 0.7 in 1990 to about 0.88 in 2013. Using the AC as a benchmark for forecast skill relative to climatology, the value of 0.6 is the acceptable score for a "useful." Figure 2 quantifies that improvement in the terms of days. From 1990 to 2013 the GFS has increased its useful forecasts of 500 hPa height from six to over eight days.

In addition to the model guidance, there are several advances in technology like satellite data that have increased resolution and frequency, increased access to observations, and satellite derived winds and rain rate products. All of these and much more aid in providing better initial conditions upon which a model forecast suite is based, and they aid in the interpretation of model data by the forecaster. Add in the Internet for the rapid delivery of all these products and it is no wonder that forecasting desk has dramatically changed over the past fifteen years.

As late as 1993, the Naval Operational Global Atmospheric Prediction System (NOGAPS) model was transmitted to the forecaster at the Naval Western Oceanography Center twice a day via the Naval Environmental Data Network (NEDN). The charts were pulled and spliced together by meteorological technicians and hand delivered to the forecaster's workstation. Today, Naval Global Environmental Model (NAVGEM), Coupled Ocean Atmosphere Mesoscale Prediction System (COAMPS), GFS, and a host of other global and regional models, are delivered via the Internet to provide a variety of products directly to the forecaster's computer in almost any format at least four times a day.

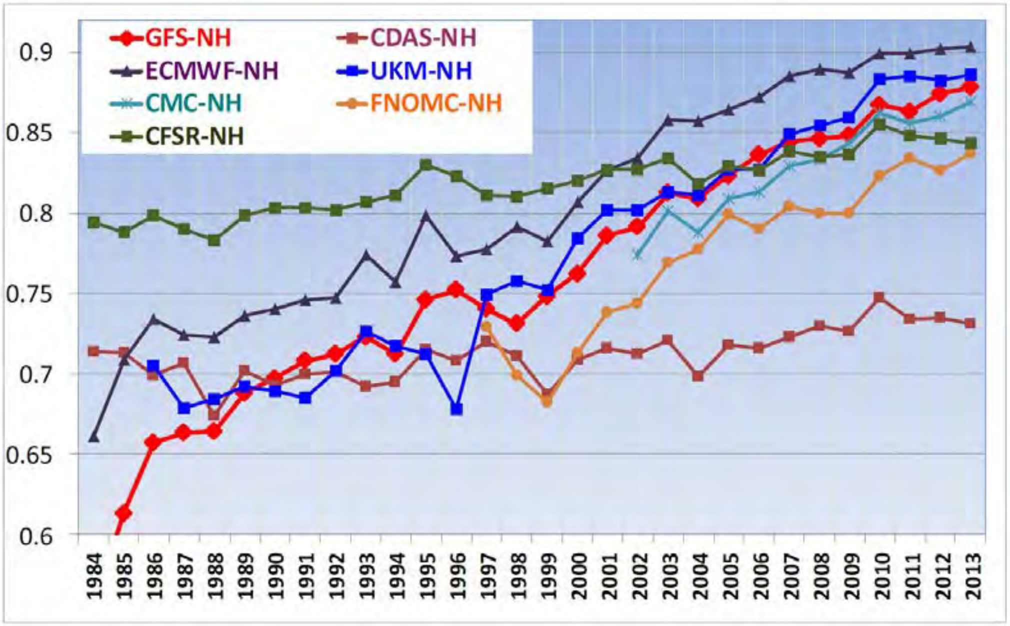


Figure 1. Annually-averaged anomaly correlation for the five day forecast of 500-hPa heights averaged over the Northern Hemisphere (after Yang 2013)

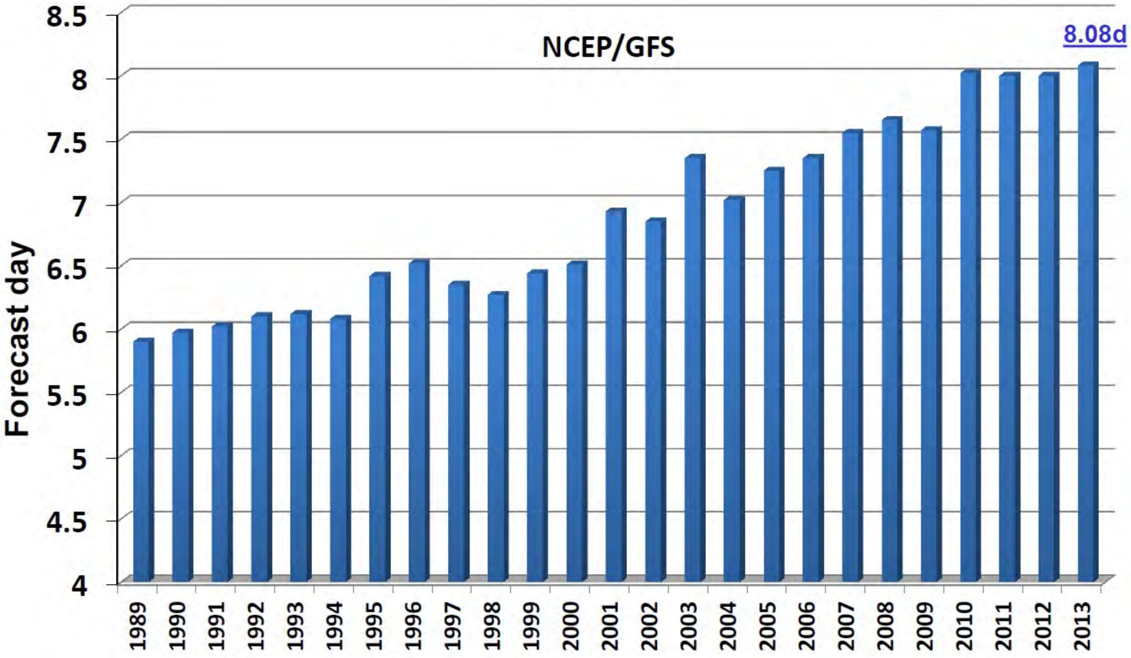


Figure 2. Annually-averaged forecast day at which the 500 hPa height forecast loses useful skill (AC=0.6) for the Northern Hemisphere (after Yang 2013)

Even with this significant improvement in model guidance and technology associated with observations and delivery of guidance, it is still widely known that NWP does not provide completely accurate analyses and forecasts, and are only valuable in guiding the human forecaster in the prediction process under some uncertainty (Stuart et al. 2006). Even so, it has been difficult to quantify exactly how much the forecaster improves the process on a daily basis. This is partly because the level of improvement is highly dependent on skill level and dedication of the particular forecaster (Doswell 1986). While skill level can be increased through training and experience, factors like dedication, motivation, initiative and other intangible characteristics are under the control of the forecaster alone. Unfortunately, these characteristics are difficult for the Navy to specifically seek since there is not a traditional interview process when selecting entry-level forecasters. Additionally, the Navy career comes with multiple responsibilities that may be important for individual career advancement but may be counterproductive to developing a true professional forecaster. Rotating through various duty stations every two to four years and additional duties such as driving unmanned vehicles and performing hydrographic surveys help to slow down the experience process. This is not to say that there are not extremely talented forecasters in the Navy. There are many forecasters who consistently outperform the average.

When examining the training and development of Navy forecasters, there are additional factors that stand out as areas of concern in regards to properly grooming skillful forecasters. No longer do forecasters start their apprenticeship by obtaining weather observations, analyzing the current state of the atmosphere with hand-drawn charts, or take upper-air soundings to analyze the air column using the skew-T diagram. The lack of these types or practical experiences combines with the requirements for collateral duties as defined above to prevent the forecaster from obtaining valuable experience.

Additional factors have impacted the Navy weather forecast process. There has been a the realignment of the meteorology and oceanography (METOC) community into specialized directorates. Civilian forecasters now sit at the forecast desk of all Naval Air Stations (NAS) and several key maritime forecasting desks at the Fleet Weather Centers

(FWC). Both of these factors have led to a reduction in the hands-on forecasting experience for the typical Navy forecaster to a level that is far less than what it was fifteen to twenty years ago. With all these limiting factors to gaining meaningful experience, it would be expected that the Navy forecaster is leaned heavily on much improved model guidance. Lastly, despite the advances in the skill level of the model and the broadening of the expected technical expertise, the baseline forecasting training has yet to be significantly updated to keep pace with modernization of the forecasting positon. The Training Course Control Document for Aerographer's Mate Class C-1 Course, dated June 2013 is still very much the same forecasting course it was in 1996.

The goal of this thesis is to simply compare Navy forecaster performance to the performance of a numerical model to determine the level of value being added to the NWP guidance. Beyond assessing value, a specific forecast application is considered to define how frequent forecast input would be critical to a daily operation. This provides a measure of the relative frequency by which a Navy forecaster input would be a critical part of the decision-making process.

B. IMPORTANCE TO NAVAL APPLICATION

In ever-increasing budget constraints and manning reductions, there is a requirement to seek efficiencies in the forecast process. These include improved techniques, relevant training, and/or automation where feasible. Once the level of value added to a NWP guidance model by the Navy forecaster is assessed, better decisions can be made as to how to use resources to capitalize on that value. Additionally, over a broad range of forecasts that are assessed, it may be a relatively small number that have direct impact on the decision-making process. Whether the value is minimal or indispensable, better decisions can be made to affect the training, equipping and/or the placement of Navy forecasters throughout the Navy's operations. While this study will only look into a small portion of the Navy forecaster's responsibility, it should be considered a reliable indication of overall forecasting performance.

C. BACKGROUND

1. Terminal Aerodrome Forecast

To assess the FITL, a suitable forecast process is required. In terms of this thesis, a suitable process is one in which several factors can be examined. These are defined as:

1) The forecast is produced over a set operational timeline and schedule;
2) There are equivalent model-based and forecaster-based forecast products;
3) There is an identifiable mission-critical role in which the forecast is a critical part of the decision-making process.

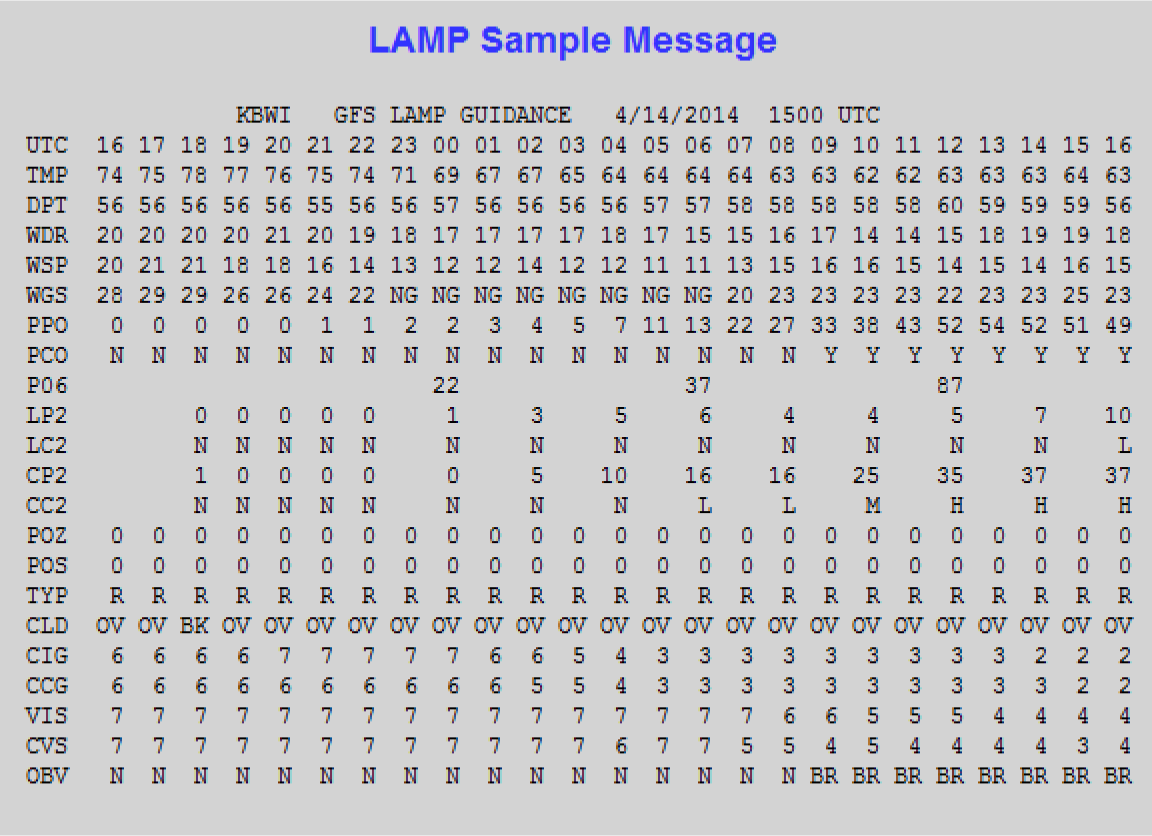
Based on these criteria, production of the Terminal Aerodrome Forecast (TAF) is chosen as the forecast process to be examined in this thesis.

Although weather forecasts are often provided out to five days, the Navy forecaster's operational impact is generally centered over the next 24 h forecast period. Specifically, naval airfields rely on the production of the TAF that is produced for a 24 h period and updated at least every eight hours. The TAF is the only operational forecast in which format, transmission time, and content are standardized across the Navy and produced specifically for a sole purpose of safety of flight. Other operational forecasts are tailored to individual customers based on their specific mission and assets. Of all types of forecasts, TAFs are required to be most precise in terms of measurable weather conditions and in terms of timing of those elements (Riordan and Hansen 2002).

Governed by Naval Meteorology and Oceanography Command instruction 3143.1H, the TAF is developed by forecasters for individual airfields to specifically support safety of flight for in and outbound flights. The TAF is issued every eight hours and provides expected weather conditions for the next 24 hours for that particular airfield. It is considered a micro-scale forecast and requires precise techniques and terminology. It is also used locally to make critical base operation decisions, such as fueling and movement of ammunition. The TAF addresses predominate and temporary forecast conditions. The predominate forecasts are expected to occur during a majority of the forecast period, whereas the temporary conditions are expected to occur less than an hour at a time and less than half the forecast period.

2. Localized Aviation Model Output Statistics Program (LAMP)

The LAMP is a system of objective analyses, simple models, regression equations, and related thresholds which together provide guidance for sensible weather forecasts (Ghirardelli 2005). Issued hourly, the LAMP updates GFS-Model output statistics (MOS) using the most recent observations. The GFS-MOS are station specific text bulletins produced every six hours to be used as forecasting guidance. It uses the GFS model as a baseline and improves on that using observational and geoclimatic data specific to the individual station (Antolik 2012). The LAMP is run on NCEP computers and disseminated centrally from NCEP. Lamp guidance is provided for over 1500 stations as well as thunderstorm guidance on a 20 km grid out to 25 hours. The LAMP is primarily produced and distributed as an aviation forecasting reference model.



LAMP Sample Message

```
               KBWI   GFS LAMP GUIDANCE   4/14/2014  1500 UTC
UTC  16 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16
TMP  74 75 78 77 76 75 74 71 69 67 67 65 64 64 64 64 63 63 62 62 63 63 63 64 63
DPT  56 56 56 56 56 55 56 56 57 56 56 56 56 57 57 58 58 58 58 58 60 59 59 59 56
WDR  20 20 20 20 21 20 19 18 17 17 17 17 18 17 15 15 16 17 14 14 15 18 19 19 18
WSP  20 21 21 18 18 16 14 13 12 12 14 12 12 11 11 13 15 16 16 15 14 15 14 16 15
WGS  28 29 29 26 26 24 22 NG NG NG NG NG NG NG NG 20 23 23 23 23 22 23 23 25 23
PPO   0  0  0  0  0  1  1  2  2  3  4  5  7 11 13 22 27 33 38 43 52 54 52 51 49
PCO   N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  Y  Y  Y  Y  Y  Y  Y  Y
P06                          22                37                87
LP2         0  0  0  0  0     1     3     5     6     4     4     5     7    10
LC2         N  N  N  N  N     N     N     N     N     N     N     N     N     L
CP2         1  0  0  0  0     0     5    10    16    16    25    35    37    37
CC2         N  N  N  N  N     N     N     N     L     L     M     H     H     H
POZ   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
POS   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
TYP   R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R  R
CLD  OV OV BK OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV OV
CIG   6  6  6  6  7  7  7  7  7  6  6  5  4  3  3  3  3  3  3  3  3  3  2  2  2
CCG   6  6  6  6  6  6  6  6  6  6  5  5  4  3  3  3  3  3  3  3  3  3  3  2  2
VIS   7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  6  6  5  5  5  4  4  4  4
CVS   7  7  7  7  7  7  7  7  7  7  7  7  6  7  7  5  5  4  5  4  4  4  4  3  4
OBV   N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N BR BR BR BR BR BR BR BR
```

Figure 3. A sample LAMP Bulletin. Available from the National Weather Service at http://www.nws.noaa.gov/mdl/gfslamp/docs /LAMP_description.shtml.

In a LAMP bulletin (Figure 3), each forecast hour is presented across the columns from left to right. The meteorological elements that are verified in this thesis are cloud cover (CLD), primary ceiling heights (CIG), conditional ceiling heights (CCG), primary visibility (VIS) and conditional visibility (CVS).

The production of LAMP bulletins as hourly updates to the six hourly GFS-MOS bulletins is diagramed in Figure 4. For example, the 0600 UTC GFS-MOS bulletin is issued at approximately 1000 UTC since there is an approximate 4 h processing time. The LAMP bulletins are then issued hourly based on the 1000 UTC GFS-MOS bulletin from 1000 UTC through 1500 UTC. After 1500 UTC, the 1600 UTC GFS-MOS bulletin is available, which is then the basis for subsequent LAMP bulletins.

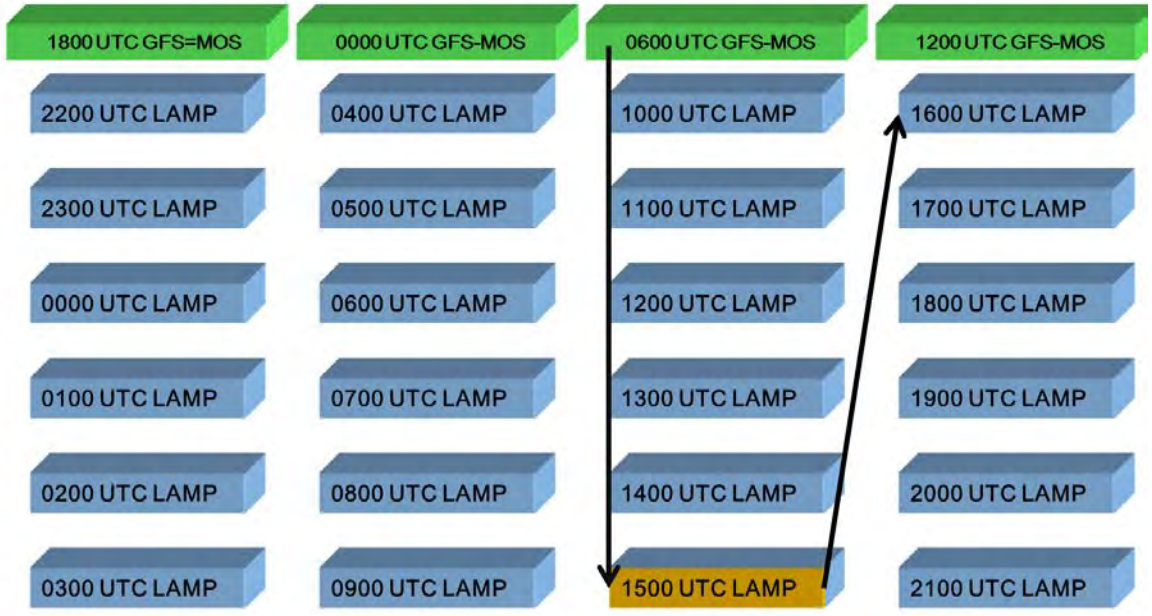


Figure 4. Schedule of LAMP updates in relation to the GFS-MOS bulletins

The LAMP was chosen as the model guidance for this study partly because of its hourly format and availability, but also for a recent verification study that scored LAMP better than a number of regional models. In this study, it was demonstrated that the LAMP categorical forecasts of ceiling height below 1000 ft and visibility below 3 miles are more accurate than the 20 km Rapid Update Cycle (RUC20) and the Weather Research and Forecasting Nonhydrostatic Mesoscale Model (WRF-NMM) (Rudack and Ghirardelli 2010).

The Critical Success Index (CSI) scores for the three models compared in the study (Figures 5 and 6), for October 2006 through March 2007, compared favorably with respect to persistence forecasting. Persistence can be defined as the existence of statistical dependence among successive occurrences of a given event (Wilkes 1995). The CSI is a statistic used in place of a hit rate when an event desired occurs significantly less than non-occurrence (Wilkes 1995). The specific format of the CSI is defined in Chapter II., but the CSI accounts for correct forecasts, erroneous forecasts and forecasts of events that do not occur. The CSI score varies from zero to one, with one being a perfect score. Since 2006, LAMP has undergone a number of improvements, including a 2012 upgrade of the ceiling parameters (McClung 2012) and has also benefited from the continued improvement of the GFS model.

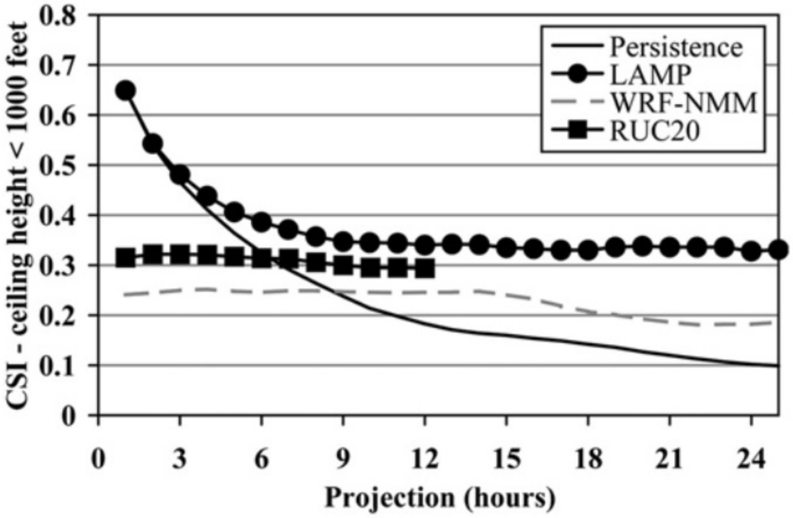


Figure 5. The CSI for ceiling below 1000 ft for Oct 2006-Mar 2007 (Rudack and Ghirardelli 2010)

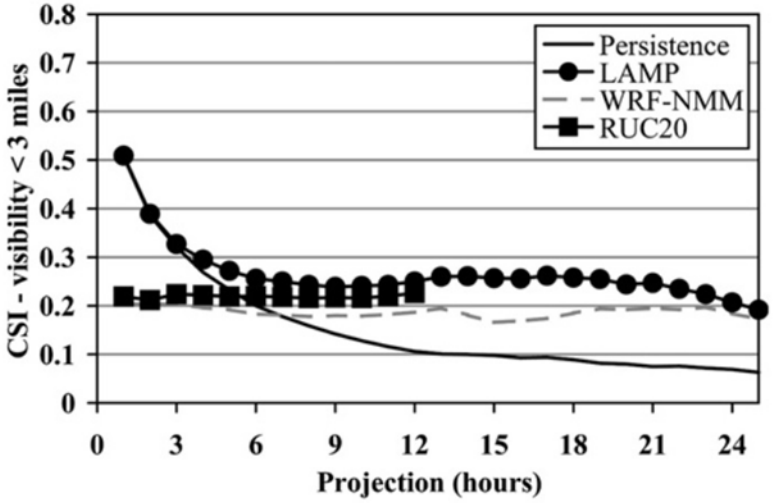


Figure 6. The CSI for visibility below 3 nm for Oct 2006-Mar 2007 (Rudack and Ghirardelli 2010)

II. METHODOLOGY

A. DATA SELECTION AND COLLECTION

The 1500 UTC TAF and LAMP were selected as the primary forecasts to be verified due to their availability throughout the calendar year 2013. The 1500 UTC forecasts are also issued during the periods of active runway hours across the continental United States and should represent the forecaster’s best effort. The TAFs and observations were collected from a weather information service provider named OGIMET (www.ogimet.com). OGIMET is the only site archiving TAFs electronically for either civilian or Department of Defense forecasts. The OGIMET database begins in 2005 for some stations and Navy TAFs are available as far back as September 2006. The LAMP bulletins were attained by email request to the National Weather Service Office of Science and Technology. Forecast stations (Figure 7) were selected to sample various environmental conditions with respect to continental locations. Naval Air Station (NAS) Ocean (KNTU) and NAS Jacksonville (KNIP) were selected to represent the eastern portion of North America. NAS Ft. Worth (KNFW), NAS Meridian (KNMM), and NAS Fallon (KNFL) were selected to represent the continental region. Finally, NAS Lemoore (KNLC) and NAS Whidbey Is (KNUW) were selected to represent western North America. Additionally, conditions at KNLC represent the interior central valley portion of California while KNUW is a Pacific Northwest coastal location. Wheeler Army Air Field (AAF) (PHHI) in Hawaii was selected for a tropical/island station.

Figure 7. Forecast station locations

In addition to the full 24 hr verification in 2013, this study separately verified the 13-h through 24 h period of each forecast to eliminate the nowcast. The intent here is to provide a measure of forecaster skill several hours after the initial observation.

The earliest TAFs available from archives are from September 2006. In an effort to determine the rate of improvement based on this verification style, the TAFs from October 2006 through March 2007 were collected and compared with the corresponding time periods in 2013. Both NAS Lemoore and AAF Wheeler were not included in this comparison due to low number of times when Instrument Meteorological Conditions (IMC) occur.

B. INSTRUMENT METEOROLOGICAL CONDITIONS

As the results will later show, IMC occurs far more infrequently than Visual Meteorological Conditions (VMC). Therefore, this study focused on verification of IMC weather conditions. The IMC conditions include broken to overcast ceilings below 1000 ft and visibility less than 3 miles. VMC conditions occur when ceilings are 3000 ft or above and visibility is 5 miles or above. Marginal Visual Meteorological Conditions (MVMC) occur when ceilings are greater or equal to 1000 ft but less than 3000 ft and/or visibility is greater than or equal to 3 miles but less than 5 miles. The terms Instrument Flight Rules (IFR) and Visual Flight Rules (VFR) are often interchanged with IMC and

VMC. However, the latter terms correctly identify the flight rules for pilots that are dictated by the meteorological conditions. IMC puts IFR into effect while VMC and MVMC put VFR into effect.

Outside of lightening, IMC conditions have the most significant impact on flight operations at an airfield. Not all precipitation events produce IMC conditions, and although verifying precipitation events could be a valuable tool in some cases, it is the lower ceilings and/or visibility that the precipitation produces that cause impacts to air operations. The forecast process for ceilings and visibility generally takes into account most weather elements represented in the TAF and included in the model. Therefore, the verification of IMC events will give a more than fair representation of forecasting skill as a whole.

C. VERIFICATION PROCESS

Observations for each station are transmitted at the beginning of every hour. Additionally, intermediate observations, called specials, are transmitted when certain weather criteria are met. For this study, all observations for each hour are grouped together and the lowest ceiling and visibility from any of those observations were used to represent the observed event. Similarly, in situations where the TAF had multiple conditions represented between the predominate and temporary forecast lines, the lower of the two values for ceiling and visibility were used for verification. The LAMP uses conditional lines for its temporary forecasts. Although these lines are conditional on the occurrence of the forecasted precipitation, which is a probabilistic forecast, the lower ceiling or visibility in either the predominate or conditional lines were used as the forecasted event, regardless of the probability.

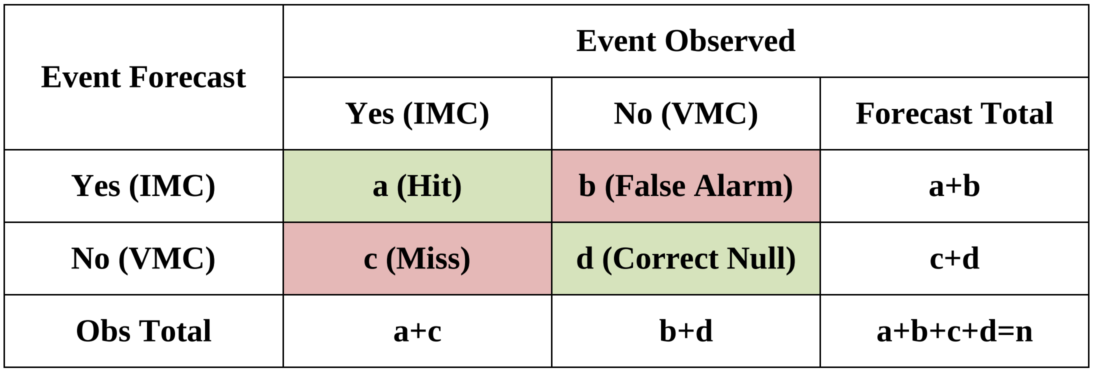
To parse the TAF data, the Microsoft .Net Framework 4 program was used to place the original bulletins into a Microsoft Excel workbook. Excel was then the main tool used to ingest observations and parse the LAMP data. Excel then verified both the TAF and LAMP to the observation for each hour of the day. Multiple formula were then used to collect the required data and statistics to use in the results chapter of this study.

D. STATISTICS

The verification of forecast IMC and forecast VMC conditions lends itself to a categorical system based on a forecast yes/no verified against the observed yes/no. As defined above, the occurrence of IMC conditions is the event of interest. Therefore, the categorical forecast verification is based on a hit rate with respect to the forecast and occurrence of IMC conditions.

Using a 2-by-2 contingency table (Figure 8), there are two corms of the traditional hit rate that will be utilized in this study. First, the traditional hit rate for forecasts of IMC conditions is defined using a/(a+c). This verifies every IMC forecast from the TAF and the LAMP forecast to as a simple percentage of the observed events that were correctly forecast. Secondly, the fraction of IMC forecast conditions that are hit is defined as a/(a+b). This hit rate defines the TAF and LAMP hourly IMC forecast skill as a simple percentage of how often the categorical forecast was correct. Because IMC conditions occur infrequently compared to VMC, a correctly forecast VMC event is considered as a correct null. The critical success index (CSI) or threat score is a better measure of categorical forecast accuracy when the number of correct null cases is large compared to the event of interest. Using Figure 8, the CSI is calculated as a/(a+b+c). Therefore, no credit is provided for a correct null forecast. The CSI will be calculated for IMC forecasts in the TAF and LAMP.

Another important verification measure is the false alarm rate (FAR), which is defined using Figure 8 as b/(b+d). It can be argued that forecast misses are a far greater problem than false alarms since a false alarm at least prepares the customer better than a miss. But, if false alarms occur too frequently you can create the “Boy who cried wolf” situation, where the customer no longer takes the proper precautions for any IMC forecast (Roulston and Smith 2003). In this stud, emphasis is placed on the HR and CSI as measures of relative forecast accuracy for the forecaster-generated TAF and the automated LAMP.



Event Forecast	Event Observed		
	Yes (IMC)	**No (VMC)**	**Forecast Total**
Yes (IMC)	**a (Hit)**	**b (False Alarm)**	**a+b**
No (VMC)	**c (Miss)**	**d (Correct Null)**	**c+d**
Obs Total	**a+c**	**b+d**	**a+b+c+d=n**

Figure 8. A schematic categorical forecast verification 2-by-2 contingency table where the event of interest is IMC conditions.

THIS PAGE INTENTIONALLY LEFT BLANK

III. RESULTS

A. FREQUENCY OF IMC OCCURRENCE

1. Observed Ceiling and Visibility Categories

There were 67,805 observation hours collected for the eight stations in 2013. Of those, only 4,130 or 6%, were IMC ceilings (Figure 9) and only 2,718 or 4%, were IMC visibility (Figure 10). Therefore, ceilings and visibility conditions had minimal impact on flight operations 94% of the time.

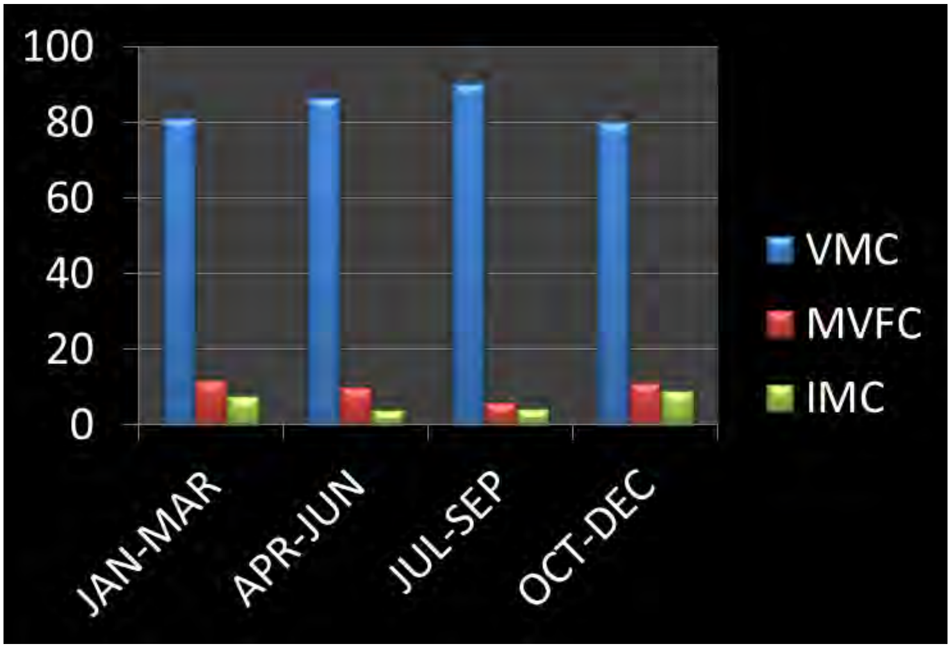


Figure 9. Observed ceiling conditions for all 8 stations that occurred during 2013. Conditions are defined as visual meteorological conditions (VMC), marginal visual meteorological conditions (MVMC), and instrument meteorological conditions (IMC).

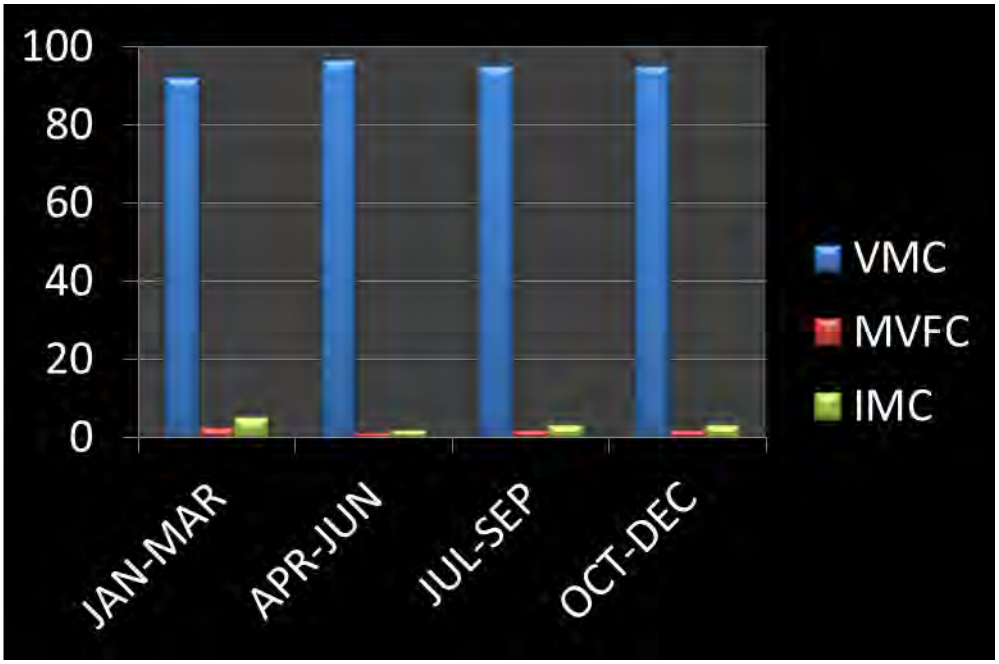


Figure 10. Observed visibility conditions for all 8 stations that occurred during 2013. Conditions are defined as visual meteorological conditions (VMC), marginal visual meteorological conditions (MVMC), and instrument meteorological conditions (IMC).

Of the 67,805 observation hours collected, 63,463 were covered by both a TAF and a LAMP forecasts to be used in this study. Using IMC, MVMC, and VMC as the three separate forecast categories to verify, the TAF forecast accuracy was 78%, for both ceiling and visibility, while the LAMP forecast accuracy was 81% for ceiling and 79% for visibility. (Figure 11). Therefore, on first look, there is no statistical difference between the overall accuracy of both forecast systems. Due to the relationship between IMC and IFR, as described in an earlier chapter and to assist in focusing on IMC forecast accuracy, the term "VMC" will include all VMC and MVMC observations or forecasts, unless otherwise noted.

The next set of verifications completed determined if there was an hour-to-hour correspondence between all (i.e., IMC and VMC) observed conditions and all forecast conditions during 2013. The forecasts were verified against the observations to determine how often the hourly observed conditions were actually forested correctly. Of those 63,463 observations, 59,515 ceiling observations and 60,873 visibility observations were

VMC. Using the hit rate formula d/(b+d), 95%, or 56,695 of the ceiling observations, and 94%, or 56,988 of the visibility observations were accounted for by the TAF, with very similar numbers, 96% and 93%, respectively, for the LAMP (Figure 12). When IMC observations are the condition of interest, the hit rate is defined by a/(a+c). For verification of the 3,948 IMC ceiling observations, both the TAF and LAMP accounted for only 47% of the observed IMC ceiling hours and 43% of the 2,590 IMC visibility hours (Figure 13). To put this into perspective, this left more than half the operation impacting ceilings and visibility unforecasted in 2013. Again, when looking at the observations and corresponding forecasts, there is very little difference in hit rates between the TAF and the LAMP.

From the characterizations of IMC and VMC conditions overall, it is clear that the meteorological input, which is assumed to be critical during IMC conditions, is especially key during this relatively infrequent period of time. However, it is during these times when the Navy forecaster must be prepared to assess infrequent environmental conditions and know how they are represented in all of their guidance products.

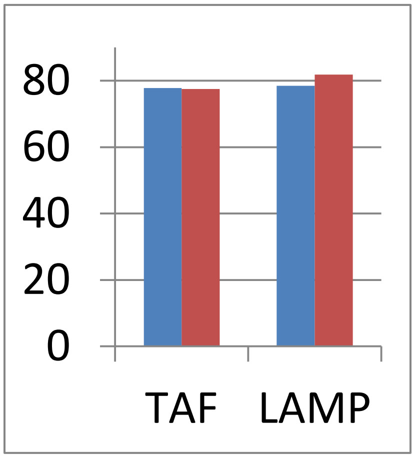


Figure 11. The TAF and LAMP hit rates (percent) for VMC-MVMC-IMC categorical forecasts for all stations in 2013. Hit rates for ceiling forecasts are defined by red bars and for visibility forecasts by blue bars

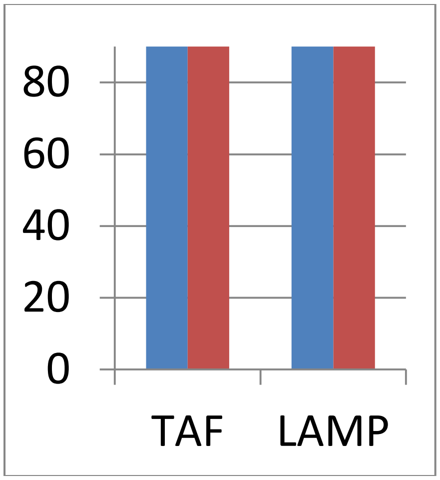


Figure 12. The TAF and LAMP hit rates (percent) for VMC observations for all stations during 2013. The red bars define hit rates for ceiling forecasts and the blue bars define hit rates for visibility forecasts

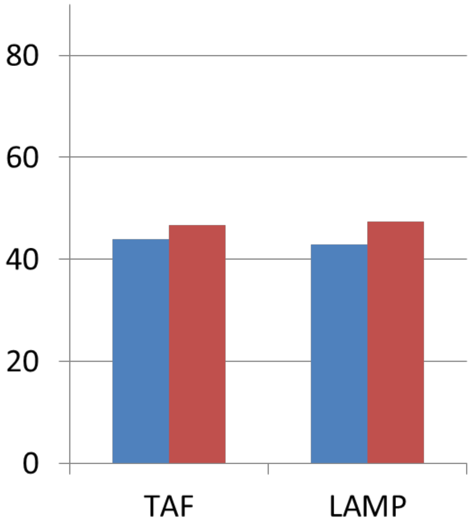


Figure 13. The TAF and LAMP hit rates (percent) for IMC observations for all stations in 2013. Hit rates for ceiling forecasts are defined by red bars and for visibility forecasts by blue bars

2. Observed Ceiling and Visibility Categories by Season

The statistics defined above are unconditional accuracies for all stations throughout 2013. The results may be sensitive to season and/or station location. Therefore, the distributions of these two characteristics are defined prior to assessing the forecast verifications relative to season and station.

The distribution of observed conditions by each quarter of the year is provided in Table 1. During the summer quarter (JUL-SEP), IMC ceiling conditions occurred only 4% of the total time, which was the lowest frequency of all the seasons. The fall transition months (OCT-DEC) had the highest occurrence of IMC ceiling conditions with 9%. For visibility, IMC conditions occurred with the highest frequency of 5% during the winter (JAN-MAR) months.

As expected, the winter season contains the greatest occurrence of ceiling and visibility IMC conditions. Therefore, forecaster input would be of most value during that season.

Table 1. The seasonal frequency of meteorological category occurrence for all stations during 2013

JAN-MAR 16790 OBS	CEILINGS			VISIBILITY	
VMC	13604	81%	VMC	15432	92%
MVMC	1940	12%	MVMC	465	03%
IMC	1246	07%	IMC	893	05%
APR-JUN 16983 OBS	CEILINGS			VISIBILITY	
VMC	14692	87%	VMC	16443	97%
MVMC	1651	10%	MVMC	206	01%
IMC	640	03%	IMC	334	02%
JUL-SEP 16983 OBS	CEILINGS			VISIBILITY	
VMC	15286	90%	VMC	16156	95%
MVMC	971	06%	MVMC	275	02%
IMC	726	04%	IMC	552	03%
OCT-DEC 17049 OBS	CEILINGS			VISIBILITY	
VMC	13735	81%	VMC	16156	95%
MVMC	1796	10%	MVMC	341	02%
IMC	1518	09%	IMC	552	03%

3. Observed Ceiling and Visibility Categories by Station

The distribution of observed conditions by station is provided in Table 2. The lowest occurrence of IMC conditions occurred at NAS Lemoore with only 91 ceiling IMC events and 231 visibility IMC events. Nearly all of these events occurred in the winter months. The maximum occurrence of IMC conditions was at NAS Whidbey Island. Overall Whidbey experienced 1,122 ceiling IMC events and 812 IMC visibility events. This equaled 13% and 9% of their observational hours, respectively.

Table 2. Frequency of meteorological category by station during 2013

LEMOORE 8431 OBS	**CEILING**			**VISIBILITY**	
VMC	8256	98%	VMC	7840	93%
MVMC	84	01%	MVMC	360	04%
IMC	91	01%	IMC	231	03%
WHEELER 8431 OBS	**CEILING**			**VISIBILITY**	
VMC	6751	80%	VMC	8241	98%
MVMC	1469	17%	MVMV	84	01%
IMC	211	03%	IMC	106	01%
MERIDIAN 8431 OBS	**CEILING**			**VISIBILITY**	
VMC	6591	78%	VMC	7588	90%
MVMC	1841	22%	MVMC	262	03%
IMC	940	11%	IMC	581	07%
JACKSONVILLE 8431 OBS	**CEILING**			**VISIBILITY**	
VMC	7308	87%	VMC	8101	96%

MVMC	637	08%	MVMC	115	01%
IMC	486	06%	IMC	215	03%
WHIDBEY IS. 8557	**CEILING**			**VISIBILITY**	
VMC	5973	70%	VMC	7520	88%
MVMC	1462	17%	MVMC	225	03%
IMC	1122	13%	IMC	812	09%
OCEANA 8557 OBS	**CEILING**			**VISIBILITY**	
VMC	7111	83%	VMC	7958	93%
MVMC	706	08%	MVMC	207	02%
IMC	740	09%	IMC	392	05%
FT. WORTH 8536 OBS	**CEILING**			**VISIBILITY**	
VMC	7164	84%	VMC	8262	97%
MVMC	1024	12%	MVMC	124	01%
IMC	348	04%	IMC	150	02%
FALLON 8431 OBS	**CEILING**			**VISIBILITY**	
VMC	8163	97%	VMC	8092	96%
MVMC	76	01%	MVMC	108	01%
IMC	192	02%	IMC	231	03%

B. FORECAST PRODUCTS VERIFICATION

1. 2013 Forecast Verification.

In section A.1, The hit rates were based on total observations in each category, a/(a+c) for IMC conditions or d/(b+d) for VMC conditions. In this section, the hit rate, or fraction of hits formula used will account for all forecasts issued, and are defined as a/(a+b) for IMC forecasts and d/(c+d) for VMC forecasts.

Considering that the VMC conditions occurred 94% of the time, and that the forecast accuracy for VMC is above 96% for both LAMP and TAF (Table 3), a categorical forecast of VMC will be considered the correct null forecast for this verification. Because of the dominance of the correct null event, the focus is on the verification of IMC events.

Table 3. VMC forecast hit rates for all stations during 2013.

2013 FORECASTS (c+d)	**TAF Hits**		**2013 FORECASTS (c+d)**	**LAMP Hits**	
CEILING 58760	56651	96%	**CEILING** 59315	57238	96%
VISIBILITY 58059	56639	98%	**VISIBILITY** 58270	56792	97%

2. IMC Forecast Accuracy during 2013

a. Forecast IMC Fraction of Hits

For a forecast of IMC, the fraction of hits is defined as a/(a+b). In this case, the fraction of hits for both the TAF and the LAMP IMC visibility forecasts were near 22% for all stations (Figure 14). These values are much lower than the IMC and VMC hit rates define above where both the TAF and LAMP hit rates were 43% for the IMC category. For ceiling forecasts the fraction of hits for the TAF ceiling IMC forecasts was

40% and for the LAMP ceiling IMC forecasts it was 45% (Figure 14). These values are closer to the 47% observational hit rates defined above. Although the LAMP was 5% better than the TAF for forecasts of IMC ceiling conditions with 543 fewer misses, TAF and LAMP had similar False Alarm Ratios (FAR) of 53%.

The distribution of the fraction of hits by season (Table 4) indicates that LAMP had a higher fraction of hits for categorical forecasts of IMC ceiling conditions during winter, spring, and summer and was slightly lower than TAF in the fall (Oct-Dec). The fraction of hits for the TAF categorical IMC forecasts of visibility were higher during the fall and winter months (OCT-MAR).

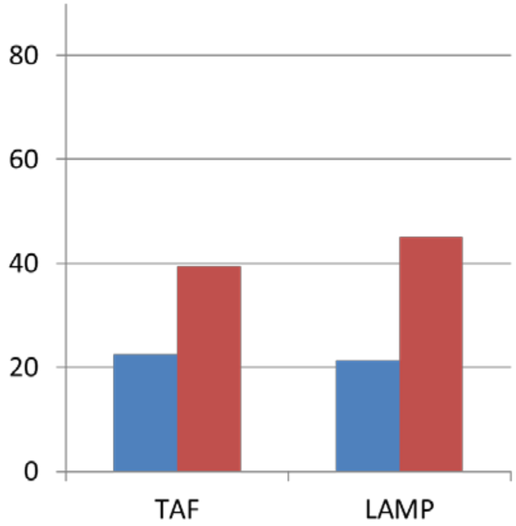


Figure 14. The fraction of hits (percent) for IMC categorical forecasts for all stations during 2013. The red bars define hit rates for ceiling forecasts and the blue bars define hit rates for visibility forecasts.

Table 4. The fraction of hits for IMC categorical forecasts for all stations during 2013. The number of forecasts verified is listed for each element of ceiling or visibility. The number of correct forecast is listed in the middle box.

JAN-MAR FORECASTS	**TAF**		**JAN-MAR** FORECATS	**LAMP**	
CEILING 1499	627	42%	CEILING 1393	671	48%
VISIBILITY 1354	408	30%	VISIBILITY 1746	450	26%
APR-JUN FORECASTS	**TAF**		**APR-JUN** FORECASTS	**LAMP**	
CEILING 947	236	25%	CEILING 657	207	32%
VISIBILITY 998	126	13%	VISIBILITY 555	98	18%
JUL-SEP FORECASTS	**TAF**		**JUL-SEP** FORECASTS	**LAMP**	
CEILING 845	319	38%	CEILING 619	299	48%
VISIBILITY 1322	195	15%	VISIBILITY 1359	193	14%
OCT-DEC FORECASTS	**TAF**		**OCT-DEC** FORECASTS	**LAMP**	
CEILING 1371	660	48%	CEILING 1479	694	47%
VISIBILITY 1257	385	31%	VISIBILITY 1533	371	24%

b. Forecast IMC Critical Success Index

As defined in chapter II, CSI is a measure of success that is used in place of hit rate when the event desired event occurs significantly less than a non-occurrence, which is considered as a correct null forecast. In this case, VMC occurs at a far greater frequency than IMC. Although hit rate only takes into account the hits and misses for all events and categories, CSI also takes into account false alarms.

Table 5 and 6 define the CSI scores for both the TAF and the LAMP for ceiling and visibility forecasts. As the hit rates and fraction of hits discussed above would suggest, the LAMP has a higher CSI of .30 versus .27 for the TAF since LAMP performs better in all three CSI components; hits, misses, false alarms (Table 5). For visibility forecasts, the TAF marginally outperforms the LAMP in all three components for CSI as the TAF CSI of .18 is only slightly higher than the LAMP value of .17 (Table 6).

Table 5. The distribution of forecast and observed ceiling categories plus the CSI for each case during 2013.

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	1842	2109	**IRF**	1871	2077
VFR	2820	56651	**VFR**	2277	57238
CSI	0.27		**CSI**	0.30	

Table 6. The distribution of forecast and observed visibility categories plus the CSI for each case during 2013

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	1114	1420	**IRF**	1112	1478
VFR	3817	56639	**VFR**	4081	56792
CSI	0.18		**CSI**	0.17	

3. Forecast Accuracy for the 13–24 h Forecast Interval

It is assumed that the forecast process will be less dependent on aids and more dependent on forecaster experience and capability as the forecast interval increases. Therefore, the second 12-h period is verified separately from the first 0–12 h forecast interval. For the 13–24 h forecasts, the IMC fraction of hits (Table 7) are all within 1% of the full 24 hr data. The CSI scores all decrease at a rate to be expected as the forecast interval increases away from the initiating observation (Tables 8 and 9). For ceiling, the TAF CSI decreases from .27 to .26 while the LAMP CSI decreases from .30 to .28. For visibility, the TAF CSI decreases from .18 to .14, while the LAMP CSI decreases from .17 to .16. The only notable change is that the LAMP goes from slightly underperforming the TAF in visibility forecast for the 24 hr forecast, to outperforming the TAF for the 13–24 hours.

Table 7. The hit rates (percent) for IMC categorical forecasts for all stations at 12–24 h forecast interval during 2013. The number of forecasts verified is listed for each element of ceiling or visibility. The number of correct forecast is listed in the middle box.

2013 13–24HR FORECASTS	**TAF**			**LAMP**	
CEILING 2390	987	42%	**CEILING** 2390	1064	45%
VISIBILITY 1490	502	34%	**VISIBILITY** 1490	601	40%

Table 8. The ceiling forecast CSI for forecast interval 12–24 h for at all stations during 2013.

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	987	1398	**IRF**	1064	1326
VFR	1484	28094	**VFR**	1371	28257
CSI	0.26		**CSI**	0.28	

Table 9. The visibility forecast CSI for forecast interval 12–24 h for at all stations during 2013

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	502	1398	**IRF**	601	889
VFR	1597	28707	**VFR**	2182	28346
CSI	0.14		**CSI**	0.16	

4. Forecast Accuracy during 2006 and 2007

For this set of data, NAS Lemoore and AAF Wheeler were not included in the 2006–2007 or 2013 data due to low IMC counts. The forecast hit rate for the TAF and LAMP in October 2006 through March 2007 as well as the hit rates for October through December 2013 combined with January through March 2013 are detailed in Tables 10 and 11. The improvements in both forecast systems are significant with the TAF improving at a much higher level than the model. For 2006–2007, the CSI statistics (Tables 12 and 14) are both much lower than the overall 2013 CSI values (Tables 5 and 6). But, when compared to the same quarters of October through December 2013, and January through March 2013 (Tables 13 and 15), the difference becomes even greater. During these two comparable quarters in 2013, the TAF ceiling forecast CSI was improved by 19% and the LAMP forecast CSI was improved by 17% compared to the values from 2006–2007.

When comparing CSI data, the TAF improved ceiling forecasts by 69% compared to the 66% LAMP improvement. The visibility CSI doubled for the TAF and just 38% increase for the LAMP forecast. The improvement in the models is obvious when looking at Figures 1 and 2. But, the greater improvement of the TAF is not as obvious. One significant change is that during 2013, the 1500 UTC forecast was written on-station at each of the six stations verified. From 2006 through 2012 these forecasts were all done via reach back at Fleet Weather Center San Diego or Norfolk.

Table 10. Te fraction of hits for the IMC forecasts during October 2006–March 2007.

2006/7 **FORECASTS**	**TAF**			**LAMP**	
CEILING 1927	525	27%	**CEILING** 1549	511	33%
VISIBILITY 1551	231	15%	**VISIBILITY** 1661	305	18%

Table 11. The fraction of hits for the IMC forecasts during Jan–Mar 2013 and Oct–Dec 2013.

2013 **FORECASTS**	**TAF**			**LAMP**	
CEILING 2723	1248	46%	**CEILING** 2681	1325	49%
VISIBILITY 2304	707	30%	**VISIBILITY** 2585	678	26%

Table 12. The CSI for ceiling forecasts made during October 2006–March 2007.

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	525	902	**IRF**	511	916
VFR	1402	22677	**VFR**	1038	22139
CSI	0.19		**CSI**	0.21	

Table 13. The CSI for ceiling forecasts during the period of Jan–March 2013 and Oct–Dec 2013.

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	1248	1244	**IRF**	1325	1167
VFR	1475	20866	**VFR**	1356	21446
CSI	0.31		**CSI**	0.34	

Table 14. The CSI for visibility forecasts made during October 2006 – March 2007.

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	231	461	**IRF**	305	387
VFR	1320	22493	**VFR**	1356	22556
CSI	0.11		**CSI**	0.15	

Table 15. The CSI for visibility forecasts during the combined period of Jan–March 2013 and Oct–Dec 2013.

TAF			LAMP		
Forecast	IFR Obs	VFR Obs	Forecast	IFR Obs	VFR Obs
IFR	707	772	IRF	678	772
VFR	1597	21751	VFR	1907	21751
CSI	0.23		CSI	0.20	

5. 2013 Non-VMC Accuracy "Saw Something"

The verification of forecast IMC conditions explained above paired the MVMC events with the VMC events. This gave a "yes" or "no" verification for IMC events. When pairing MVMC with IMC, this provides a "yes" or "no" verification of *below* VMC events, which expands the correct category. Essentially, this will give the TAF and the LMAP credit when the forecast and the observation are both below VMC. This is not as strict as verifying IMC alone and allows credit for when the TAF or LAMP essentially lead a forecast to be one of marginal conditions, or essentially the forecast "saw something coming," but missed the actual IMC category. This Non-VMC or "saw something coming" verification gives credit for any hit below 3000 feet ceilings and 5 miles visibility. For example, the TAF has ceilings at 2000 feet and the observation has 900 feet. This is a missed IMC event, but when pairing the MVMC and IMC categories, this would be a Non-VMC event hit.

When verified in this set scenario, both the TAF and the LAMP improve over the IMC scores significantly. Once again though, they both remained statistically equal. The ceiling forecast hit rate was 67% and visibility forecast hit rates was 71% (Figure 16). The CSI values also improved for ceiling forecasts as the TAF CSI was .36 and the LAMP ceiling forecast CSI was .42 (Table 16). The visibility forecast CSI however, remained mostly unchanged. This is attributed to the significantly high false alarm rate in the b block (Figure 8) of the 2-by-2 contingency table (Table 17). This indicates that both the LAMP and the TAF significantly over forecast MVMC conditions. It is not clear from this study if that over forecasting is in the predominate forecast lines, or the temporary forecast lines.

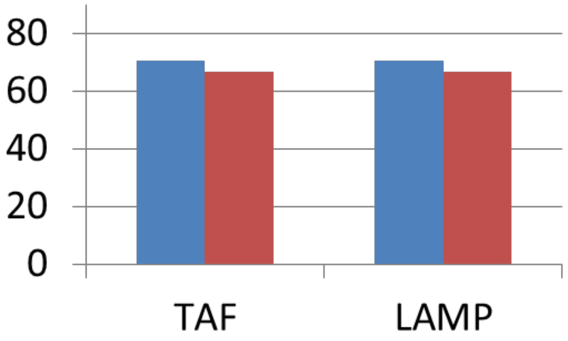


Figure 15. The hit rate (percent) for forecast Non-VMC conditions during 2013 "saw something coming." The red bars define hit rates for ceiling forecasts and the blue bars define hit rates for visibility forecasts

Table 16. The CSI for non-VMC ceiling category forecasts during 2013.

TAF				**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**		Forecast	**IFR Obs**	**VFR Obs**
IFR	6500	8158		**IRF**	6594	5805
VFR	3245	45560		**VFR**	3151	47913
CSI	0.36			**CSI**	0.42	

Table 17. The CIS for non-VMC visibility category forecasts during 2013.

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	2809	11445	**IRF**	2801	11057
VFR	1168	48041	**VFR**	1176	47913
CSI	0.18		**CSI**	0.18	

6. Reach Back Forecasting versus On-Station Forecasting

Between 2005 and 2006, all naval air stations transitioned from forecasting detachments being located on-station to having all forecasting duties performed via reach back from either FWC San Diego or FWC Norfolk. In 2013, to improve forecasting results during the operational hours civilian forecasters were employed at all naval air stations during the Monday through Friday operational hours. The 1500 UTC TAF is produced almost entirely by these civilian forecasters. The only exceptions would be weekends or holidays. During weekend, holidays and evening hours, the TAFs were continued to be produced via reach back. This study was made up entirely of 1500 UTC TAFs and thus it reflects mostly on-station forecaster verification. AAF Wheeler was not used in this analysis due to their reliance on reach back for all TAFs. A small sample of 0700 UTC data were collected to compare the skill of the reach-back forecasters with the on-station forecasters. The 0700 UTC data collected were from October through December 2013 (Table 18) and compared to the same time period for the 1500 UTC data. When comparing the forecast accuracy for October-December 2013 (Table 19), the 0700 UTC TAF accuracy was 1% better for ceiling and 3% lower for visibility than the 1500 UTC TAF accuracy. The 0700 UTC LAMP forecast accuracy was 8% better for ceiling and 11% better for visibility than the 1500 UTC accuracy.

When verifying the IMC forecast, the TAF IMC forecast accuracy at 0700 UTC (Table 20) was only 1% lower for ceiling and equal for visibility compared to the 1500

UTC forecasts (Table 21). The accuracy of the 0700 UTC LAMP was 5% better for ceiling and 7% better for visibility compared to the 1500 UTC LAMP (Tables 20 and 21).

For the CSI scores (Tables 22 through 25), the 0700 UTC TAF slightly outperformed the 1500 UTC ceiling and visibility forecasts. The 0700 UTC LAMP also outperformed the 1500 UTC LAMP ceiling and visibility forecasts. Although there is only one quarter of data used in this portion of the study, both the reach back and on-station TAFs verifications were with respect to the exact same weather over the same exact periods. Considering the numerous advantages that an on-station forecaster has over a reach back forecaster, it is somewhat surprising that the reach back forecaster performed as well as, or even slightly better than the on-station forecaster. When considering just these scores, the 0700 UTC LAMP seems to perform as better model guidance than the 1500 UTC LAMP. This shadowing of the model performance could lead to the interpretation that both the on-station and reach back forecasters are relying heavily on the model, and thus the reason for the reach back forecasters better than expected results compared to the on-station forecaster.

Table 18. The 0700 UTC forecast accuracy for categorical forecasts for all stations during Oct–Dec 2013. The number of forecasts verified is listed for each element of ceiling or visibility. The number of correct forecast is listed in the middle box.

OCT-DEC 2013 0700 UTC FORECASTS	**TAF**			**OCT-DEC 2013 0700 UTC FORECASTS**	**LAMP**	
CEILING 14345	11000	77%		**CEILING** 14345	11345	79%
VISIBILITY 14298	10768	75%		**VISIBILITY** 14298	11542	81%

Table 19. The 1500 UTC forecast accuracy for overall categorical forecasts for all stations during Oct–Dec 2013. The number of forecasts verified is listed for each element of ceiling or visibility. The number of correct forecast is listed in the middle box.

OCT-DEC 2013 **1500 UTC** **FORECASTS**	**TAF**		**OCT-DEC 2013** **1500 UTC** **FORECASTS**	**LAMP**	
CEILING 14123	10787	76%	**CEILING** 15657	11058	71%
VISIBILITY 14123	10981	78%	**VISIBILITY** 15657	10891	69%

Table 20. The 0700 UTC forecast accuracy for IMC categorical forecasts for all stations during Oct–Dec 2013. The number of forecasts verified is listed for each element of ceiling or visibility. The number of correct forecast is listed in the middle box.

OCT-DEC 2013 **0700 UTC IMC** **FORECASTS**	**TAF**		**OCT-DEC 2013** **0700 UTC IMC** **FORECASTS**	**LAMP**	
CEILING 1548	727	47%	**CEILING** 1305	704	54%
VISIBILITY 1570	466	30%	**VISIBILITY** 1170	365	31%

Table 21. The 1500 UTC forecast accuracy for IMC categorical forecasts for all stations during Oct–Dec 2013. The number of forecasts verified is listed for each element of ceiling or visibility. The number of correct forecast is listed in the middle box.

OCT-DEC 2013 1500 UTC IMC FORECASTS	**TAF**			**OCT-DEC 2013 1500 UTC IMC FORECASTS**	**LAMP**	
CEILING 1371	660	48%		**CEILING** 1437	692	48%
VISIBILITY 1250	385	31%		**VISIBILITY** 1518	371	24%

Table 22. The CSI for ceiling forecasts made at 0700 UTC during Oct–Dec 2013

TAF				**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**		Forecast	**IFR Obs**	**VFR Obs**
IFR	727	735		**IRF**	704	758
VFR	1168	12062		**VFR**	601	12282
CSI	0.32			**CSI**	0.34	

Table 23. The CSI for ceiling forecasts made at 1500 UTC during Oct–Dec 2013

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	660	752	**IRF**	682	720
VFR	711	11984	**VFR**	745	11966
CSI	0.31		**CSI**	0.32	

Table 24. The CSI for visibility forecasts made at 0700 UTC during Oct–Dec 2013

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	466	378	**IRF**	365	482
VFR	1104	12350	**VFR**	805	12693
CSI	0.24		**CSI**	0.22	

Table 25. The CSI for visibility forecasts made at 1500 during Oct–Dec 2013

TAF			**LAMP**		
Forecast	**IFR Obs**	**VFR Obs**	Forecast	**IFR Obs**	**VFR Obs**
IFR	385	450	**IRF**	371	471
VFR	865	12261	**VFR**	1147	12134
CSI	0.23		**CSI**	0.19	

IV. NAS FALLON CASE STUDY

A. OVERVIEW

There may be countless instances where the TAF and the LAMP outperform one another, and it would be easy to selectively choose events that made one or the other appear to be significantly better. But, the aircraft mishap on NAS Fallon in March 6, 2012 was a particularly significant event in that it was a fatal crash and the weather was not forecast correctly in advance of takeoff. (NTSB, 2014) The National Transportation Safety Board (NTSB) did not cite the poor weather as a specific reason for the mishap, but does list the conditions as "significantly lower than forecasted" in the contributing factors (NTSB, 2014). Although not the sole cause of this accident, it can be reasonably expected that a better forecast could have deterred the pilot from taking off in poor weather conditions, and thus possibly avoided the mishap all together.

B. DATA FOR MARCH 6, 2012

(1) NAS Fallon TAFs

Figure 18 lists the TAFs issued for NAS Fallon at 1200 UTC, 1500 UTC, and 1700 UTC 6 March 2012. In 2012, these TAFs were issued from Fleet Weather Center San Diego. Highlighted in the yellow boxes are the forecast lines valid for time of takeoff and time of mishap for each TAF. The TAF used for preflight weather brief was issued originally at 0700 UTC and then amended at 1200 UTC. The conditions between 1600 UTC and 2000 UTC were forecast to be no lower than 5 miles visibility and 4000 feet ceilings in light snow. A new TAF was routinely issued at 1500 UTC, which is a routine forecast time. This 1500 UTC TAF is the valid forecast at the time of scheduled take off of 1650 UTC. The forecast is now unrestricted visibility 4000 feet ceilings throughout the takeoff and mishap time. At 1720 UTC, the TAF is amended to include temporary conditions of 0.5 miles visibility and 1500 feet ceilings in light snow. These conditions are forecast on station until 2000 UTC.

(2) NAS Fallon Weather Observations

In the Appendix, the weather observations for 1456 UTC – 2000 UTC 6 March 2012 at NAS Fallon are listed. In summary, the weather was VMC all day until light snow brought visibility down to 1 and 0.5 miles at 1646 UTC, and by 1650 the visibility was at 0.5 miles with ceilings at 1200 feet. The visibility mostly stayed in IMC with MVMC ceilings until the snow stopped at 1912 UTC.

(3) NAS Fallon LAMP

Figure 20 is the LAMP bulletin for NAS Fallon issued at 0700 UTC 6 March 2012. Although there were LAMP bulletins issued every hour prior to and after the 0700 UTC TAF and the 1200 UTC amended TAF, this bulletin is a good representation of the model guidance at the same time the TAF was issued. Highlighted in yellow boxes are the LAMP forecasts for 1800 and 1900 UTC. Outlined in blue, LAMP indicates conditional visibility (CVS) of 0.5 to less than 1 mile (Code 2) for 1800 UTC and 1 to less than 2 miles (Code 3) for 1900 UTC, and a conditional ceiling (CCG) of 1500 feet (Code 4) for both 1800 and 1900 UTC. Outlined in the orange is the probability forecast of precipitation (PPO) and the type of precipitation expected (TYP). Snow was forecasted with a probability of 23%.

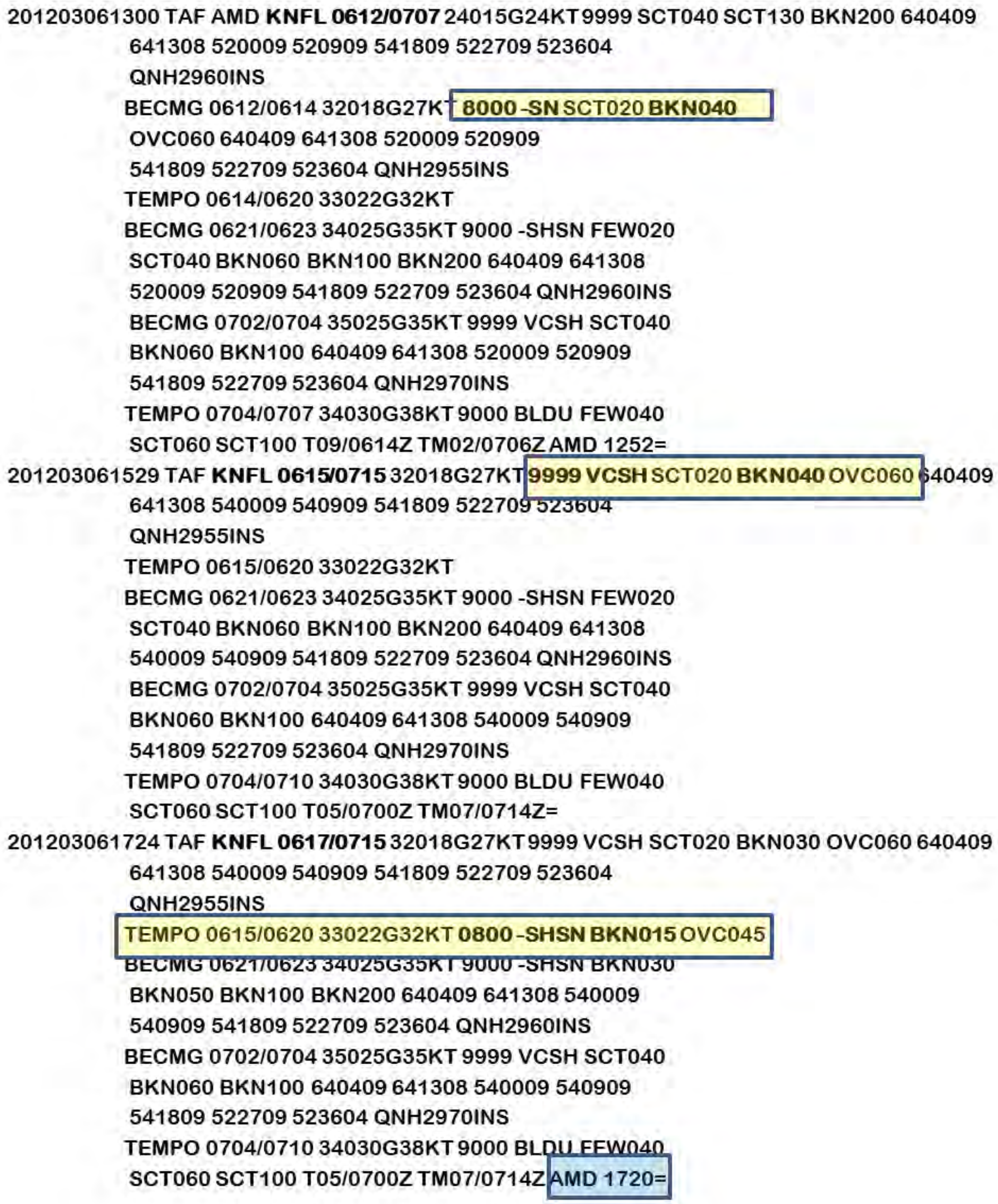
C. AN ARGUMENT FOR PROBABILITY FORECASTING

Although it is not known if the forecaster for the NAS Fallon TAF was using the LAMP bulletin as guidance, it cannot be overlooked that the LAMP bulletin gave at least a hint of IMC visibility and lower MVMC ceilings during the flight mission window. According to the NTSB report, just prior to take off at 1645 UTC, the pilot radioed the duty observer for a weather update when conditions deteriorated below what was originally forecasted. It is possible that if the pilot had been briefed of even a 23% chance of IMC conditions, he may not have decided to go forward with the mission once he saw the conditions deteriorating in front of him. Although 23% seems like conditions are more likely to not occur than to occur, it is still a hint that something has changed in the atmosphere and is thus providing a sense of some change more than a TAF using deterministic forecasting.

It should be noted that the LAMP guidance was not a perfect forecast for this event. For the same day, the 1400 UTC LAMP bulletin (Figure 21), which would have been the guidance for the 1500 UTC TAF, decreased the probability of precipitation from 23% to 14% and slightly raised the visibility one code value to 1 to less than 2 miles (Code 3) at 1800 UTC and 2 less than 3 miles (Code 4) at 1900 UTC. It also eliminated the ceilings and went to scattered skies. So although the model cannot be used, if properly studied, tendencies in the model's probability forecasts can be tracked and later used to develop more accurate forecasting guidance.

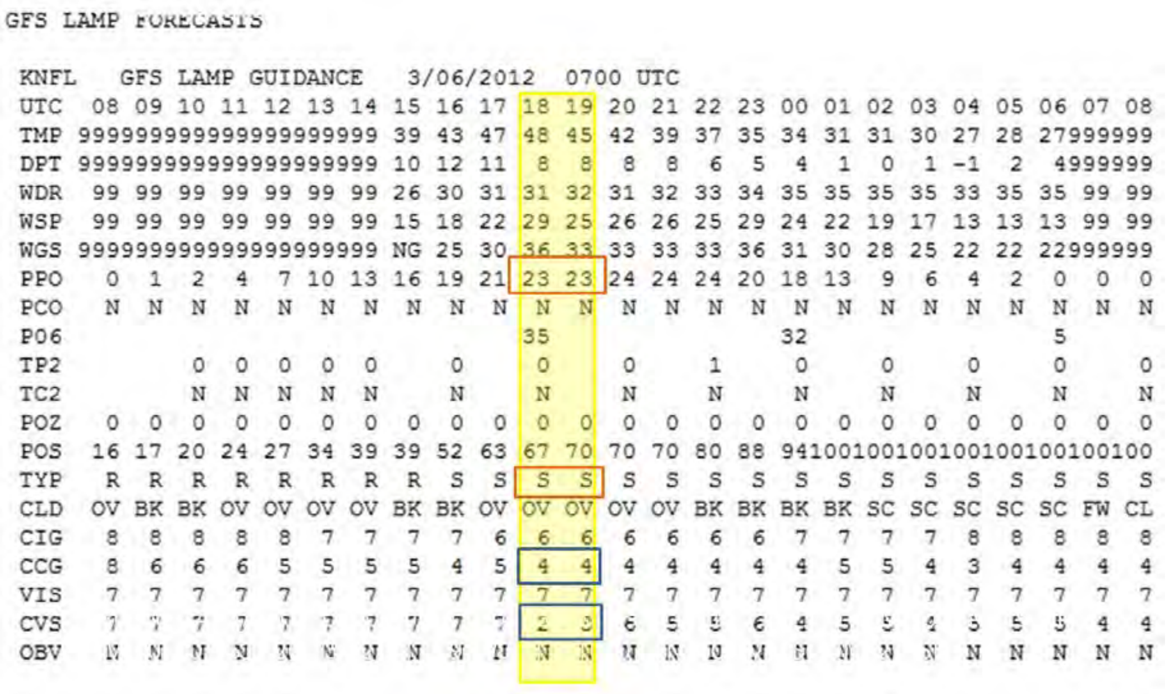
.

Figure 16. NAS Fallon TAFs issued at 1200, 1500, and 1700 UTC for 6 March, 2012.



```
201203061300 TAF AMD KNFL 0612/0707 24015G24KT 9999 SCT040 SCT130 BKN200 640409
           641308 520009 520909 541809 522709 523604
           QNH2960INS
          BECMG 0612/0614 32018G27KT 8000 -SN SCT020 BKN040
           OVC060 640409 641308 520009 520909
           541809 522709 523604 QNH2955INS
          TEMPO 0614/0620 33022G32KT
          BECMG 0621/0623 34025G35KT 9000 -SHSN FEW020
           SCT040 BKN060 BKN100 BKN200 640409 641308
           520009 520909 541809 522709 523604 QNH2960INS
           BECMG 0702/0704 35025G35KT 9999 VCSH SCT040
           BKN060 BKN100 640409 641308 520009 520909
           541809 522709 523604 QNH2970INS
          TEMPO 0704/0707 34030G38KT 9000 BLDU FEW040
           SCT060 SCT100 T09/0614Z TM02/0706Z AMD 1252=
201203061529 TAF KNFL 0615/0715 32018G27KT 9999 VCSH SCT020 BKN040 OVC060 640409
           641308 540009 540909 541809 522709 523604
           QNH2955INS
          TEMPO 0615/0620 33022G32KT
          BECMG 0621/0623 34025G35KT 9000 -SHSN FEW020
           SCT040 BKN060 BKN100 BKN200 640409 641308
           540009 540909 541809 522709 523604 QNH2960INS
           BECMG 0702/0704 35025G35KT 9999 VCSH SCT040
           BKN060 BKN100 640409 641308 540009 540909
           541809 522709 523604 QNH2970INS
          TEMPO 0704/0710 34030G38KT 9000 BLDU FEW040
           SCT060 SCT100 T05/0700Z TM07/0714Z=
201203061724 TAF KNFL 0617/0715 32018G27KT 9999 VCSH SCT020 BKN030 OVC060 640409
           641308 540009 540909 541809 522709 523604
           QNH2955INS
          TEMPO 0615/0620 33022G32KT 0800 -SHSN BKN015 OVC045
          BECMG 0621/0623 34025G35KT 9000 -SHSN BKN030
           BKN050 BKN100 BKN200 640409 641308 540009
           540909 541809 522709 523604 QNH2960INS
          BECMG 0702/0704 35025G35KT 9999 VCSH SCT040
           BKN060 BKN100 640409 641308 540009 540909
           541809 522709 523604 QNH2970INS
          TEMPO 0704/0710 34030G38KT 9000 BLDU FEW040
           SCT060 SCT100 T05/0700Z TM07/0714Z AMD 1720=
```

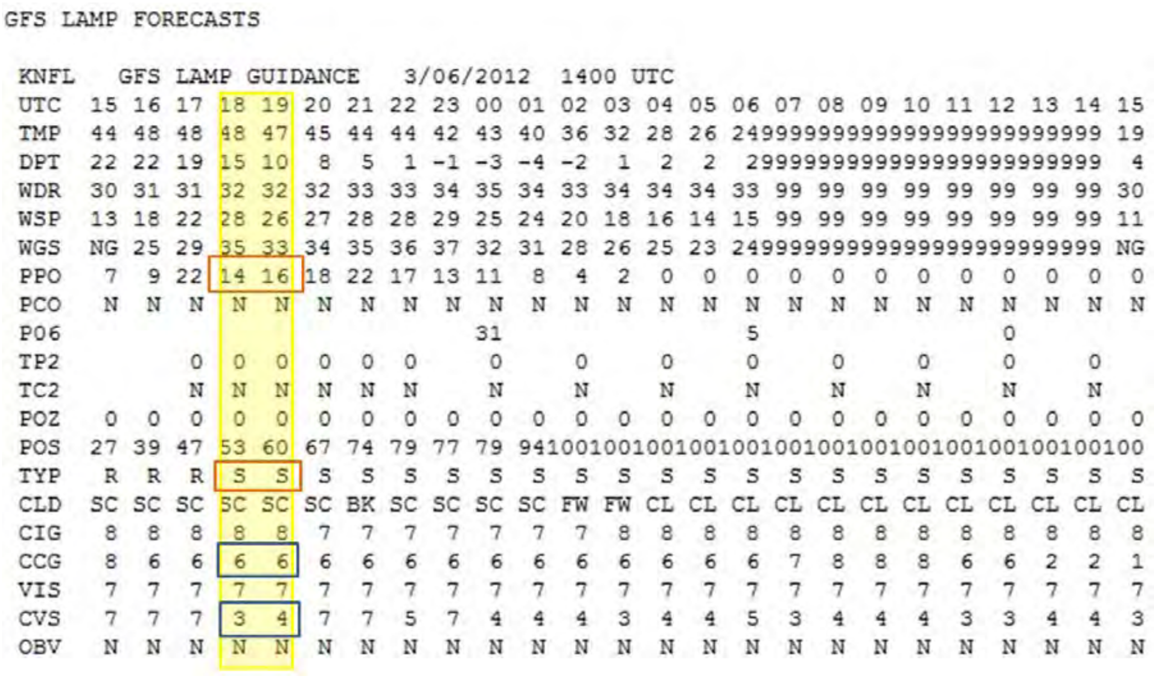
Figure 17. NAS Fallon LAMP bulletin issued 0700 UTC 6 March 2012.



```
GFS LAMP FORECASTS

KNFL   GFS LAMP GUIDANCE    3/06/2012  0700 UTC
UTC  08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07 08
TMP 999999999999999999999 39 43 47 48 45 42 39 37 35 34 31 31 30 27 28 27999999
DPT 999999999999999999999 10 12 11  8  8  8  8  6  5  4  1  0  1 -1  2  4999999
WDR  99 99 99 99 99 99 99 26 30 31 31 32 31 32 33 34 35 35 35 35 33 35 35 99 99
WSP  99 99 99 99 99 99 99 15 18 22 29 25 26 26 25 29 24 22 19 17 13 13 13 99 99
WGS 999999999999999999999 NG 25 30 36 33 33 33 33 36 31 30 28 25 22 22 22999999
PPO   0  1  2  4  7 10 13 16 19 21 23 23 24 24 24 20 18 13  9  6  4  2  0  0  0
PCO   N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N
P06                                 35                32                 5
TP2         0  0  0  0  0     0     0     0     1     0     0     0     0     0
TC2         N  N  N  N  N     N     N     N     N     N     N     N     N     N
POZ   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
POS  16 17 20 24 27 34 39 39 52 63 67 70 70 70 80 88 94100100100100100100100100
TYP   R  R  R  R  R  R  R  R  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S
CLD  OV BK BK OV OV OV OV BK BK OV OV OV OV OV BK BK BK BK SC SC SC SC SC FW CL
CIG   8  8  8  8  8  7  7  7  7  6  6  6  6  6  6  6  7  7  7  7  8  8  8  8  8
CCG   8  6  6  6  5  5  5  5  4  5  4  4  4  4  4  4  4  5  5  4  3  4  4  4  4
VIS   7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7
CVS   7  7  7  7  7  7  7  7  7  7  2  3  6  5  5  6  4  5  5  4  3  5  5  4  4
OBV   N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N
```

Figure 18. NAS Fallon LAMP bulletin issued 0700 UTC 6 March 2012.



```
GFS LAMP FORECASTS

KNFL   GFS LAMP GUIDANCE    3/06/2012  1400 UTC
UTC  15 16 17 18 19 20 21 22 23 00 01 02 03 04 05 06 07 08 09 10 11 12 13 14 15
TMP  44 48 48 48 47 45 44 44 42 43 40 36 32 28 26 24999999999999999999999999 19
DPT  22 22 19 15 10  8  5  1 -1 -3 -4 -2  1  2  2  2999999999999999999999999  4
WDR  30 31 31 32 32 32 33 33 34 35 34 33 34 34 34 33 99 99 99 99 99 99 99 99 30
WSP  13 18 22 28 26 27 28 28 29 25 24 20 18 16 14 15 99 99 99 99 99 99 99 99 11
WGS  NG 25 29 35 33 34 35 36 37 32 31 28 26 25 23 24999999999999999999999999 NG
PPO   7  9 22 14 16 18 22 17 13 11  8  4  2  0  0  0  0  0  0  0  0  0  0  0  0
PCO   N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N
P06                                 31                 5                 0
TP2            0  0  0  0  0  0     0     0     0     0     0     0     0     0
TC2            N  N  N  N  N  N     N     N     N     N     N     N     N     N
POZ   0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
POS  27 39 47 53 60 67 74 79 77 79 94100100100100100100100100100100100100100100
TYP   R  R  R  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S  S
CLD  SC SC SC SC SC SC BK SC SC SC SC FW FW CL CL CL CL CL CL CL CL CL CL CL CL
CIG   8  8  8  8  8  7  7  7  7  7  7  7  8  8  8  8  8  8  8  8  8  8  8  8  8
CCG   8  6  6  6  6  6  6  6  6  6  6  6  6  6  6  6  7  8  8  8  6  6  2  2  1
VIS   7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7  7
CVS   7  7  7  3  4  7  7  5  7  4  4  4  3  4  4  5  3  4  4  4  3  3  4  4  3
OBV   N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N  N
```

THIS PAGE INTENTIONALLY LEFT BLANK

V. CONCLUSION

A. SUMMARY

The observational statistics indicate that for the stations chosen in this study the weather conditions are above IMC over 94% of the time. Both the forecaster and the model correctly verify those conditions over 95% of the time. This is a clear indication that fair-weather not only occurs frequently, but is fairly easy to predict. The IMC events occur only occurring 6% of the time. Unfortunately, both the model and the forecaster have only about a 47% hit rate for the ceiling IMC events and 43% hit rate for visibility IMC events (Figure 22) . Since the occurrence of IMC conditions is when the customers are predominantly relying on the forecaster, the forecast accuracy during those instances becomes the primary source of the customer's judgment of a forecaster's value, despite the low frequency of occurrence.

When the full 24 hr forecast is compared to the 13 through 24 h forecasts, there are no significant differences with the 00-12 h forecasts. But, when the October 2006 through March 2007 data are compared to the same months in 2013, there is a significant improvement in skill across for both the model and the forecaster. These improvements can likely be attributed to the improved accuracy in model forecasts. However, skill with respect to visibility forecasts by the forecaster improved at a significantly higher rate than the model did during this period. This might be attributed to the change of reach back forecasting form 2006 through 2012, to the on station forecasts produced in 2013.

Using CSI as the main indicator of skill, there is very little difference between the model and the TAF. Even when using the Non-VMC HR and CSI, both the model and TAF performed equally well. However, the forecaster did not improve upon the model's performance. Therefore, this study could not determine any significant value added by the forecaster over the model in 2013. As for whether those CSI scores are overall good or poor is difficult to determine. However, the most recent verification that could be found from 2008 (Figures 23 and 24), shows LAMP with an average CSI of .36 for ceilings and an average of .28 for visibility. Although these numbers are higher, they are consistent with what this study has calculated and therefore provide some legitimacy into the methods of verification.

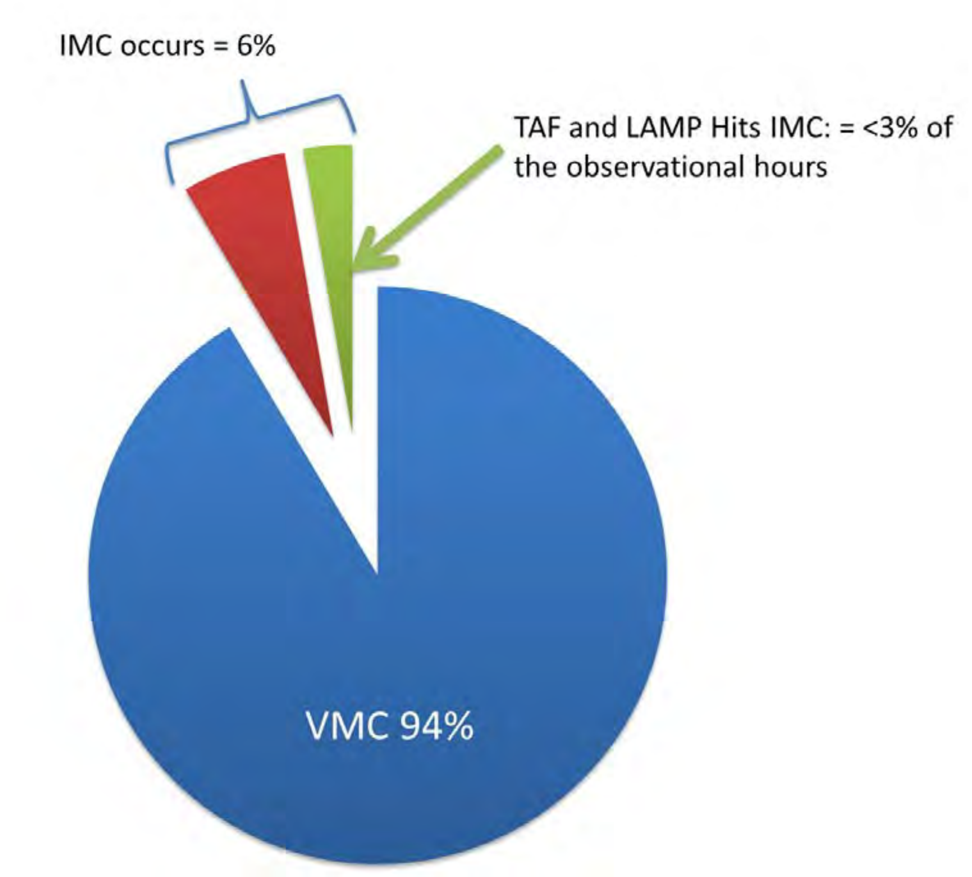


Figure 19. 2013 Observational hours VMC vs IMC (all stations)

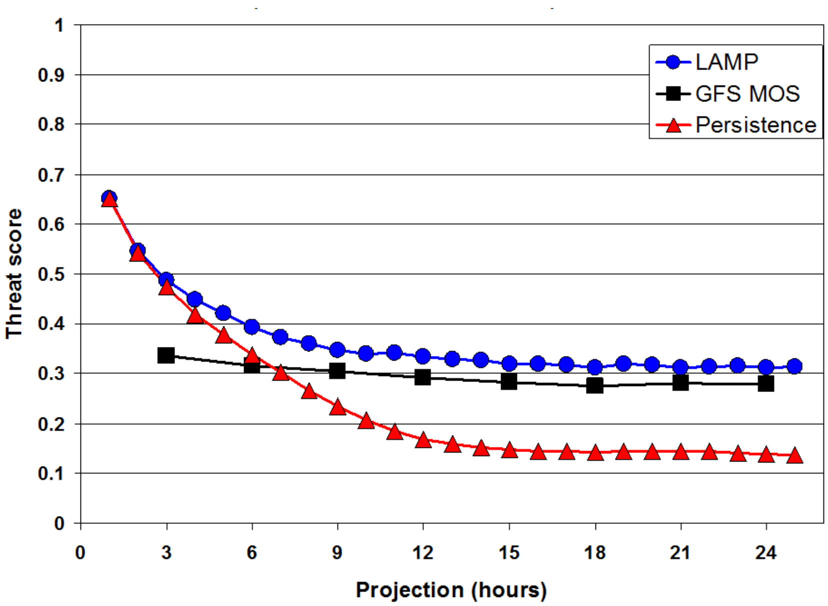


Figure 20. Verification of ceiling IMC forecasts by LAMP during October 2007-March 2008 (from Rudack and Ghirardelli, 2010)

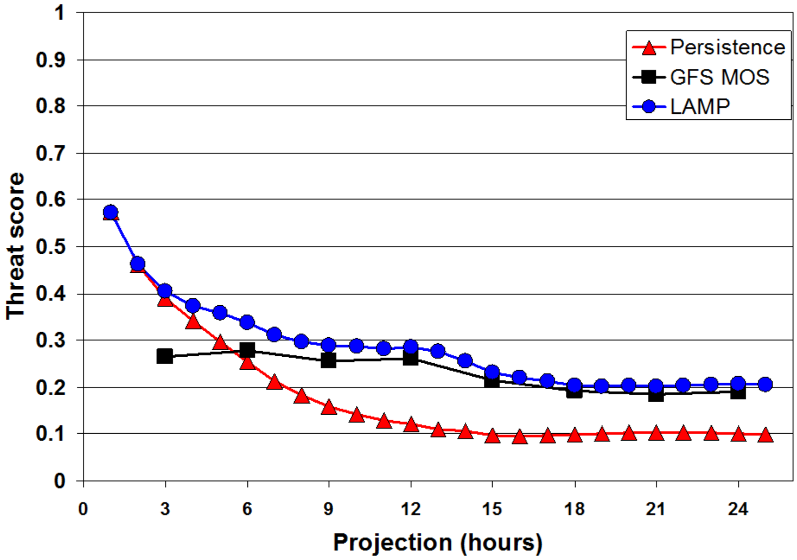


Figure 21. Verification of ceiling IMC forecasts by LAMP during October 2007-March 2008 (from Rudack and Ghirardelli 2010)

B. RECOMMENDATIONS FOR EXPLOITING MODEL STRENGTH

(1) Probabilistic Forecasting

As shown in the case study, using probabilistic forecasting techniques has potential to be a better decision aid than a deterministic forecast. At the very least, the forecasters can track the models probability forecasts and develop rules of thumb to incorporate into their TAF writing as a measure of the forecast utility. For example, a 23% chance of precipitation at NAS Fallon, might weigh differently than a 23% chance of precipitation at NAS Oceana. But ideally, the Navy will learn to use probabilistic forecasting in the TAF and other forecasting products. This will provide the customer more information into what the forecaster is expecting.

(2) Model Interpreters

With the lack of hands on training available in the fleet compared to twenty years ago, and the ever increasing shift to have Aerographer’s Mates perform non-forecasting jobs, it seems more productive to have them become more of a model interpreter than a forecaster. More model training needs to be added to the base level forecasting school and incorporated into the training pipeline in order for them to understand proper techniques to use the model more adequately. Case studies tracking model performance in various environments should be a part of the daily routine, or at least during the 94% of shift time that is VMC. Cataloging these model performances will lead to better “rules of thumb” for forecasters to access when faced with time sensitive forecasting, or in meteorological events that they have not experienced during their tour.

(3) Standardized Verification Program

The Navy did not perform verification of its TAFs in 2013. In combination with training, verification is the primary method to improve on forecasting skill. The National Weather Service is currently refitting their online verification tool to be compatible with the Navy TAFs. Once online, the verification program should be standardized across all stations and overseen at the CNMOC level. Oversight and standardization will ensure that forecasting weaknesses will be noticed earlier and incorporated into the training process across the fleet.

C. RECOMMENDATIONS FOR FUTURE STUDIES

(1) Model tendencies

Run a verification program to grade the skill of LAMPs probability forecasts to identify if there are any tendencies to be exploited by forecasters at each station.

(2) Thunderstorm and wind data

Thunderstorm and high wind condition may not always be associated with an IMC event. Yet they both have the potential to impact air operations equally. The TAF and LAMP bulletin for thunderstorm and wind data should be verified to determine the level of value the forecaster is providing during these two meteorological events.

(3) Trends

For the possibility of predictable trends that may occur in the model guidance should be examined. If trends exist, they can be exploited to define the utility associated with probabilistic forecasts.

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX

```
201203061456 METAR KNFL 061456Z 26019G24KT 10SM FEW060 SCT080 BKN120 06/M02
              A2965 RMK AO2 SLP025 ACSL DSNT NW
              T00561017 56004=
201203061556 METAR KNFL 061556Z 28021G25KT 10SM FEW050 BKN075 BKN120 07/M02
              A2967 RMK AO2 PK WND 26026/1546 SLP030
              SH DSNT W-NW AND NE T00671022=
201203061636 SPECI KNFL 061636Z 33021G33KT 10SM -SN BKN050 BKN065 OVC120
              03/M03 A2969 RMK AO2 PK WND 33033/1631
              SNB36 P0000=
201203061636 SPECI KNFL 061636Z 33021G33KT 10SM -SN BKN050 BKN065 OVC120
              03/M03 A2969 RMK AO2 PK WND 33033/1631
              SNB36 P0000=
201203061646 SPECI KNFL 061646Z 34021G31KT 1 1/2SM -SN BKN033 BKN047 OVC085
              02/M02 A2970 RMK AO2 PK WND 33033/1631
              SFC VIS 2 1/2 SNB36 RCRNR P0000=
201203061646 SPECI KNFL 061646Z 34021G31KT 1 1/2SM -SN BKN033 BKN047 OVC085
              02/M02 A2970 RMK AO2 PK WND 33033/1631
              SFC VIS 2 1/2 SNB36 RCRNR P0000=
201203061650 SPECI KNFL 061650Z 34021G33KT 1/2SM SN OVC012 01/M02 A2970
              RMK AO2 PK WND 35033/1648 SNB36 RCRNR
              P0000=
201203061650 SPECI KNFL 061650Z 34021G33KT 1/2SM SN OVC012 01/M02 A2970
              RMK AO2 PK WND 35033/1648 SNB36 RCRNR
              P0000=
201203061656 METAR KNFL 061656Z 35024G33KT 1/2SM SN FZFG OVC012 M01/M03
              A2971 RMK AO2 PK WND 35033/1654 SNB36
              SLP041 RCRNR P0000 T10061028=
201203061703 SPECI KNFL 061703Z 35022G33KT 1/2SM -SN BKN015 OVC045 M01/M03
              A2971 RMK AO2 PK WND 36031/1701 SFC
              VIS 3/4 RNRNR P0000=
201203061703 SPECI KNFL 061703Z 35022G33KT 1/2SM -SN BKN015 OVC045 M01/M03
              A2971 RMK AO2 PK WND 36031/1701 SFC
              VIS 3/4 RNRNR P0000=
201203061720 SPECI KNFL 061720Z 35023G34KT 1 1/2SM -SN BKN015 OVC045 M01/M04
              A2972 RMK AO2 PK WND 36041/1705 SFC
              VIS 2 WR// P0000=
201203061720 SPECI KNFL 061720Z 35023G34KT 1 1/2SM -SN BKN015 OVC045 M01/M04
              A2972 RMK AO2 PK WND 36041/1705 SFC
              VIS 2 WR// P0000=
201203061727 SPECI KNFL 061727Z 36021G34KT 1 1/2SM -SN BKN022 BKN042 OVC050
              M01/M04 A2973 RMK AO2 PK WND 36041/1705
              SFC VIS 2 WR// P0000=
201203061727 SPECI KNFL 061727Z 36021G34KT 1 1/2SM -SN BKN022 BKN042 OVC050
```

```
              M01/M04 A2973 RMK AO2 PK WND 36041/1705
              SFC VIS 2 WR// P0000=
201203061734 SPECI KNFL 061734Z 36028G33KT 2SM -SN BKN030 OVC045 M01/M05
              A2973 RMK AO2 PK WND 36041/1705 SFC
              VIS 3 WR// P0000=
201203061734 SPECI KNFL 061734Z 36028G33KT 2SM -SN BKN030 OVC045 M01/M05
              A2973 RMK AO2 PK WND 36041/1705 SFC
              VIS 3 WR// P0000=
201203061748 SPECI KNFL 061748Z 35021G29KT 1SM -SN OVC025 M01/M04 A2976
              RMK AO2 PK WND 36041/1705 TWR VIS
              1 1/2 WR// P0000=
201203061748 SPECI KNFL 061748Z 35021G29KT 1SM -SN OVC025 M01/M04 A2976
              RMK AO2 PK WND 36041/1705 TWR VIS
              1 1/2 WR// P0000=
201203061756 METAR KNFL 061756Z 36019G29KT 3SM -SN BR SCT025 BKN034 OVC041
              M02/M04 A2976 RMK AO2 PK WND 36041/1705
              SLP056 WR// P0000 60000 T10171039
              10094 21017 53031=
201203061822 SPECI KNFL 061822Z 34023G28KT 2SM -SN OVC027 M01/M04 A2978
              RMK AO2 PK WND 34030/1812 WR// P0000=
201203061822 SPECI KNFL 061822Z 34023G28KT 2SM -SN OVC027 M01/M04 A2978
              RMK AO2 PK WND 34030/1812 WR// P0000=
201203061836 SPECI KNFL 061836Z 34026G33KT 3SM -SN BKN023 BKN028 OVC040
              M01/M05 A2979 RMK AO2 PK WND 35033/1836
              WR// P0000=
201203061836 SPECI KNFL 061836Z 34026G33KT 3SM -SN BKN023 BKN028 OVC040
              M01/M05 A2979 RMK AO2 PK WND 35033/1836
              WR// P0000=
201203061850 SPECI KNFL 061850Z 34022G34KT 3/4SM -SN BKN025 OVC037 M01/M06
              A2980 RMK AO2 PK WND 34034/1843 SFC
              VIS 1 WR// P0000=
201203061850 SPECI KNFL 061850Z 34022G34KT 3/4SM -SN BKN025 OVC037 M01/M06
              A2980 RMK AO2 PK WND 34034/1843 SFC
              VIS 1 WR// P0000=
201203061852 SPECI KNFL 061852Z 34020G34KT 3/4SM -SN BKN022 BKN028 OVC037
              M01/M06 A2981 RMK AO2 PK WND 34034/1843
              SFC VIS 1 WR// P0000=
201203061852 SPECI KNFL 061852Z 34020G34KT 3/4SM -SN BKN022 BKN028 OVC037
              M01/M06 A2981 RMK AO2 PK WND 34034/1843
              SFC VIS 1 WR// P0000=
201203061856 METAR KNFL 061856Z 35025G31KT 3/4SM -SN BKN020 BKN028 OVC041
              M01/M05 A2981 RMK AO2 PK WND 34034/1843
              SFC VIS 1 SLP072 WR// P0000 T10111050=
201203061903 SPECI KNFL 061903Z 34022G34KT 1 1/2SM -SN BKN018 BKN026 OVC041
              M01/M05 A2981 RMK AO2 PK WND 35034/1858
              SFC VIS 2 WR// P0000=
201203061903 SPECI KNFL 061903Z 34022G34KT 1 1/2SM -SN BKN018 BKN026 OVC041
```

```
             M01/M05 A2981 RMK AO2 PK WND 35034/1858
             SFC VIS 2 WR// P0000=
201203061912 SPECI KNFL 061912Z COR 34018G30KT 7SM BKN020 BKN030 BKN037
             M01/M05 A2982 RMK AO2 PK WND 35034/1858
             SH VC E-S-SW SNE12 WR// P0000=
201203061912 SPECI KNFL 061912Z COR 34018G30KT 7SM BKN020 BKN030 BKN037
             M01/M05 A2982 RMK AO2 PK WND 35034/1858
             SH VC E-S-SW SNE12 WR// P0000=
201203061947 SPECI KNFL 061947Z 35020G25KT 10SM BKN020 BKN030 BKN037 01/M06
             A2982 RMK AO2 PK WND 35034/1858 SNE12
             WR// P0000=
201203061947 SPECI KNFL 061947Z 35020G25KT 10SM BKN020 BKN030 BKN037 01/M06
             A2982 RMK AO2 PK WND 35034/1858 SNE12
             WR// P0000=
201203061956 METAR KNFL 061956Z 35021G29KT 8SM -SN SCT030 BKN037 BKN070
             01/M06 A2982 RMK AO2 PK WND 35034/1858
             SLP076 SNE12 SH VC N-E-SE P0000 T00061061=
201203062004 SPECI KNFL 062004Z 01019G30KT 10SM -SN SCT030 BKN040 BKN070
             OVC200 01/M06 A2982 RMK AO2 PK WND
             36030/2001 SNB01 VIS LWR NE-E P0000=
```

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF REFERENCES

Antolik, M.S., 2012: Model Output Statistics (MOS)- Objective Interpretation of NWP Model Output. [Available online at http://www.nws.noaa.gov/mdl/synop /presentations/millersv2005.ppt.]

Doswell, C,1986: The Human Element in Weather Forecasting. *Natl. Wea. Dig.*, **11**, 6–17.

Ghirardelli, J.E., 2005: An Overview of the Redeveloped Localized Aviation MOS Program (LAMP) for Short-Range Forecasting. Preprints, *21st Conference on Weather Analysis and Forecasting*. Washington, D.C., Amer. Meteor. Soc., 13B.5. [Available online at http://www.nws.noaa.gov/mdl/lamp/publications /LAMP_overview_paper_AMS2005_final.pdf.]

McClung, T, 2012. Amended: Changes to Localized Aviation Model Output Statistics Program (LAMP) Products. NWS Tech.Note/11-46, 2 pp.

National Transportation Safety Board, 2014: Probable cause report for accident for March 6, 2012 in Fallon, NV. NTSB ID/ DCA12PA049. [Available online at http://www.ntsb.gov/aviationquery/brief.aspx?ev_id=20120307X13644.]

Riordan, D and B. Hansen, 2002: A Fuzzy Case-Based System For Weather Prediction. *Engineering Intelligent Systems*, **3**, 139–146.

Roulston, M., and L.A. Smith, 2004: The Boy Who Cried Wolf Revisited: The Impact of False Alarm Intolerance on Cost-Loss Scenarios. *Wea. Forecasting*, **19,** 391–397.

Rudack, D.E. and J.E. Ghirardelli, 2010: A comparative verification of Localized Aviation Model Output Statistics Program (LAMP) and Numerical Weather Prediction (NWP) model forecasts of ceiling and visibility. *Wea. Forecasting*, **24**, 1161–1178.

Stuart, N., P. Market, B. Telfeyan, G. M. Lackmann, K. Carey, H. E. Brooks, N. Nietfeld, B. C. Motta, and K. Reeves, 2006: The Future of Humans in an Increasingly Automated Forecast Process. *Bul. Amer. Meteor. Soc.*, **87**, 1497–1498.

Wilkes, D, 1995: *Statistical Methods in the Atmospheric Sciences*. Academic Press, 467 pp.

Yang, F, 2013: Review of GFS Forecast Skills in 2013. [Available online at http://www.emc.ncep.noaa.gov/gmb/wx24fy/doc/GFS.performance.review.2013.pdf.]

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California