NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

ANALYSIS OF WEATHER FORECAST IMPACTS ON UNITED STATES AIR FORCE COMBAT OPERATIONS

by

Karen Darnell

March 2006

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REPORT DOCUMENTATION PAGE			*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.			
1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2006	**3. REPORT TYPE AND DATES COVERED** Master's Thesis	
4. TITLE AND SUBTITLE: Analysis of Weather Forecast Impacts on United States Air Force Combat Operations		**5. FUNDING NUMBERS**	
6. AUTHOR(S) Darnell, Karen, M.			
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.			
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited		**12b. DISTRIBUTION CODE** A	
13. ABSTRACT (maximum 200 words) Accurate weather forecasts are vital to air combat operations. Quantitative assessments of forecasts and their operational impacts are essential to improving weather support for war fighters. We adapted an existing U.S. Navy, web-based, near–real time system for collecting and analyzing data on the performance and operational impacts of military forecasts. We used the adapted system to collect and analyze data on Air Force Weather (AFW) forecasts, and the planning and execution of flying operations, at six Air Combat Command and Pacific Air Forces bases. We analyzed the data to develop quantitative metrics of forecast performance and operational impacts. Our results indicate that planning weather forecasts (PWFs) have a higher potential for making positive contributions to air operations than do mission execution forecasts (MEFs). This is notable because AFW units spend significantly less time developing PWFs than MEFs. Surface visibility, cloud ceilings, and cloud layers caused most negative mission impacts, indicating these phenomena should be a focus of future research and training. We found high levels of mission success even when forecasts were inaccurate, perhaps due to aircrew and mission flexibility. Our analyses revealed a need for improved education of flying units on the nature and availability of AFW products.			
14. SUBJECT TERMS meteorology, forecast verification, forecast performance, operational verification, operational impacts, aircrews, aviators, mission execution forecast, planning weather forecast, air combat, combat operations, Air Force Weather, Air Combat Command, Pacific Air Forces, metrics		**15. NUMBER OF PAGES** 121	
		16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UL

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**ANALYSIS OF WEATHER FORECAST IMPACTS ON
UNITED STATES AIR FORCE COMBAT OPERATIONS**

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Submitted in partial fulfillment of the
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MASTER OF SCIENCE IN METEOROLOGY

from the

**NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

Accurate weather forecasts are vital to air combat operations. Quantitative assessments of forecasts and their operational impacts are essential to improving weather support for war fighters. We adapted an existing U.S. Navy, web-based, near–real time system for collecting and analyzing data on the performance and operational impacts of military forecasts. We used the adapted system to collect and analyze data on Air Force Weather (AFW) forecasts, and the planning and execution of flying operations, at six Air Combat Command and Pacific Air Forces bases. We analyzed the data to develop quantitative metrics of forecast performance and operational impacts. Our results indicate that planning weather forecasts (PWFs) have a higher potential for making positive contributions to air operations than do mission execution forecasts (MEFs). This is notable because AFW units spend significantly less time developing PWFs than MEFs. Surface visibility, cloud ceilings, and cloud layers caused most negative mission impacts, indicating these phenomena should be a focus of future research and training. We found high levels of mission success even when forecasts were inaccurate, perhaps due to aircrew and mission flexibility. Our analyses revealed a need for improved education of flying units on the nature and availability of AFW products.

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LIST OF ACRONYMS AND ABBREVIATIONS

AB	Air Base
ACC	Air Combat Command
AETC	Air Education and Training Command
AF	Air Force
AFAA	Air Force Audit Agency
AFB	Air Force Base
AFI	Air Force Instruction
AFMAN	Air Force Manual
AFW	Air Force Weather
AFWSPV	Air Force Weather Strategic Plan and Vision
AMC	Air Mobility Command
BW	Bomb Wing
CINC	Commander in Chief
COE	Center of Excellence
CWT	Combat Weather Team
FAC	Forecast Accuracy
FAR	False Alarm Rate
IRTSS	Infrared Target Scene Simulation
MAJCOM	Major Command
ME	Mission Execution
MEF	Mission Execution Forecast
MEFP	Mission Execution Process
MEFFAC	Mission Execution Forecast Accuracy
MEFFAR	Mission Execution Forecast False Alarm Rate
MEFPOD	Mission Execution Forecast Probability of Detection
MEFVER	Mission Execution Forecast Verification
METOC	Meteorology and Oceanography
NPS	Naval Postgraduate School
OPVER	Operational Verification
OWL	Operational Weather Limiters Search
OWS	Operational Weather Squadron
PACAF	Pacific Air Forces
PIREPS	Pilot Reports
PMC	Positive Mission Contribution
POD	Probability of Detection
PPMC	Potential Positive Mission Contribution
PWF	Planning Weather Forecast
TAWS	Target Acquisition Weapons Software
TDY	Temporary Duty
UAV	Unmanned Aerial Vehicle
USAFWS	United States Air Force Weapons School

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ACKNOWLEDGMENTS

Praise God!! Writing a thesis is not my forte as Col David Smarsh and Prof Tom Murphree soon found out. However, they both helped me work through to completion…many thanks!

I truly appreciate the support from the weather personnel at participating bases: Lt Rob Branham, Lt Jody 'Chevy' Chevalier, Maj Corey Hummel, Maj Robert Leejoice, Capt Christopher Lovett, Lt Jeanne Szczes, and Lt Randi Watt. You coordinated data collection and many other time-consuming issues which obviously were huge requirements for this project. I would be happy to return the favor some day.

To my patient and persistent computer brains, Sharon Prichard and Bruce Ford, thank you!

Many thanks to my fellow classmates in the NPS meteorology class of 2006, your study sessions and sense of humor made NPS an enjoyable experience.

Mark, Emily, Caleb, and Katelyn, thanks for always supporting me and allowing me the time away from you to do "homework"…I LOVE YOU…xo♥!

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I.   INTRODUCTION

A.   BACKGROUND

Accurate weather forecasts are vital to planning and conducting effective combat operations. Focused quantitative analyses of military weather forecasts and their operational impacts are essential to ensure high quality weather support for war fighters. In today's resource limited and changing environment, more effective and efficient processes and procedures are essential. Improved processes, when employed throughout an organization, can save manpower and resources and enhance mission accomplishment. In this study, we have analyzed some of the challenges facing Air Force weather (AFW) personnel, especially the difficulties associated with obtaining operator feedback on mission execution forecasts (MEFs) that is required of CWTs (AFMAN 15-129). To address these difficulties, we have developed and tested a system to improve the feedback process. The system was designed to improve operator feedback to the CWTs without increasing CWT workloads.

1.   War on Terrorism

The United States military has seen many changes in the way business is done since September 11, 2001, when the United States experienced horrific attacks by terrorists. In the Air Force Chief of Staff's remarks at the 2005 Air Force Defense Strategy and Transformation Seminar Series in Washington D.C. on 9 February 2005, General Moseley indicated there were about 30,000 active, Guard, and Reserve airmen deployed (Moseley 2005). In an Air Force Policy Letter Digest article in December 2005, Air Force Secretary Michael W. Wynne said the Air Force is evolving in response to a new global war on terrorism (Wynne 2005). Secretary Wynne indicated in this article that the Air Force deployed more than 300 aircraft and 24,000 airmen in support of the war on terrorism.

Deploying so many airmen inevitably results in fewer being available to sustain home station operations. In many situations, this causes home stations to refocus their operations, which results in many processes and procedures

being altered. The new processes and procedures will logically be in the forefront of a unit's focus, while previously developed tasks (e.g., required routine training, administrative and planning requirements) may be given a lower priority. In the AFW career field, some of the less critical and less easily executed tasks include the determination of forecast performance metrics and collection of customer feedback. These tasks generally do not have firm timelines, and many AFW units lack the expertise to perform them well. However, in a working environment in which units are faced with increasing deployments and limited resources, these tasks can make AFW units more effective and efficient. Thus these tasks become even more essential for achieving overall mission success. This highlights the need for highly effective and efficient processes that, once implemented, can improve effectiveness while reducing needed resources.

2. Reengineering Air Force Weather

a. *Initiation and Implementation*

In addition to deployments, AFW personnel have seen many internal changes in the way business is done over the last ten years intended to increase effectiveness while improving war fighter support. In 1997, the Air Force director of weather (AF/A3O-W) implemented a reengineering plan to realign its force structure at the operational and tactical levels of warfare. The changes were necessary because manpower cuts, among other factors, caused AFW to fall below the critical personnel levels necessary to sustain itself (AFWSPV 2004).

AFW accomplished both a support and a personnel restructuring. Part of the restructure was to stand up operational weather squadrons (OWSs) focused at the operational level of warfare. The OWS took over production of several tasks from the base weather station, such as terminal aerodrome forecasts, weather watches, warnings, and advisories. This freed up the combat weather teams (CWTs) at military bases to focus on mission-tailored forecasting for their supported units (AFWSPV 2004). AFW leadership envisioned that by

focusing the base-level weather team on products, such as MEFs, weather teams would be more likely to become fully integrated into flying operations (AFAA 2005).

While some units are still trying to fully implement portions of the restructuring, many have been hindered in doing so by additional taskings and deployments that have been levied as a result of the war on terrorism. Tasks such as daily building patrols, terrorism training, 100% identification checks into many base facilities that had no checks before, evacuation drills, accountability drills, and simple medical training have inundated an already full schedule. This has resulted in many personnel and units becoming task saturated.

As noted in a recent Air Force audit (AFAA 2005), the scramble to keep up with demands placed on CWTs by Air Force instructions and directives is challenging. Due to these challenges, restructuring has, in some cases, not achieved its full potential (AFAA 2005).

b.   Reengineering Challenges

Although the AF/A3O-W reengineering plan was implemented with extensive guidance, some CWTs are not able to fully implement some aspects of the vision. After holding positions out of the AFW career field for six years, I re-entered it in June 2001 by taking a position as the CWT commander at an Air Force installation supporting fighter aircraft. I had previously read the Air Force Instructions (AFIs) regarding reengineering and looked forward to stepping into a new organizational framework. What soon became apparent was that the concept was challenging to implement, both from a CWT and customer perspective, due to limited resources, and perhaps resistance to change by some personnel.

It took me nearly two years as a CWT flight commander to integrate weather personnel into two of the flying squadrons at my installation. In fact, one squadron never did allow this during my time as the CWT flight commander. Integration was only possible when squadron and group leadership were willing to endure some of the pain involved. Often, when customer leadership changes,

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so does the integration of the CWT and its weather support. The challenge is to institutionalize a process so that when leadership changes, weather support does not. Once weather personnel are integrated into the flying squadrons, it is much easier to obtain operator feedback. Integration helps customers get to know CWT personnel, which in turn helps the CWT get customer feedback. The increase in feedback our weather team gained by integrating our personnel into the customers' environment was invaluable. This feedback enabled us to make some drastic operator-driven changes to our MEFs, which led to improved weather support to the customer.

Since 2003, the same CWT I led has reverted back to little or no integration of weather personnel into the flying squadrons. This is, in part, due to decreased manning because of deployments supporting the war on terrorism. Because this integration concept might not be possible at many CWTs, our study developed and tested a system for gaining operator feedback for individual missions that can be easily adapted to almost any CWT. This system was designed to help streamline CWT processes and procedures.

3. **Air Force Manual 15-129, Air and Space Weather Operations - Processes and Procedures**

CWT operations are outlined in chapter 4 of Air Force Manual 15-129, Air and Space Weather Operations – Processes and Procedures, 2004 (hereafter referred to as AFMAN 15-129). This manual applies to all Air Force personnel and organizations conducting weather operations. Because each CWT has its own unique mission and responsibilities, the manual gives general guidance on what needs to be accomplished. Each CWT must tailor its weather products to its customers in such a manner that it provides environmental information ready for use by customers in making mission planning and execution decisions. This support can be provided in a number of ways, but should follow what AFMAN 15-129 calls the MEF process (MEFP). The purpose of the MEFP is to "temporally and spatially refine forecast products to provide decision-quality environmental information for an operational decision-making process" (AFMAN 15-129).

The MEFP is a twelve step process:

1) Determine the what, when, where, who, and how of the primary and secondary missions.
2) Define weather thresholds.
3) Define products, services, and data types.
4) Coordinate operations.
5) Obtain weather situational awareness.
6) Conduct mission-scale analysis.
7) Predict mission execution weather parameters.
8) Tailor forecast parameters to mission.
9) Disseminate MEF.
10) Conduct mission watch.
11) Update forecast products/information.
12) Conduct MEF verification.

These 12 steps fall into four phases:

1) planning and coordinating (determined by CWT leadership; steps 1-4),
2) preparing (steps 5-8)
3) executing (steps 9-10)
4) follow-up (steps 11-12)

The MEFP is a process for continuous assessment and improvement of weather support. To achieve this improvement, the full process should be routinely used and its effects regularly assessed. This is especially true when customer missions change, because then the MEFs, and the steps for evaluating the MEFs, must also change. In this study, we have focused on the follow-up phase of the MEFP for aviation support. This is sometimes regarded as the final phase, but is actually the restart of the first phase, and provides weather personnel with a foundation on which to build and remodel the MEF.

a. Update Forecast Products/Information

The main goal of step eleven is to improve weather support by modifying the MEFs based on customer feedback. Customer feedback may change as customer leadership changes. But the resulting changes to the MEFs should be relatively small because each CWT should have a weather support plan in place that outlines the what, when, and how of the CWT's products and processes. These plans help stabilize the CWT's products and processes, ensure well defined customer support, and make CWT operations more efficient.

b. *Conduct Mission Verification*

Step twelve of the MEFP directs CWTs to perform seven tasks (AFMAN 15-129):

1)   Implement systematic procedures to analyze and measure accuracy/relevancy of environmental services provided to parent/host unit.
2)   Debrief operator.   Face-to-face feedback is preferred; employ other feedback methods whenever direct feedback cannot be obtained.
3)   Disseminate output from weather debriefs or pilot reports (PIREPS) to OWSs and other weather team members.
4)   Perform technical verification (evaluate forecast skills, under/over forecast, bias, etc.).
5)   Conduct operations verification based on established "Go/No Go" thresholds.
6)   Develop and apply metrics to process improvement.   Use feedback to develop rules of thumb and lessons learned.
7)   Accomplish, document, train with, and cross feed forecast reviews.

The seven tasks for step 12 are all important, but, in practice, they can be very difficult to complete, especially given the resource limitations described earlier in this chapter. In this study, we focused on developing and testing a system to facilitate the completion of four of these tasks: 1, 2, 5, and 6. Our goals were to create a system that simplified the process of: (1) collecting data with which to verify forecasts and assess customer performance; (2) collecting customer feedback data; (3) analyzing forecast and customer performance; (4) relating forecast and customer performance to determine the operational impacts of the forecasts; and (5) identifying methods for improving weather support for customer operations. These five goals directly address tasks 1, 2, 5, and 6.

Implicit in these tasks and goals is the understanding that good forecast performance (e.g., high forecast accuracy) does not necessarily indicate good customer performance (e.g., success in completing missions). There are many ways in which accurate forecasts can fail to provide optimal support for mission planning and execution (e.g., by failing to provide relevant forecasts or to provide forecast information in a timely, understandable and readily useable format)

The preferred method to obtain customer feedback is face-to-face discussion (AFMAN 15-129). However, this is not always possible due to resource constraints. Further, if a CWT has educated its customers on weather impacts and the customers know what feedback is needed, then a face-to-face debrief may not be needed. Whatever the method for collecting customer feedback, it is important that the feedback comes from the customer and not from CWT personnel inferring what the customers would say if asked. The system we developed for this study was designed to collect data directly from aircrews on the accuracy of the forecasts they received, the success of their missions, the usefulness and specific impacts of the forecasts on the planning and execution of their missions, the weather phenomena that were encountered during the mission, and the impacts of those phenomena on the execution of the mission..

4.   Air Force Instruction 15-114, Functional Resource and Weather Technical Performance Evaluation

Guidance and procedures for measuring and evaluating the operational effectiveness and technical performance of atmospheric and space environmental support, collectively termed weather support, is defined in Air Force Instruction 15-114, Functional Resource and Weather Technical Performance Evaluation, 2001 (hereafter referred to as AFI 15-114). This 14-page document defines three categories of forecast assessment:

1) forecast impacts on mission execution determined by operational verification (OPVER)
2) forecast accuracy determined by aerodrome forecast verification
3) resource protection effectiveness determined by warning/advisory verification (WARNVER)

a.   OPVER

AFI 15-114 calls operational verification of the MEF (MEFVER) the "single most important mission-oriented, operational effectiveness assessment requirement for CWTs." The instruction further explains that this type of OPVER will be used by the Air Staff to explain AFW capabilities to Department of Defense and National senior leaders. According to AFI 15-114, "CWTs develop OPVER criteria through close coordination with operators. CWTs then collect verification data by debriefing customers and/or analyzing observed versus

forecast conditions to determine forecast impact on tactical-level mission effectiveness." However, most CWTs do not have the resources or expertise to develop such an OPVER process. Our study is intended to help correct this problem by streamlining the OPVER process.

b. Automating Readiness and Technical Performance Metrics

Paragraph two of AFI 15-114 calls for a system that, "automates *all* metrics, from data collection, aggregation, to data quality control. The end-state will be an automated web-based system with the capability to provide ad hoc analyses and reports (assessments) for all levels of AFW support." The instruction also provides guidance on how to proceed until this automation is realized. The system we have developed in this study automates many of the steps needed to calculate the required metrics.

5. Air Force Agency Report

The Air Force Audit Agency (AFAA) issued a "Weather Operations Metrics" report on 27 September 2005 (AFAA 2005), in response to a request from AF/A3O-W, to determine whether or not the Air Force effectively implemented MEFVER. Specifically, the AFAA was asked to determine if weather personnel effectively:

1) accomplished mission execution forecast verification
2) included mission operator feedback on weather forecasts in MEFVERs
3) identified improvement opportunities (AFAA 2005)

There were 19 CWTs reviewed in the audit, three of which also participated in our research project. The audit was performed during February-April 2005 using documents dated 13 March 1998 through 17 March 2005. The audit found that AFIs do not provide standardized procedures for obtaining mission operator feedback on weather forecasts and do not require operations personnel to provide formal feedback on weather forecast accuracy and mission impact. The audit found that low customer feedback rates had a negative impact on weather teams' efforts to identify improvement opportunities. Specifically, the audit mentioned that low response rates from customers hindered data usage and prevented weather teams from deriving any usable information from

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customer feedback. The audit also indicated that the relevant AFIs did not provide sufficient guidance or clear procedures for identifying improvement opportunities within the MEFVER program (AFAA 2005).

The audit team made several recommendations to the Deputy Chief of Staff, Air and Space Operations (AF/XO). The recommendations that apply to this study are to:

1) establish standardized procedures for obtaining mission operator feedback on weather forecasts
2) direct AF/XOO-W and Air Force Director of Operational Training (AF/XOO-T) to coordinate and amend existing processes to require operators to provide formal feedback on weather forecast accuracy and mission impact.

The AF/A3 concurred with the audit results and stated they would be rewriting and updating AFI 15-114 to establish standardized procedures for obtaining mission operator feedback on weather forecasts and identifying improvement opportunities within the MEFVER program, with an estimated completion date of 1 March 2006. The AF/A3 also agreed to amend existing processes to require operators to provide formal feedback on weather forecast accuracy and mission impact with an estimated completion date of 1 November 2005.

Some of the problems cited in the audit report could be fixed if CWTs were fully integrated into the flying squadrons they support. AFW does not have the manpower to this, so other fixes must be found. In our study we developed a potential solution to the problem of Air Force personnel not consistently and completely obtaining customer feedback and identifying improvement opportunities. The audit recommended AFW establish standardized procedures for obtaining mission operator feedback on weather forecasts. Further, the audit directed Air Staff agencies to coordinate and amend existing processes to require operators to provide formal feedback on weather forecast accuracy and mission impact (AFAA 2005). Our research project provides a process for meeting these recommendations and directives.

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6.   Air Force Weather Strategic Plan and Vision

The AFW Strategic Plan and Vision (AFWSPV) issued August 2004 (AFWSPV 2004) was intended to set AFW's course for transformation starting with fiscal year 2008. The plan outlines eight "transformation vectors" that guide the weather core processes of collection, analysis, prediction, tailoring, and dissemination. The eight vectors are:

1) Integrate environmental information collection into the theater intelligence, surveillance, and reconnaissance collection plan.
2) Anticipate and manage the data explosion from the next generation environmental satellites, unmanned vehicles, national technical means, smart tankers, future combat system vehicles, etc.
3) Advocate space weather models going from climatologically and statistically based to physics based.
4) Anticipate and manage increasing model resolution, vertical domain from surface to near space, and physics requirements based on new weapon systems coming into the inventory.
5) Move from a "graphically based" to "digitally based" product line.
6) Exploit automated decision tools as a mainstream product (some will be machine-to-machine (M2M), others will be semi-automated).
7) Fully integrate weather information into decision cycles at the appropriate levels of command.
8) Fully embed people with users as "weather/climate consultants"

In our study, we have addressed the last three vectors, especially in terms of exploiting automation (vector 6), determining where weather information is integrated into aviator decision cycles, from the base level down (vector 7), and the value of embedded weather personnel in flying squadrons (vector 8).

AFWSPV (2004) states, "if you 'boiled down' the AFW business to its essence, you would find that we *integrate* into operations and intelligence, that our analyses provide *battlefield situational awareness*, and our predictions and tailored products enhance *decision superiority* for commanders at every level" (AFWSPV 2004). Our study provides a prototype system for enabling improved: (1) integration of AFW personnel into operations; (2) CWT awareness of how aviators view and use AFW products to plan and execute their missions; and (3) tailoring of products to improve customer decision making.

B.   PREVIOUS WORK

1.   Metrics of Forecast Performance and Impacts on War Fighting Operations

In 2005, Captain Jeff Jarry, USAF, (Jarry 2005) performed analyses of MEFVER data for FY 2004 provided by the Air Mobility Command (AMC).   The three main motives behind his study were to:

1) determine if AFW personnel within AMC were adding value to war fighting operations
2) improve the collection and analysis of AFW MEFVER data
3) provide constructive inputs for the review and update process for the Air Force regulations that govern metrics verification programs and procedures

Jarry (2005) analyzed MEFVER data from 13 CWTs. However, some of the CWTs did not provide data on all of the MEFs they issued and it was not clear how many missions were actually supported by the reported MEFs. Jarry's results clearly indicated a need for a more automated and near-real time system for collection and analyses of data.

Jarry (2005) also found that "the main return on investment in the CWTs probably comes from their forecasts of relatively uncommon, but mission critical, No Go conditions". A No Go forecast is issued when one or more phenomena are forecasted to be below thresholds as determined by weather personnel. Weather personnel receive the thresholds from their customers.

Jarry (2005) points out that MEFVER data collection needs to be done in a more consistent and complete way. Further, he states that, "(CWTs) also need to record for each MEF how operators used the forecasts and the successes and failures of the corresponding mission.   If this data were collected and appropriately archived and analyzed, AFW would be in a much better position to objectively and quantitatively demonstrate both its performance and the value it provides to operations, and to do so on a near-real time basis." In our study we have developed and tested a system for meeting this need.

2.   System for Conducting Quantitative Near Real Time Analyses

In September 2005, Lieutenant Commander Mark Butler, USN, completed a project designed to develop and operationally implement an online system for

collecting and analyzing data on the performance and operational impacts of forecasts, and then reporting the results of the analyses in near real time (Butler 2005). The results of this project were:

1) identification of the data necessary for quantitatively determining forecast performance and the operational impacts of those forecasts

2) development of an online data collection system linked to an online database for archiving and analyzing the required data into a readily accessible form

3) development of a web-based interface that would provide users with near real-time access to the metrics results (i.e., the results of the data analyses)

4) development of a final metrics report format that fully supported the needs of the users (i.e., Naval meteorology and oceanography (METOC) and AFW units and their operational customers)

The system was tested and operationally implemented at the Naval Strike and Air Warfare Center at Naval Air Station Fallon. The system has been deemed quite effective by the METOC officer in charge of Naval Pacific Meteorology and Oceanography Detachment (hereafter referred to as NPMOD) at NAS Fallon (Cantu 2005). NPMOD provides METOC support to Naval strike airwings preparing for upcoming deployments. A major feature of the system is its ability to assess the operational impacts of METOC support, a process that at the time of the Butler study did not exist in any other civilian or military organization (Butler 2005).

C.   GOALS OF THIS STUDY

We designed our study to address the directives, requirements, recommendations, needs, and challenges described in the preceding sections of this chapter. We focused in particular on developing methods for improving the collection and analysis of aviator feedback on the forecasts they received in support of their missions. Using this feedback, we calculated metrics of the performance and operational impacts of these forecasts, *from the perspective of the aviation customers*. We chose to focus on weather support for air combat operations in two major commands, Air Combat Command (ACC) and Pacific Air Forces (PACAF). Working with these major commands, gave us the opportunity

to assess weather support for a wide range of platforms, including fighters, bombers, and unmanned aerial vehicles.

Our first goal was to adapt the Butler (2005) web-based, near-real time system for collecting and analyzing AFW, ACC, and PACAF data in order to assess:

1)   forecast performance
2)   weather phenomena with operational impacts
3)   operational impacts of those forecasts and phenomena.

Our emphasis was on the third of these assessments.

Our second goal was to implement and test our system with ACC and PACAF CWTs. Our objective was to create a highly streamlined and automated system so that there would be little or no additional work for the CWTs and their customers to do.

Our third goal was to use the results from system implementation to provide AFW, ACC, and PACAF personnel with advice on how to alter procedures and allocation of resources to better accomplish their goals. Our objectives were to calculate and provide forecast performance and operational impacts metrics, improve terminal forecast reference notebooks, provide advice on the alteration of MEFs and instrument refresher courses, and provide near-real time results in a format ready for use by leadership.

Our intention was to provide improved tools for CWTs to use in meeting the requirements described in AFMAN 15-129 and AFI 15-114, and for leadership to use in addressing the findings in the AFAA (2005) report. We also set out in this study to make progress along three of the AFWSPV vectors, 6-8 --- in particular by helping to automate CWT processes, quantifying the use and impacts of weather information in customer decision making processes, assessing the value of embedded CWT personnel, and minimizing the impacts of, or reducing the need for, full integration.

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II. DATA AND METHODS

A. DATA COLLECTION METHODS

1. Initiation of Data Collection Efforts

Our data collection efforts were focused on fighter aircraft for several reasons. First, fighters represent a significant AF weapon system. Second, fighters were chosen to expand on other studies, such as Jarry (2005) which covered AMC air transport aircraft. Finally, the majority of my weather experience has been in support of fighter aircraft.

To initiate our collection efforts, we contacted the standardization and evaluation branch in the weather division at headquarters ACC to obtain data from CWTs supporting ACC assets. ACC is the primary provider of combat airpower to U.S. war fighting commands. To support global implementation of national security strategy, ACC operates fighter, bomber, reconnaissance, battle-management, and electronic-combat aircraft. ACC also provides command, control, communications and intelligence systems, and conducts global information operations.

The ACC web site (ACC 2006) explains their mission as a force provider, organizing, training, equipping, and maintaining combat-ready forces for rapid deployment and employment to meet the challenges of peacetime air sovereignty and wartime air defense. ACC numbered air forces provide air components to U.S. Central and Southern Commands, with Headquarters ACC serving as the air component to U.S. Northern and Joint Forces Commands. ACC also augments U.S. European, Pacific and Strategic Commands forces (ACC 2006).

To support our project, the ACC director of weather contacted all the ACC CWTs encouraging support of our project. Five CWTs agreed to collect data for our project. These CWTs support a variety of ACC aircraft, including A-10s, B-1s, B-2s, F-16s, and U-2s. Three of the CWTs were involved in the AFAA

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metrics audit (AFAA 2005). This is important to note because our project was designed to provide a system for assisting CWTs in addressing some of the deficiencies noted in the audit.

After coordination and initiation of data collection with the ACC CWTs, we expanded our data to include two CWTs in PACAF. PACAF's primary mission is to provide ready air and space power to promote U.S. interests in the Asia-Pacific region during peacetime, through crisis, and in war (PACAF 2006). CWTs in PACAF have fully integrated weather personnel into the flying squadrons. This gave us an opportunity to collect data that could be used to assess the value added by embedding weather personnel. We focused our efforts on collecting data from two PACAF units in Korea because they are more operational and fly more missions than CONUS units.

2. Know Your Customer

Our process of coordinating with the ACC CWTs started with us providing guidance on building customer relationships and collecting customer feedback. This section and the following section describe the major steps we recommended be taken by the CWTs to improve their knowledge of, and interaction with, their customers. Our objective was to facilitate the participation, and increase the effectiveness, of the CWTs in the customer feedback portion of our project.

a. Understand Supported Mission and Aircraft

The first step is developing a firm understanding of the supported mission and aircraft. Without this understanding, collection of useful data will be difficult. This involves obtaining weather thresholds defined in the weather support plan. After reviewing the plan, one must visit the supported flying squadrons and obtain weather sensitivities from squadron leadership, planners, and safety officers. This information then needs to be combined with weather threshold data to develop a basis for tailored forecasts.

Good references to use in the process of understanding supported aircraft are 11-series AFIs covering flying operations. AFI 11-214, Air Operations Rules and Procedures, 2001 (hereafter referred to as AFI 11-214), provides rules and procedures for air-to-air and air-to-surface operations and training. The AFIs

give overarching guidance that is often supplemented by MAJCOMs and Air Force installations. These supplements will never be more lenient when it comes to thresholds, but may be more restrictive, so it is necessary to review all guidance from the AFIs and the supplements, from the MAJCOM supplements right down to those from the base, group, and squadron.

An excellent location to find weather limitations for specific aircraft is in a document called the Operational Weather Limiters Search (OWL). The OWL can be found on the website of the 15th Operational Weather Squadron (OWL 2006). This is not an official Air Force document but can still be helpful for general guidance and is a good, easy to read, starting point for aircraft thresholds. Once the general guidance is procured, interviews with standardization and evaluation staff in the operations group can help firm up the limitations and thresholds for the specific aircraft supported. In addition, the airfield operations staff will be able to provide takeoff and landing criteria for the airfield.

Finally, weather personnel must have a firm understanding of the aircrew they support. There are differing takeoff and landing criteria based on an aircrew's experience level. It is important to know those criteria so the thresholds can be incorporated into the forecasts. The flying squadron director of operations can be interviewed to gain knowledge about aircrew in upgrade training, average number of days per week individuals fly, crew rest requirements, and overall demands placed on flying customers. Integration with the supported unit is important.

b.   Develop a Timeline of How Business is Conducted

Once the customer is known, a basic timeline of the customer's planning, execution, and debriefing process needs to be defined. This timeline should start at the point where decisions are first made at the particular installation. The wing scheduling office is a good place to start because this office typically coordinates the basic flying schedule for the entire wing. Once the general flow of aviation operations is understood, then a general weather support timeline can be developed. Figure 1 shows a schematic operational timeline with

decision points at which weather products can be injected into the decision making process. Long range planning, such as the scheduling of exercises and deployments by wing offices, will use climatological weather products, whereas an aircrew planning a flight they will execute within three hours will use a MEF.

Specific customer requirements are very important to know to determine times when weather support is needed, and what type of support is required (e.g. cloud ceilings, surface visibility, satellite image, thermal crossover data), and what format should be used (e.g. electronic copy, face-to-face briefing). This information is critical in order to provide the support the customer needs to make decisions on tactics, weapon type, and scheduling.

3. Design of Data Collection Process

A firm understanding of the customer's processes is also critical to the collection of the data needed to assess forecast performance and the operational impacts of forecasts. For example, knowledge of the points within the customer's processes at which weather information is used by the customer is critical for determining what data needs to be collected on the weather information provided to the customer and the decisions made by the customer based on that information.

Figure 2 shows a schematic flow chart for planning, executing, and debriefing air operations (left column), and the corresponding data collection needed to analyze the performance and operational impacts of the weather support provided for the operations (right column). The chart starts at the wing level and works its way down to the mission execution and debrief of the mission. The mission debrief is crucial because this is where weather personnel can learn how the weather products they provided, and the weather phenomena actually encountered, impacted the mission. Information from debriefs is a major part of the foundation for improving weather support to aviators, and a focal point in our data collection process. Much of our study focused on developing methods for efficiently collecting information from aviators on how the forecasts and the actual weather encountered affected their missions.

In order to determine the types of data that needed to be collected, we developed flow charts depicting all the weather related steps in the mission, from the receipt of a planning weather forecast all the way to a mission debrief. These flow charts describe three main events in mission planning, execution, and post-mission assessment:

1) Once a planning weather forecast is received by an aviator, a determination is made by the aviator as to whether or not the mission plan should be changed.

2) The aviator then receives the mission execution forecast and once again determines whether or not the mission plan should be changed.

3) Unless the crew decides to cancel the mission, it is flown and the crew determines whether or not weather negatively impacted the mission and whether the mission was successful or unsuccessful.

In developing our flow charts, we found it helpful to work backward from an end result of either a successful mission or an unsuccessful mission. Figure 3 shows all the ways a successful mission can result from: (1) a planning weather forecast (PWF) indicating a negative mission impact; and (2) a PWF indicating no negative mission impact. Figure 4 shows all the ways an unsuccessful mission can result from both of these types of PWFs. The process is essentially the same as for successful missions. For each figure, there are 16 paths shown by arrows. These paths represent the different types of weather information that could be provided to an aircrew, the different types of decisions the aircrew could make in response to that information, the different impacts the actual weather could have on the mission, and the different types of mission outcome.

Our data collection process was designed to collect the data needed to determine, for each mission, which of these paths was followed. Our data analysis process was designed to determine how and to what extent weather forecasts, and the weather phenomena encountered during the mission, affected aviator decisions and mission success.

Once we determined what data needed to be collected, we developed a generic data collection form to be completed by aircrews. Figure 5 shows this form, which is broken into three main sections: operational impacts, forecast performance, and target acquisition weapons software (TAWS) data. TAWS data encompasses both operational and forecast performance information, although not all aircraft use TAWS.

Note that the data collected via this form is focused on weather phenomena that were expected to have, and/or did have negative impacts on the mission. This is because we chose to limit the scope of our project to the phenomena that are most difficult to forecast and that have the most potential for altering mission plans and hindering mission execution, which are the negatively impacting phenomena (Hinz 2004, Jarry 2005, Butler 2005).

Note also that this form collects data solely from aviators. Thus, the data collected via this form represents aviator reports of: (1) negative weather impacts the aviators inferred from the forecasts they received; (2) the changes the aviators made to their mission plans in response to the negative impacts they inferred from the forecasts; (3) the weather phenomena encountered by the aviators during their missions; and (4) the changes made by the aviators to their missions due to the negatively impacting weather phenomena they encountered; and (5) the degree of success of their missions.

We had two main motivations for collecting this data solely from the aviators. First, we wanted to develop and test a process for meeting the requirements imposed on CWTs to collect and evaluate customer feedback. Second, the aviators commonly make their own inferences from the forecasts about negative weather impacts, and do not rely on the negative impacts that may or may not be provided by the CWTs. Thus, In effect, the aviators are acting as forecasters. They are at least acting as forecasters of the negative impacts, and perhaps also of the weather itself, if they do not assume the forecasts are accurate (i.e., if they do not believe the forecasts). Thus, we felt it

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was important to assess the performance and operational impacts of the aviators' forecasts. These issues are discussed further in the data analysis section (section F) below.

Figure 6 shows a separate generic data collection form developed to gain feedback on a relatively new program called infrared target scene simulation (IRTSS). IRTSS software creates a three-dimensional picture of what the target area will look like under specific environmental conditions. IRTSS has not yet been fielded throughout the Air Force, but is being used by at least one of the bases participating in this study, as part of the military's evolution toward effects-based operations (AFWSPV 2004). The IRTSS data collection form is relatively basic because the IRTSS program is still in its early stages.

B. CWT DATA COLLECTION

The generic data collection form was sent to the participating CWTs with a request to tailor the form to reflect their specific customers' missions. When drafting answer options for each question, the CWTs were directed to offer enough options to cover what they anticipated to be 80 percent of their customers' likely responses. The different CWTs support very different missions, which proved to be challenging in developing a relatively uniform data collection and analysis process.

1. Beale AFB

a. Supported Missions

The Beale AFB web site (Beale 2006) provides the following description of the mission of the 9th Reconnaissance Wing: "[It] is responsible for providing national and theater command authorities with timely, reliable, high-quality, high-altitude reconnaissance products. To accomplish this mission, the wing is equipped with the nation's fleet of U-2 and RQ-4 reconnaissance aircraft and associated support equipment". There are also T-38 and reserve KC-135 aircraft stationed at Beale AFB, California.

The U-2 provides high-altitude, all-weather surveillance and reconnaissance, day or night, in direct support of U.S. and allied forces. It delivers critical imagery and signals intelligence to decision makers throughout all

phases of conflict, including peacetime indications and warnings, low-intensity conflict, and large-scale hostilities (Factsheets 2006).

The Beale CWT collected data for U-2 operations because of the U-2's unique missions and thresholds, and because U-2 units have a more formal debrief process which increased collection opportunities. The U-2 performs both "high" and "low" altitude flights. The low flights receive their MEF via a computer terminal in the squadron, but the high flights actually go to the weather station to receive their MEF. Because of the direct interaction with the aircrews, data was collected on the high flights. The generic data collection form (Figure 5) was only slightly tailored for the U-2 high flights.

b.   Data Collection Methods

The Beale CWT attempted to collect data in November and December 2005, but had little success in getting pilots to return the forms. The data collection forms were being handed to the aviators when they received their briefing at the weather station with the request that they be filled out and returned after the mission. After little success in getting pilots to fill out and return the forms, the CWT emailed the forms to the pilots during an intensive data collection period on 9-13 January 2006 and was more successful in getting completed forms from the pilots.

2.   Creech AFB

a.   Supported Missions

The mission at Creech AFB, Nevada has evolved significantly in the past year (Creech 2005). In March 2005, the Air Force unmanned aerial vehicle (UAF) center of excellence (COE) was stood up, and on 20 June 2005, the Indian Springs Air Force auxiliary air field was renamed Creech AFB in honor of General Wilbur L. "Bill" Creech. October 2005 saw the standup of the Joint UAV COE at Creech AFB (Creech 2005).

Creech AFB is home to the 11th and 15th Reconnaissance Squadrons (Creech 2006), whose primary mission is to provide theater commander in chiefs (CINCs) with deployable, long endurance, real-time aerial reconnaissance, surveillance, and target acquisition flying the RQ-1A Predator.

The Predator reports battlefield conditions to war fighters using medium-altitude, multi-sensor, platforms and also collects and distributes imagery products to CINCs and national level leadership (Creech 2006). Additionally, the 11th Reconnaissance Squadron conducts all Predator aircrew qualification training (Creech 2006). The generic data collection form (Figure 5) was not changed for Creech AFB because the CWT had difficulty coordinating the form with aviators.

b. Data Collection Methods

The weather flight commander at Creech AFB found little to no time to coordinate the generic data collection form and therefore was not able to develop a tailored data collection form and implement a data collection process. Thus, we did not collect data from Creech AFB.

3. Dyess AFB

a. Supported Missions

The Dyess AFB web site (Dyess 2006) explains the mission of the 7th Bomb Wing (BW) as follows. The 7th BW is the premier operational B-1B unit in the U.S. Air Force. It has the capability to project lethal airpower anywhere in the world and strike at a moment's notice. During Operation DESERT FOX, a Dyess B-1 matched with a B-1 from Ellsworth Air Force Base, S.D., bombed Iraqi Republican Guard barracks at Al-Kut, Iraq, with 500-pound MK-82s (Dyess 2006). This first-ever combat bomb drop displayed the destructive firepower of the B-1 and echoed the battle cry "MORS AB ALTO," Latin for Death From Above (Dyess 2006). The B-1 carries the largest payload of both guided and unguided weapons in the Air Force inventory and is the backbone of America's long-range bomber force. It can rapidly deliver massive quantities of precision and non-precision weapons against any adversary, anywhere in the world, at any time (Factsheets 2006).

There are six flying squadrons located at Dyess AFB, Texas; four B-1 squadrons and two C-130 squadrons, although the CWT only coordinated data collection with the B-1s because of their unique mission. The generic data collection form (Figure 5) was slightly altered to adapt to the B-1 mission. Initial data collection revealed the need to adjust wording in the data collection form to

make it more understandable to aviators. Data collection was started in November and continued through the intensive data collection period of 9-13 January 2006.

b. Data Collection Methods

The CWT at Dyess AFB coordinated data collection with the operations officers at the flying squadrons. The flying squadrons agreed to maintain blank data collection forms at the squadron operations desk, since this is one of the locations at which aviators fill out paperwork upon completion of their missions. CWT personnel entered data into electronic forms and forwarded them to NPS for data analyses.

4. Nellis AFB

a. Supported Missions

Several different types of operations occur simultaneously at Nellis AFB, Nevada. We focused data collection efforts on the USAF weapons school (USAFWS), air warrior, and red flag because their schedule is regimented and predictable. The mission of the USAFWS (Nellis 2006) is to teach graduate-level instructor courses, which provide the world's most advanced training in weapons and tactics employment to officers of the combat air forces. Aircraft flown at the USAFWS include A-10, AC-130, B-1, B-2, B-52, F-15C, F-15E, F-16C, F-117, HH-60, MC-130, and MH-53 (Nellis 2006).

Air warrior and red flag are exercises conducted at the 414th combat training squadron (Nellis 2006) using realistic training scenarios that are intended to develop the combat readiness and survivability of participants. Combat units from the U.S. and several allied countries engage in combat training scenarios conducted within the Nellis Range Complex (Nellis 2006).

The USAFWS schedule encompasses both academic and flying phases. The prime opportunity for data collection is during the flying, or mission execution (ME), phase. The ME phase lasts one week with several flights each day. The generic data collection form (Figure 5), was only slightly adjusted to

accommodate USAFWS missions. TAWS is heavily used at the USAFWS as well as IRTSS, so the IRTSS questionnaire in Figure 6 was also used at Nellis AFB.

b.   Data collection Methods

Data collection at the USAFWS was coordinated with a squadron commander at the school who forwarded all the aviators an electronic copy of the data collection form requesting/directing support. Completed forms were sent to NPS for analyses.

Data collection forms were also provided to weather personnel supporting both air warrior and red flag. These weather personnel were not stationed at Nellis AFB, but rather on temporary duty (TDY) for the purpose of providing weather support to the aviators participating in the two exercises. Aviators were provided paper copies of data collection forms prior to mission execution and completed forms were sent to NPS for analyses.

5.   Whiteman AFB

a.   Supported Missions

Whiteman AFB, Missouri is the home of the 509th Bomb Wing, which according to their web site (Whiteman 2006) operates and maintains the Air Force's premier weapon system, the B-2 bomber. The B-2 Spirit is a multi-role bomber capable of delivering both conventional and nuclear munitions. A "dramatic leap forward in technology" (Factsheets 2006), the bomber represents a major milestone in the U.S. bomber modernization program. The B-2 brings "massive firepower to bear, in a short time, anywhere on the globe through previously impenetrable defenses" (Factsheets 2006).

Two bombing squadrons are located at Whiteman AFB and data was collected from both. The generic data collection form (Figure 5) was significantly shortened for use at Whiteman AFB because the aviators place the majority of their emphasis on the MEF with little on the planning weather forecasts (PWFs).

b. Data Collection Methods

PWFs are provided to aircrews telephonically and via the web, although MEFs are briefed in person approximately three hours prior to takeoff. The Whiteman AFB CWT just recently integrated weather personnel into the flying squadrons, in part due to classification issues with the B-2. Classification issues also result in restrictions to CWT access at locations in which the aviators perform debriefs. Thus, paper copies of the data collection form were placed in the debrief area at the maintenance operations squadron and then faxed to the CWT upon completion.

6. PACAF Units

a. Supported Missions

The two PACAF bases from which we collected data were Kunsan Air Base (AB) and Osan AB, both located in South Korea. CWT personnel are well integrated into the flying squadrons, which is why these bases were asked to participate.

Kunsan AB is located on the western side of the South Korean peninsula bordered by the Yellow Sea, approximately 150 miles south of Seoul. Kunsan AB is home to the 8th Fighter Wing made up of two F-16 fighter squadrons (Kunsan 2006). The F-16 Fighting Falcon is a compact, multi-role, highly maneuverable fighter aircraft which has proven itself in air-to-air combat and air-to-surface attacks (Factsheets 2006). It provides a relatively low-cost, high-performance weapon system for the U.S. and allied nations (Factsheets 2006).

Osan AB is located just 48 miles south of the Korean DMZ and is home to the 51st Fighter Wing "Mustangs" (Osan 2006). It is the most forward deployed permanently-based wing in the Air Force and provides mission ready airmen to execute combat operations and receive follow-on forces. The wing has 24 PAA, F-16, and A-10 squadrons, along with a C-12 airlift flight, conducting a full spectrum of missions in defense of the Republic of Korea (Osan 2006). The A/OA-10 Thunderbolt II (Factsheets 2006) is the first Air Force aircraft specially designed for close air support of ground forces. The aircraft are a simple,

effective, and survivable twin-engine jet that can be used against all ground targets, including tanks and other armored vehicles (Factsheets 2006).

b. Data Collection Methods

The CWTs at Kunsan AB and Osan AB did not have the time to coordinate applicable questions and answer options on the data collection form, so the Nellis AFB data collection form, including the TAWS section, was used.

CWT personnel are fully integrated into the flying squadrons at Kunsan AB, available four to five hours prior to takeoff time and remaining until the last aviator steps out the door to fly. Paper copies of the data collection form were completed by flight leads on behalf of all the aircraft in their flight, consisting of either a 2-ship or 4-ship formation. Completed forms were mailed to NPS for analyses.

At Osan AB, one CWT person is embedded in each of the flying squadrons, providing mass briefings three hours prior to takeoff and updates (step briefings) one hour prior to takeoff. The Osan AB CWT was already collecting feedback from flight leads in the form of a paper copy, so our data collection form was used in place of the existing one. CWT personnel briefed flying squadron leadership on the purpose and importance of the form to help ensure data quality and quantity. Completed forms were mailed to NPS for analyses.

C.   NPS AVIATOR SURVEY

Initial feedback from the ACC and PACAF CWTs indicated the data collection form was too lengthy, which might negatively affect the number of forms that were completed, and the quality of the data on the forms that were completed. To improve the forms, we surveyed AF pilots and navigators attending NPS. We also conducted subsequent follow up surveys and interviews with the NPS aviators to validate and interpret the results from our analyses of the data collected from the ACC and PACAF aviators.

Although most NPS aviators have only been in a non-flying job for a short time, being in the academic environment has provided them the opportunity to

reflect on their experiences. Their NPS experiences have perhaps also given them a motivation for contributing to our research project, since they too were collecting and analyzing data for their thesis research projects. Figure 7 is the survey emailed to the 36 AF aviators at NPS, most of who have attained the rank of major, have at least nine years of active duty AF experience, and several hundred hours of flying experience.

D. SUMMARY OF DATA COLLECTED

1. Aircrafts and Missions

Data was collected from six AF bases on six different types of aircraft. Figure 8 gives a summary of the missions flown during the data collection timeframe, including average number of missions flown per day, average length of each mission, and the type of mission (e.g., air-to-air, air-to-ground, bombing). A significant number of the missions were from fighter aircraft, perhaps because fighter missions are shorter than bombing and reconnaissance missions and therefore more frequent.

2. Data

Data collection was initiated in November 2005 and ended in January 2006, with the objective of having data collection forms completed by aviators, not CWT personnel. Concentration was placed on collected data from all the bases on five consecutive days, 9-13 January 2006, and for no less than five consecutive hours each day (and preferably for the entire day). We did not attempt to collect the same percentage of data from each base due to differences in flight operations and CWT manning.

E. LIMITATIONS OF DATA COLLECTION PROCESS

1. Assumptions

We made several assumptions regarding or data collection process. First we assumed that the CWTs were provided sufficient guidance on how to get to know their customer prior to coordinating their data collection forms. Second, we assumed that the CWTs were successful at tailoring their data collection forms to develop mission appropriate questions and answer options. Third, we assumed those individuals filling out the data collection forms fully understood the

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questions (especially after we had altered the initial forms in response to aviator and CWT feedback). Fourth, we assumed the aviators providing the data would provided relatively accurate descriptions and assessments of the forecasts they received, the missions changes they made in response to the forecasts, the weather they encountered during their missions, and the missions changes they made in response to the weather they encountered,

2. Limitations

A major shortcoming was the limited amount of data collected due to the limited time we had to collect data. This was exacerbated by the extended periods of holiday leave and down time that occurred during our data collection period. We also relied on aviators to provide accurate assessments of weather forecasts, weather phenomena encountered, planning changes, and weather impacts during execution. The quality of the data they provided, especially the weather data, is difficult to determine, since we did not, and in general were not able to, verify the aviator data with independently collected data. In some cases security limitations, especially at Whiteman AFB, restricted our ability to collect data.

F. DATA ANALYSIS METHODOLOGY

1. Overview

Hinz (2004), Jarry (2005), and Butler (2005) used a method in which they collected weather and operator data, used that data to determine forecast and operator performance metrics, and then compared these two sets of metrics to determine operational impacts metrics. This method is schematically depicted in Figure 9 in the form of a flow chart showing the data collected on the top row, performance analyses in the middle row, and the assessment of operational impacts on the bottom row. For our project, all the data was provided by aviators. We then analyzed the aviator data to assess forecast performance, aviator performance, and the impacts of the forecast and the actual weather encountered on the operational performance of the aviators. The results of our analyses are metrics of forecast and operational performance, and the operational impacts of the forecasts and actual weather phenomena.

In prior studies, such as Hinz (2004), Jarry (2005), and Butler (2005), data was collected data from weather personnel, and analyzed by weather personnel. We chose to work with data obtained directly from customers because we wanted to get and assess the value of direct customer feedback.

2.   Goals

The focus of our project was not on collecting and analyzing large quantities of data, but rather developing a process for collection and analyses. We did not attempt to come up with thorough analyses of forecast and operational performance, or of the operational impacts of forecasts and weather phenomena encountered during mission execution.   Our goal was to design, develop, and test a new process for collecting and analyzing customer feedback. The deliverable product we set out to create was a prototype system capable of efficiently collecting and analyzing customer data for use in analyzing forecast and operational performance, and the operational impacts of forecasts and weather phenomena encountered during mission execution.

To develop such a prototype system, we created system components to perform the following functions.   From an operational perspective, a primary system function is to determine what operational decisions were being made based on PWFs and MEFs.   We also wanted to determine key timeframes in which aviators use weather forecasts, and whether or not aviators felt forecasts were available when they needed them.

From a meteorological perspective, a primary system function is to determine how accurate the weather forecasts were, the probability of detecting negatively impacting weather phenomena, and the subsequent false alarm rate for negatively impacting weather phenomena.   Previous studies determined these parameters from the perspective of weather personnel.   Our objective was to determine them from the perspective of aviators.   We also wanted to determine how believable the weather forecasts were to the aviators.   In addition, we wanted to identify the weather phenomena with negative operational impacts that were most commonly misforecasted, and those that most commonly resulted in unsuccessful missions.

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Overall, our main goal was to develop a prototype system for analyzing a combination of operational and weather performance data provided by aviators in order to assess the impacts of forecasts and weather phenomena on the planning and execution of air combat missions. One of our main motivations was to enable CWTs to satisfy several requirements in AFMAN 15-129, AFI 15-114, the AFAA report, and the AFWSPV. These requirements include the development of a user-friendly system for measuring the operational impacts of weather forecasts. Once our prototype is tested, it will be adaptable to any CWT in AFW. Our prototype will also be adaptable to Naval METOC units to assist in their assessment of the operational impacts of METOC products.

An additional goal was to support the developers and implementers of TAWS and IRTSS by collecting and analyzing TAWS and IRTSS data. New versions of TAWS continue to be fielded and because of feedback, the versions get better and more accurate. Nellis AFB is the primary active duty AFB using IRTSS and since Nellis agreed to participate in this project, IRTSS developers requested our support in obtaining operational feedback.

3. Metrics Calculated

The main results of our analyses were five quantitative metrics of forecast performance (items a-e, below), and 15 quantitative metrics of operational impacts (items, f–t, below). Several of these metrics, especially those of forecast performance, have been used in prior studies (e.g., Hinz 2004, Jarry 2005, Butler 2005). However, our calculation of these metrics was based on a different type of data than that used in prior studies. The main difference is that our data: (1) came entirely from the users of the forecasts, the aviators, not from weather personnel; and (2) focused exclusively on weather phenomena that was forecasted to and/or did have negative impacts on the missions. Despite these differences, comparisons of the two types of metrics are useful, and are discussed in chapter III.

For our study, we focused on negatively impacting phenomena in the forecasts and in the pilot report observations. Thus, our forecast performance metrics are comparable to, for example, red forecast accuracy metric of Hinz

(2004) and the no go forecast accuracy of Jarry (2005). In our case, forecast performance metrics are based on the aviators inferring from the forecasts the weather phenomena that they think will cause negative impacts, and then verifying that inference when they execute the mission. In a sense, this means that we treat the aviators as forecasters because we rely on them to infer the phenomena that will have negative impacts, and also as verifiers of the forecasts because they provide the observations of the actual weather. Before we calculated forecast performance metrics based on the aviator data, we checked that the time and location of the forecasts matched the time and location of the missions. Only the data from missions with matching times and locations were used in the calculation of those metrics.

a. Forecast Accuracy for Negatively Impacting Weather Phenomena

Forecast accuracy (FAC) is the percentage of forecasts that were accurate (Hinz 2004, Jarry 2005). For our study, FAC is the number of missions for which negatively impacting weather was inferred, and actually occurred, by the aviators, divided by the number of missions for which negatively impacting weather was inferred, all multiplied by 100 to come up with a percentage.

b. Probability of Detection for Negatively Impacting Weather Phenomena

Probability of detection (POD) is defined as a verification measure of categorical forecast performance equal to the total number of correct event forecasts divided by the total number of events observed (NOAA 2006). For our study, POD is the number of missions for which a specific negatively impacting phenomenon (e.g., cloud ceilings below thresholds) was inferred by the aviators from the forecasts and was also observed by the aviators, divided by the number of missions for which that negatively impacting phenomenon was inferred from the forecasts by the aviators, all times 100.

c. False Alarm Rate for Negatively Impacting Weather Phenomena

The NOAA verification glossary (NOAA 2006) defines the false alarm rate (FAR) as a verification measure of categorical forecast performance

equal to the number of false alarms divided by the total number of event forecasts. A false alarm is a forecast of particular weather phenomena that does not occur. In our case, if an aviator inferred from the forecast that cloud ceilings would have a negative mission impact, but did not actually experience this on the mission, then a false alarm for cloud ceilings occurred for that mission. We defined FAR as the number of missions for which a specific negatively impacting phenomenon was inferred from the forecasts by the aviators but did not actually occur, divided by the number of missions from which that negatively impacting phenomenon was inferred from the forecasts, all times 100.

d. Observed Phenomena with Negative Impacts That Were/Were Not Forecasted

This metric describes the percentage of missions for which a specific negatively impacting phenomenon occurred during mission execution and whether the aviators inferred that phenomenon from the PWF and/or the MEF. There are four possibilities for this metric: (1) phenomenon occurred during execution, and was inferred from the PWF but was not inferred from the MEF; (2) phenomenon occurred during execution, and was not inferred from the PWF but was inferred from the MEF; (3) phenomenon occurred during execution, and was inferred from the PWF and was inferred from the MEF; (4) phenomenon occurred during execution, and was not inferred from the PWF and was not inferred from the MEF. This metric is somewhat similar to our FAC metric, but with a focus on specific phenomena, and without accounting for the total number of forecasts that were correct and incorrect.

e. Percentage of Missions for Which Negative Mission Impacts Occurred and Were/Were Not Indicated by the MEF

This metric describes the percent of missions that incurred negative weather impacts that were not inferred from the PWF or the MEF. This is similar to other metrics mentioned above but provides a more general assessment than the prior metrics.

f. Negative Mission Impacts Inferred from Planning Weather Forecast and MEF

This metric describes the number and percentage of missions for which: (1) the aviators inferred from the PWF and the MEF that a specific negative impact would occur; (b) a specific negative impact occurred during execution. By specific negative impacts, we mean impacts such as scheduling changes, weapons changes, inability to takeoff, etc.

g. Mission Plan Changes Made Due to Planning Weather Forecast and MEF

This metric describes the number of missions for which aviators made mission plan changes base on negatively impacting weather phenomena being inferred from the planning weather forecast and/or MEF.

h. Mission Plan Changes Due to Negative Mission Impacts

This metric describes the number of times a mission plan is changed due to aviators inferring negative mission impacts in forecasts.

i. Weather Phenomena Resulting in Unsuccessful Mission

This metric describes the percentage of missions deemed unsuccessful by aviators due to negative impacts from weather phenomena.

j. Planning Weather Forecast Positive Mission Contribution

This metric describes the percent of missions for which a positive mission impact (PMC) is made by the planning weather forecast. If aviators infer a negative mission impact from the planning weather forecast, make mission plan changes, and then achieve their primary mission, the PMC criteria are met.

k. MEF Positive Mission Contribution

This metric describes the percent of missions for which a positive mission impact (PMC) is made by the planning weather forecast. If aviators infer a negative mission impact from the planning weather forecast, make mission plan changes, and then achieve their primary mission, the PMC criteria are met for our study.

l. Potential Positive Mission Contribution

This metric describes the percent of missions for which a positive mission contribution (PPMC) is made by the planning weather forecast or the MEF. Our study defines a PPMC as an accurate forecast is issued, aviators make no mission plan changes in response, and the primary mission is not accomplished.

m. Planning Weather Delay Effects on Mission Accomplishment

This metric describes the percent of unsuccessful missions where the aviator would have checked the planning weather forecast earlier had it been available.

n. Negative MEF, No Mission Changes

This metric describes the percent of missions that are successful even though negative weather impacts are forecasted in the MEF, but the aviator does not make any mission plan changes due to the MEF.

o. Mission Plan Changes Due to Planning Weather and MEF

This metric describes the number of times aviators make a mission plan change due to the planning weather forecast and then change the same mission plan after seeing the MEF.

p. Unsuccessful Mission Due to Inaccurate MEF

This metric describes the percent of missions deemed unsuccessful by aviators where the aviator feels the MEF is inaccurate.

q. Weather Phenomena Actually Occurring Resulting in Mission Success/Failure

This metric describes the percent of each weather phenomena actually occurring during the mission and then whether or not the aviators deemed the mission successful/unsuccessful.

r. Planning Weather Needs

This metric describes the percent of missions evaluated where the aviator would have checked the planning weather earlier had it been available.

s. *Timeframe of MEF Usage*

This metric describes the number of hours prior to mission takeoff that aviators check the MEF.

t. *Successful Missions*

This metric describes the percent of missions considered successful by the aviator even though they did not accomplish what they intended to accomplish on the mission.

Each different data collection form required a separate data analysis worksheet based on the initial coordination with aviators. For this reason, some the metrics listed above will not be calculated for every base. Figure 10 is a description of calculations performed to analyze ACC and PACAF data, plus instructions for displaying the results of the analyses. Figure 10 is based on data collected from Kunsan AB, Nellis AFB, and Osan AB. Data analyses for the other bases will be abbreviated versions of Figure 10 because data collection was not as robust.

4. **Online Data Collection and Analysis System**

a. *Software*

To be most effective, assessment of forecast performance and the operational impacts of forecasts must be timely. Hinz (2004) and Jarry (2005) both had large lag times between their final collections of data from operational units until their final metrics reports were completed. Butler (2005) found that for a metrics program to be effective, the turn around time, from collection of data to delivery of metrics results, must be near-real time. This can be done by leveraging information technology (IT), which is just what Butler (2005) did.

Butler (2005) used three computer languages, Hypertext Markup Language (HTML), PHP: Hypertext Preprocessor (PHP), and My Structured Query Language (MySQL), to allow users to enter data via the internet into a database located at NPS, have the data analyzed, and then receive results in near real-time. For in-depth explanation of this process, see Butler's (2005) Chapter II. The bottom line is that by leveraging IT, a lag time of six months can be decreased to a few minutes.

b.   *Flow of Data*

For our system, an adaptation of the Butler (2005) system, once data is entered into the database, it is analyzed by the IT software and results are provided to the user in both numerical and graphical form. Figure 11 shows the flow of data, from collection by aviators, to analyses at NPS, to near-real reporting of results. Aviators were able to input their data directly into the online data collection form, an example of which is given in Figure 12 for Osan AB. Data analysis worksheets were developed to manipulate the aviator feedback received via the data collection forms. Most of the analyses were automated and completed via the online system. Further explanations of the data flows and analyses can be found in Butler's (2005) Chapter II.

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III. RESULTS

A. OVERVIEW

One of the three goals of this study was to adapt an existing web-based system from Butler (2005) for data collection and analysis for Air Force use at the CWT level. The adapted system we created can be found at http://wx.met.nps.navy.mil/metrics. The second goal was to implement and test the system, and analyze the results. The third goal was to use results to provide advice to AFW, ACC, and PACAF on how to alter their procedures and identify improvement opportunities. This chapter focuses on the third goal by discussing the data we collected and the results of our data analyses. The most pertinent results are presented in this report. Additional results fount at http://wx.met.nps.navy.mil/metrics/airforce/accu.html. Since the primary focus of this research was on the process and not the collection and analysis of an abundance of data, only preliminary conclusions about forecast performance and the operational impacts of forecasts can be determined. However, our results do allow us to make a thorough assessment of our main goal, the development, testing, and operational application of an online prototype metrics system.

After data collection began, initial answers implied aviators misunderstood some of the questions in the form. For example, some completed data collection forms indicated aircrews were providing feedback on more than one mission per form, and it wasn't clear which answers pertained to each mission, rendering the data unusable. Therefore, revisions were made to the wording of some questions. Collection resumed and data quality and quantity increased. Overall, approximately nine percent of the data collection forms were suspect and consequently left out of analyses.

Data of sufficient quality to be used in our data analyses was collected for a total of 107 missions during the intensive data collection period of 9-13 January 2006. As noted in chapter II, this figure of 107 missions is probably an underestimate of the actual number of aircraft that flew, because in some cases

multiple flights that were part of the same mission were reported on one data collection form. Of the 107 missions, 40 percent were flown out of the two participating bases in PACAF. Figure 13 is a summary of data collected, categorized by air base (rows) and air frame (columns). The summary describes the percent of total missions performed by each base, the percentage of squadron missions completing data collection forms, and to which major command (ACC or PACAF) each base was assigned. The CWT at Creech AFB was never able to collect data with all of the organizational transitions and other challenges they faced.

Planning weather forecasts (PWFs) were defined, for this study, as forecasts issued prior to six hours in advance of takeoff time, while forecasts within six hours of takeoff were referred to as mission execution forecasts (MEFs). When aviators were asked the earliest time prior to mission takeoff they first looked at the PWF, if available, the overwhelming response was 12-24 hours prior. The MEF was reviewed between one and three hours prior to mission takeoff.

We found that terms used in the data collection form may indicate multiple definitions at differing AF bases. For example, the PACAF data indicated that the term "mission successful" had several meanings. We concluded that, in general, if aviators accomplished something useful, but not necessarily what they intended to accomplish, the mission was deemed successful by the aviators. Results indicated 82 percent of all missions analyzed were deemed successful by aviators, while only seven percent were considered unsuccessful, and for 11 percent of the missions success was not assessed by the aviators.

B.   PERFORMANCE AND IMPACTS RESULTS

1.   Forecast Accuracy Results

The FAC was calculated for all weather phenomena that actually occurred during the missions and led aviators to infer negative mission impacts. Figure 14 shows the FAC for forecasts of phenomena (listed on the horizontal axis) from which aviators inferred negative mission impacts. PWF FAC is shown in blue, MEF FAC in purple, and the average of PWF and MEF FAC in yellow. It is

important to note large values of FAC for a given phenomenon are generally associated with a very small sample. The FAC for turbulence, and contrails was zero because these weather phenomena were never inferred from the forecasts or observed. The FAC for in-flight icing and icing run times was zero because the aviators reported that the never accurately inferred these weather phenomena from the forecasts but did observe them. This may mean the forecasts were inaccurate, that the aviators did not accurately assess the forecast, or that they did not accurately infer the negative impacts of the forecasted phenomena. It is also possible that the forecast was accurate but that mission plan changes were made that led to the unexpected negative impacts. These could include small changes in mission timing and/or location, weapons, tactics, etc.).

The PWF FAC shows 100 percent accuracy in forecasting visibility aloft. This may be misleading because visibility aloft actually occurred, and had a negative impact on the mission as deemed by aviators, in only four missions. The mean PWF FAC for cloud ceiling, cloud layers, surface visibility, and visibility aloft is 69.2 percent with a standard deviation of 16.9 percent between negatively impacting weather phenomena. The highest MEF FAC was 80 percent for visibility aloft. The mean MEF FAC for cloud ceiling, cloud layers, surface visibility, and visibility aloft was 69.2 percent with a standard deviation of 8.9 percent between negatively impacting weather phenomena. In general, the PWF FAC and the MEF FAC were similar.

The mean FAC for both PFW and MEF was 69.2 percent, which is comparable to the mean No Go MEF forecast accuracy in previous studies (Hinz 2004, Jarry 2005). For example, Jarry (2005) found the mean No Go MEF FAC for AMC data during fiscal year 2004 was 65.6 percent. This suggests aviators are assessing the forecast accuracy roughly the same as weather personnel who use instrumentation for verification.

2. Probability of Detection for Negatively Impacting Weather Phenomena

The POD was calculated for all weather phenomena that actually occurred during the mission and led aviators to infer negative mission impacts. Figure 15 shows the POD for forecasts of phenomena (listed on the horizontal axis) from which aviators inferred negative mission impacts. The blue depicts PWF POD while the purple depicts MEF POD. It is important to note large values of POD for a given phenomenon are generally associated with a very small sample size. The POD for turbulence, and contrails was zero because these weather phenomena were never inferred from the forecasts or observed. The POD for in-flight icing and icing run times was zero because the aviators reported that they never accurately inferred these weather phenomena from the forecasts but did observe them. This may mean the forecasts were inaccurate, that the aviators did not accurately assess the forecast, or that they did not accurately infer the negative impacts of the forecasted phenomena. It is also possible that the forecast was accurate but that mission plan changes were made that led to the unexpected negative impacts. These could include small changes in mission timing and/or location, weapons, tactics, etc.).

Overall, the PWF and MEF both had the highest POD for surface visibility at 86.7 percent. The mean POD for PWFs was 65.5 percent with a standard deviation of 15.9 percent where the PWFPOD for surface visibility was 86.7 percent while the PWFPOD for cloud layers was 50 percent. The mean POD for MEFs was 65.5 percent with a standard deviation of 15.1 percent, which is comparable to the mean No Go MEFPOD in previous studies. The MEFPOD for surface visibility was 86.7 percent while the MEFPOD for cloud ceilings was 53.3 percent. Jarry (2005) found the mean No Go MEFPOD for the AMC fiscal year 2004 to be 67.2 percent.

3. False Alarm Rate for Negatively Impacting Weather Phenomena

The FAR was calculated for all weather phenomena that actually occurred during the mission and led aviators to infer negative mission impacts. Figure 16 shows the FAR for forecasts of phenomena (listed on the horizontal axis) from

which aviators inferred negative mission impacts. The PWFFAR is shown in blue and the MEFFAR in purple. The FAR for turbulence, and contrails was zero because these weather phenomena were never inferred from the forecasts or observed. The FAC for in-flight icing and icing run times was 100 because the aviators reported that the never accurately inferred these weather phenomena from the forecasts but did observe them. This may mean the forecasts were inaccurate, that the aviators did not accurately assess the forecast, or that they did not accurately infer the negative impacts of the forecasted phenomena. It is also possible that the forecast was accurate but that mission plan changes were made that led to the unexpected negative impacts. These could include small changes in mission timing and/or location, weapons, tactics, etc.).

The mean PWFFAR was 31.2 percent with a standard deviation of 36.7 percent. The mean MEFFAR was 52.1 percent with a standard deviation of 37.7 percent. These values are similar to previous studies as Jarry (2005) found the mean No Go MEFFAR for the AMC fiscal year 2004 MEF verification data was 34.4 percent with a standard deviation between 13 CWTs of 33.3 percent. As previously mentioned, metrics from the two studies cannot be directly compared since our data was aviator-assessed and previous studies were assessed by weather personnel using meteorological equipment. It is, although, interesting to note the comparisons.

4. Negative Impacts Inferred and Mission Plan Changes

In 36 percent of the total missions, PWFs were inferred by aviators to have negative mission impacts, but in only 21 percent of the missions did aviators change mission plans due to the PWFs. In 39 percent of the total missions, MEFs were inferred by aviators to have negative mission impacts, but in only 21 percent of the missions did aviators change mission plans after interpreting the MEF. Even though aviators only changed mission plans in response to forecasts in 21 percent of the missions, results indicate 36 percent of all missions experienced weather phenomena with negative mission impacts, as deemed by aviators. This raises the question why aviators did not change their mission plans more often. Perhaps changing mission plans was not an option or

perhaps the aviators to take their chances and hope for weather that was sufficiently benign to allow them to complete their mission or alternate mission. This might have been the case if the aviators did not have confidence in, and therefore ignored, the forecasts, or if they had a back-up plan based on the negative mission impacts they inferred. Despite the reported negative impacts, the aviators assessed 82 percent of all their missions as successful.

5. **Observed Phenomena with Negative Impacts That Were/Were Not Forecasted**

Figure 17 shows the percent of missions that experienced phenomena (on the horizontal axis) with negative impacts that were/were not forecasted in the PWF and/or the MEF. Results indicate that in six percent of all missions, the PWF was interpreted to contain negatively impacting weather phenomena when the MEF did not, and for six percent of all missions the MEF forecasted negatively impacting weather when the PWF did not. Overall, the PWF and MEF appear to be equally accurate, although the PWF did better at cloud ceilings while the MEF was better at cloud layers. When turbulence occurred and negatively impacted the mission, it was not contained in either the PWF or MEF. This may imply either the forecasts were inaccurate or the aviator did not interpret the forecast accurately. Of the three weather phenomena having the largest number of negative impacts to missions, the forecasts were most accurate for surface visibility, although surface visibility also had the highest FAR (see Figure 16). Additionally, of the top three weather phenomena having negative impacts to missions, the forecasts did the poorest job at forecasting cloud layers, which indicates this is an area deserving of further attention (e.g., further research, education and training, etc.).

6. **Percentage of Missions for Which Negative Mission Impacts Occurred and Were/Were Not Indicated by the MEF**

Figure 18 shows the percent of all missions that experienced negative impacts (on the horizontal axis) that were/were not indicated by the MEF. Low level training and instrumentation training had the lowest chance of being indicated or forecasted by the MEF which may mean that the aviators did not interpret these negative mission impacts correctly or the MEFs did not accurately

depict the weather phenomena. It may also mean the weather was too good to accomplish instrumentation training because overcast conditions were necessary and the schedule changed after the aviator looked at the MEF and the weather ended up improving. Therefore, the aviators could no longer accomplish instrumentation training, not because of forecast or interpretation inaccuracies, but because the schedule changed out of their control. Additional information on why the mission was not completed would have helped as there is not enough data to make a determination.

In 80 percent of the missions where the aviators could not see the target, they had been pre-warned by the MEF. Of the missions that could not takeoff as scheduled, the MEF was 65 percent accurate at identifying this negative impact. When aviators were not able to perform air-to-air training, forecasts indicated this impact every time.

7.   Negative Mission Impacts Inferred From Planning Weather Forecast and MEF

Figure 19 shows the percent of missions for which mission plan changes (on the horizontal axis) were made by aviators in response to negatively impacting weather phenomena indicated by only the PWF (light blue), only the MEF (dark blue), or both the PWF and the MEF (green). Although these results may include multiple plan changes in response to either the MEF or PWF, the most significant finding here is that 26 percent of mission plan changes were made by aviators in response solely to the PWF while only 20 percent were changed solely in response to the MEF. Aviators made aircrew changes in 12 percent of the missions, weapon changes in 17 percent of the missions, schedule changes in 17 percent of the missions, and mission plan changes in 11 percent of the missions. Another item to note is that mission plan changes (i.e. low-level versus high-level, strike target on the ground versus air-to-air training, etc.) were only made in response to the PWF. This clearly indicates that CWTs need to place more emphasis on PWFs.

8. Negative Impacts Inferred From PWF

Figure 20 shows the number of missions for which indicated negative impacts (colored symbols) were inferred by aviators from PWFs of indicated weather phenomena (horizontal axis). Note that the forecasted phenomena associated with the largest number of inferred negative mission impacts were cloud ceilings (associated with inability to see target), cloud layers (associated with inability to see target), and surface visibility (associated with inability to takeoff or land).

Aviators inferred from 12 PWFs that they would not be able to takeoff or land due to surface visibility negatively impacting their mission. From an AFW perspective, it is valuable to see from Figure 14 that the PWF FAC for surface visibility was nearly 70 percent. Aviators assessed 22 PWFs as having negative impacts due to surface visibility and 12 PWFs as having negative impacts due to cloud layers and cloud ceilings, although this could be misleading if aviators inferred multiple negative impacts due to the same weather phenomena.

9. Mission Plan Changes Made Due to PWF

Figure 21 depicts the number of missions for which indicated mission plan changes (colored symbols) were made based on PWFs of indicated weather phenomena (horizontal axis). Note that the mission schedule was changed for four missions in response to the PWF of surface visibility. If aviators made mission plan changes every time they inferred a negative mission impact would occur, Figure 21 would show at least the same number of mission plan changes for each weather phenomena as Figure 20 shows for negative impacts. This may be a bit confusing as multiple negative mission impacts can be inferred from one weather phenomena, and multiple mission plan changes can be made from that same phenomena. Surface visibility, for instance, was deemed to have negative mission impacts on, at the very least, 12 missions, but aviators did not make any mission plan changes for 10 of those missions. Note that in planning two of the missions, aviators made mission plan changes even though no weather phenomena were inferred to have negative mission impacts. This

suggests aviators did not believe the forecasts, or chose to give higher priority to factors other than the forecasts in planning their missions.

10. Negative Impacts Inferred From MEF

Figure 22 shows the number of missions for which indicated negative impacts (colored symbols) were inferred by aviators from MEFs of indicated weather phenomena (horizontal axis). Note that the inability to takeoff or land was inferred for 14 missions based on forecasts of surface visibility in the MEFs for those missions. Surface visibility once again was assessed to have the most negative mission impacts on takeoffs and landings, and negative impacts from this phenomenon were inferred in 14 MEFs. Negative mission impacts were inferred for a total of 23 missions due to surface visibility in the MEF, and cloud layers and clouds ceilings had the next highest inference of negative mission impacts at 14 each. The MEFFAC for surface visibility is just over 60 percent. The following section will discuss whether or not aviators made mission plan changes in response to the forecasts. It is important to note that aviators do not always have the ability to make mission plan changes in response to the forecasts.

11. Mission Plan Changes Made Due to MEF

Figure 23 depicts the number of missions for which indicated mission plan changes (colored symbols) were made based on MEFs of indicated weather phenomena (horizontal axis). As an example from this figure: weapon changes were made for four missions based on the cloud layer forecasts in the MEFs for those missions. If aviators made mission plan changes every time they inferred a negative mission impact would occur, Figure 23 would show at least the same number of mission plan changes for each weather phenomena as Figure 22 shows for each negative impact. We focus on surface visibility once again, as it was deemed to have negative mission impacts on, at the very least, 14 missions (Figure 22), but aviators did not make any mission plan changes for 10 of those missions (Figure 23), suggesting they did not believe the forecast for at least four missions. Results also indicate cloud ceilings and cloud layers were inferred to have negative mission impacts on at least 11 missions each (Figure 22) and no

mission plan changes were made during five of those 11 missions (Figure 23). This suggests cloud ceiling and cloud layer forecasts were believed less than surface visibility forecasts.

12.   Weather Phenomena Resulting in Unsuccessful Mission

After seeing how aviators interpret forecasts and then make mission plan changes, it is important to highlight which weather phenomena caused the small percentage of unsuccessful missions. Figure 24 shows the percent of missions deemed unsuccessful due to negative impacts from weather phenomena (horizontal axis).   Seven percent of all missions analyzed were deemed unsuccessful by aviators. Five percent of all mission failures were due to surface visibility, and two percent were due to visibility aloft. Results from Figures 20 and 21 suggest aviators did not believe surface visibility forecasts during four missions. If aviators had made mission plan changes each time the forecast indicated negative mission impacts, the outcome might have been different. Results also show the MEF FAR for surface visibility was nearly 40 percent, which may support the reason aviators did not make mission plan changes.

13.   Positive Mission Contribution to Successful Missions

Figure 25 depicts the percent of missions for which a positive mission contribution (PMC) was made by the PWF (seen in blue) or MEF (seen in purple). PMC criteria are summarized in the blue text box within the figure and are described in detail in Chapter II. Percentages are based on the number of missions deemed successful by aviators.   For all bases, 10.2 percent of successful missions received a PMC from their PWFs, and 10.2 percent of successful missions received a PMC from their MEFs. The PMC for Beale AFB, Nellis AFB, and Whiteman AFB was zero because there was little negatively impacting weather phenomena identified in the forecasts by aviators, thus the opportunity to have a PMC was extremely low. The greatest PMC to mission success was Osan AB, where the PWF and MEF each had roughly a six percent PMC to all successful missions. As mentioned above, Osan AB also flew 40 percent of all missions analyzed.

14. Potential Positive Mission Contribution to All Missions

Figure 26 shows the percent of all missions for which a potential positive mission contribution (PPMC) was made by the PWF (seen in blue) or the MEF (seen in purple). PPMC criteria are summarized in the blue text box within the figure and are described in detail in Chapter II. For all bases, 4.7 percent of all missions received a PPMC from their PWFs, and 3.7 percent of missions received a PPMC from their MEFs. The PPMC for Beale AFB, Nellis AFB, and Whiteman AFB was zero because there was little negatively impacting weather phenomena identified in the forecasts by aviators, thus the opportunity to have a PPMC was extremely low. The Kunsan AB PPMC was zero because aviators typically made changes when they perceived negative mission impacts would occur due to weather. Again, results indicate Osan AB had the highest PPMC at 3.7 percent. This suggests aviators had the potential to achieve their primary mission in 3.7 percent of all missions had they made mission plan changes when they perceived negative mission impacts would occur due to MEFs.

Overall, PWFs had a higher PPMC of 4.7 percent, when compared to the MEFs at 3.7 percent, while the PMC was the same for PWFs and MEFs (see figure 25). This indicates the importance of PWFs to mission planning and execution.

C. NPS AVIATOR SURVEY RESULTS

Of the 36 NPS pilots and navigators surveyed, 15 provided lengthy feedback to our survey (Figure 7). These survey results confirmed the identification from our ACC and PACAF data collection of surface visibility, cloud ceilings, and cloud layers as the three weather phenomena resulting in the most negative mission impacts, and therefore the three of most interest to them in forecasts. The survey results also suggest most aviators only look at forecasts within 24 hours of takeoff and usually only within six hours, unless the mission is "other than normal" training such as a "check ride" where the aviators are upgrading their flying qualifications. Most aviators have a secondary mission plan when stepping to their aircraft to fly and also have the flexibility to execute

the secondary plan while in flight. Thus, they will deem many missions "successful" even though the primary objective was not accomplished.

After data analyses were completed, four NPS aviators participated in a round-table discussion concerning the results. All aviators that had worked with weather personnel embedded in the flying squadron felt the support was far superior to their experiences with non-embedded weather personnel. Aviators felt embedded weather personnel had a better feel for the environment within which they operate and also had a better handle on mission-impacting weather. Aviators also felt the weather support provided by embedded CWT personnel was better tailored to their needs.

When asked about our findings which indicate PWFs might be under utilized, NPS aviators did not have consistent feedback as to whether or not they remembered using or even seeing a CWT-issued PWF. Feedback indicated aviators used various sources for planning weather purposes, such as television and internet sources.

Those aviators who had spent at least two years as instructors in Air Education and Training Command (AETC) felt they spent considerably more time planning a mission in AETC than they did when flying in ACC or PACAF units. Aviators indicated AETC missions are driven by a strict syllabus and when planning a mission, if there was a high probability of not achieving the directives in the syllabus, they would cancel instead of flying anyway and trying to accomplish something else. This confirms our assessment that the definition of a "successful" mission varies widely among flying units. It also suggests that a future study of the performance and operational impacts of forecasts issued by AETC CWTs would be useful.

D.   SUMMARY

The general consensus from the ACC and PACAF CWTs was that the data collection form was too long and therefore aircrews were reluctant to complete it. The form was also not structured in a flow consistent with aircrew thought processes after they had just completed a mission. Several data

collection forms were found where aircrews started to answer mission planning questions, the first questions on the form, with mission execution answers and then when they reached the mission execution questions, realized what they had done, and used arrows and side notes to explain. A proposed re-structured data collection form is discussed in Chapter IV.

Since the focus of this thesis was to develop a prototype, proof of concept system, in some cases there was not enough data to adequately assess results. However, we did attempt to calculate all of the performance and impacts metrics described in chapter II with the data we collected. However, for six of the impacts metrics, we felt the data quality and/or quantity was not sufficient to justify calculating them.

Of the 107 missions analyzed, 40 percent were from PACAF flying units and 60 percent from ACC units. In 82 percent of the missions, aviators deemed the mission successful, which we interpreted to mean that if the aircrew was not able to accomplish the primary mission, then an alternate plan was successfully executed. In the seven percent of unsuccessful missions due to weather phenomena, surface visibility was the primary cause. The primary weather phenomena that caused negative impacts to missions were surface visibility, cloud layers, and cloud ceilings. Of these three, the forecasts did the poorest job at predicting, and/or aviators did the poorest job at interpreting, cloud layers.

Forecast performance metrics indicated the mean FACs for the PWFs and the MEFs were 69.2 percent as assessed by aviators, which is slightly higher than the mean No Go MEF FAC in previous studies where weather personnel assessed the accuracy (e.g., Jarry 2005). Results indicated a mean POD of 65.5 percent for both the PWF and MEF, which is slightly lower than previous studies; for example, a mean No Go MEF POD of 67.2 percent from Jarry (2005). The mean PWF FAR was 31.2 percent and the mean MEF FAR was 52.1 percent. Jarry (2005) found a mean No Go MEF FAR at 34.4 percent for AMC in fiscal year 2004.

Operational impacts metrics indicated both the PWF and the MEF had a PMC of 10.2 percent. This may not be so important in a training environment, but in a war-time environment where the aviators must accomplish their primary mission, this would most likely be important. Additionally, PWFs had a PPMC to all missions analyzed of 4.7 percent while the MEF PPMC was 3.7 percent. This suggests more emphasis should be placed on PWFs, especially when several of the NPS aviators indicated they often times looked for planning weather from sources other than their CWTs because they were not aware their CWTs issued PWFs.

Many of the values we obtained in our calculation of forecast performance and operational impacts metrics were similar to those obtained in prior studies using much larger data sets (e.g., Hinz 2004, Jarry 2005). This suggests that, although we collected a limited amount of data, and collected it from aviators, not CWT personnel, the data quantity and quality were still sufficient to allow us calculate useful metrics.

The online data collection, analysis and reporting part of our system was not sufficiently tested by the aviators to assess its effectiveness from the aviator's perspective. However, we suspect that web-based collection by aviators may be more of a challenge than completing paper copies because of the need to have a computer available to every aviator at the time of their debriefs. Collecting data in locations where weather personnel are not fully integrated into the flying squadrons was a challenge due to the interface needed, and NPS aviators verified the strain on CWT-aviator coordination when weather personnel are not embedded in the flying squadrons. However, CWT manning plays a huge role in whether or not full integration is accomplished and we saw a reflection of low CWT manning in the lower amounts of data collected.

There were sharp contrasts in the amount of data collected from ACC and PACAF units, primarily due to differences in the occurrence of negatively impacting weather, which was not as common for the ACC units during our data collection period.

IV. SUMMARY, DISCUSSIONS, AND RECOMMENDATIONS

A. SUMMARY OF PROCEDURES AND RESULTS

Many new and existing challenges face AFW personnel in today's resource-limited and changing environment. Accurate weather forecasts are imperative in aviation planning and execution of combat operations. To ensure forecast accuracy and operational relevancy, quantitative analyses of forecast performance and operational impacts are essential, but should be done in the most efficient and effective manner possible. For this reason, an existing web-based, near-real time system for collecting and analyzing weather and aviation data was adapted for use by AFW, ACC, and PACAF. Consistent with Figure 9, the data came from planning and execution forecasts as well as observed weather phenomena (left side of Figure 9), and from aviation planning and execution feedback (right side of Figure 9),. Although the data was limited, we were able to calculate metrics which appear to provide useful information about overall forecast performance and operational impacts. Due to lack of negatively impacting weather phenomena at the ACC bases, much of the data on negatively impacting weather came from PACAF bases. However, our process and results can be applied to all AFW CWTs.

1. Goals Accomplished

The first goal we set out to accomplish was to adapt a system already in use by the U.S. Navy for collecting and analyzing data in near-real time. This was much more challenging than anticipated because our data collection and analyses were done by aviators and not weather personnel, which resulted in the rewrite of much of the computer code.

Our second goal was to implement and test the system with seven ACC and PACAF CWTs. Six of the seven CWTs were able to participate in data collection. But, due to IT challenges and time constraints, the online portion of the system was not operational until much of the data had already been collected. However, we did receive feedback from two CWTs indicating it would not have been a good idea to have aviators input the data directly into an online

system instead of filling out a paper copy of the data collection form. CWT personnel directly entering data into the online form is a better option. Of the six CWTs that provided data, three felt they gained valuable feedback on ways they could improve aviator support through the process of coordinating the data collection form with the aviators.

Our third goal was to use the results from system implementation to provide AFW, ACC, and PACAF operations advice on how to alter procedures and allocation of resources to better accomplish goals. We ended up calculating five quantitative metrics of forecast performance and 15 quantitative metrics of operational impacts.

2. Results

A total of 107 missions were analyzed; 82 percent deemed successful, seven percent deem unsuccessful, and 11 percent not assessed by aviators. Aviators inferred negative mission impacts from 36 percent of the PWFs, but only made mission plan changes to 21 percent of the missions in response to the PWFs. Aviators inferred negative mission impacts from 39 percent of the MEFs, but again, only made mission plan changes to 21 percent of the missions in response to these MEFs. However, aviators encountered negatively impacting weather phenomena in 36 percent of their missions.

Forecast performance metrics indicated a mean FAC of 69.2 percent for both PWFs and MEFs. The mean POD for both PWFs and MEFs was 65.5 percent. Results, for PWFs and MEFs, deviated when the FAR was calculated. The mean FAR for PWFs was 31.2 percent while the mean MEF FAR was 52.1 percent. This gives PWFs a slight edge over MEFs, which is important to note since CWTs spend significantly more time formulating MEFs than PWFs.

Operational impacts were measured by relating MEF performance metrics to operational performance metrics. We determined that surface visibility, cloud ceilings, and cloud layers were the weather phenomena that most adversely affected missions. Surface visibility was cited as the cause in 71 percent of the missions deemed unsuccessful due to weather, which represents five percent of

all missions. Aircrews made four types of mission plan changes, but only changed the mission type (e.g. low-level, refueling, and air-to-air) due to PWFs, never MEFs. This indicates PWFs may need to be given more time and attention by CWTs and aircrews.

PWFs and MEFs both provided a PMC to 10.2 percent of all successful missions. As explained in Chapter II, a forecast has a PMC when the aviator deems negative mission impacts will result from weather phenomena, makes mission plan changes based on the forecast, and subsequently achieves their primary mission. Also explained in Chapter II is a PPMC. A PPMC occurs when an accurate forecast implies negative mission impacts, aviators make no mission plan changes, and then the primary mission is not accomplished. The PWFs had a PPMC in 4.7 percent of all missions, while the MEFs had a PPMC of 3.7 percent. Once again, this suggests more emphasis needs to be placed on PWFs.

The NPS aviator survey validated findings of the top three weather phenomena needing further research and training. The high percentage of successful missions was justified by NPS aviators who explained that missions they had flown while in ACC and PACAF were deemed successful if they accomplished something useful, even if they did not accomplish their primary mission. They reported that it was common for aircrews to have a secondary mission plan and the flexibility to execute, if needed. However, aviators who had flown in both AETC and either ACC or PACAF described a notable difference when flying in AETC, versus ACC or PACAF. At ETC, mission plans are closely tied to a syllabus, with no secondary plan, so success is determined by following the syllabus. NPS aviators also provided valuable feedback regarding the CWT products. Most of the NPS aviators were not confident they knew how, when, and where to access all of the CWT products, especially PWFs. Some were unaware that the CWTs at the flying bases they had been assigned issued formal PWFs, others received planning weather by phoning the CWT, and yet others looked up planning weather via other sources on the web.

3.   Meeting AFW Challenges and Vision

Implementing an online system such as the one developed and tested in this research project, will help improve mission efficiency and effectiveness of CWTs. The results of this project will help enable CWTs to compensate for not having sufficient personnel to fully integrate themselves into all the flying squadrons they support.

Step 11 of the MEFP as outlined in chapter four of AFMAN 15-129 directs the MEF be a product for which CWTs receive continuous feedback from aviators. The system in this research project provides continuous aviator feedback. The first task in step 12 of the MEFP as outlined in chapter four of AFMAN 15-129 calls for the implementation of systematic procedures to analyze and measure accuracy/relevancy of products provided to customers. Step two directs operator debriefs, preferably face-to-face, but when this is not possible it directs CWTs to employ other feedback methods. Step five directs CWTs to conduct operations verification on established "Go/No Go" thresholds and step six requires the development and application of metrics for process improvement (AFMAN 15-129 2004). Our system meets or could readily be adapted to meet, all of these directives.

Guidance in AFI 15-114 deems operational verification of the MEF as the "single most important mission-oriented, operational effectiveness assessment requirement for CWTs." It also calls for a system that "automates *all* metrics, from data collection, aggregation, to data quality control. The end-state will be an automated web-based system with the capability to provide ad hoc analyses and reports (assessments) for all levels of AFW support" (AFI 15-114). Our system meets the AFI guidance above.

The AFAA report released September 2005 found that Air Force personnel did not consistently and completely obtain customer feedback and identify improvement opportunities, and recommended that AFW establish standardized procedures for obtaining mission operator feedback on weather forecasts (AFAA 2005). Our system is a solution to this finding.

The AFWSPV set the course for transformation starting with fiscal year 2008. The process we are proposing in this thesis takes steps, however small, toward three of the eight vectors. It creates automated decision tools which can further be exploited (vector 6), it helps determine where weather information is integrated into decision cycles at the base level and below (vector 7), and although not directly, it enables similar feedback results that could be accomplished by embedding weather personnel into flying squadrons (vector 8) (AFWSPV 2004).

B.   RECOMMENDATIONS

The task list for CWTs is lengthy and manpower challenges make achieving many of the tasks unrealistic. Implementation of the prototype system we have adapted for usage at Air Force bases will enable AFW to alleviate some of the challenges facing CWTs. Specifically, providing this prototype as an appendix to AFI 15-114 will provide CWTs an example of an automated system that is already working. It also eliminates CWTs from having to train personnel on metrics calculations.

Although missions vary drastically from fighter aircraft to bombers, to reconnaissance and surveillance, etc., generic data collection forms can be drafted for each platform. Our results indicate our data collection form was too long and the order in which questions were asked needed to be changed. Questions pertaining to the actual mission need to be asked first because aviators complete the forms immediately after they have flown their mission. Figure 27 is a revised generic data collection form for fighter aircraft. We recommend similar forms be created for differing platforms. Once these data collection forms are produced, they can be used in our prototype system for data collection.

When we started coordination with the original seven CWTs, it became apparent there is a need in the AFW community to formalize training on getting to know your customer. We recommend that a formal training process and

documents be developed and implemented, and that CWT personnel be given enough overlap with those they replace to allow for ample orientation to the flying squadrons they will be supporting.

The NPS aviators could not praise embedded weather support in the flying squadrons enough. Aviators indicated the value added when weather personnel were available in-person at the flying squadron was immeasurable. Further, they felt that once a weather person experienced the environment in which aviators operate, they were able to understand weather requirements better and established credibility with the aviators. We recommend AFW leadership reinforce flying squadron integration and CWT manning. Feedback from CWTs during our coordination and data collection processes indicated that air-to-ground platforms are the most "weather needy" and emphasis should be placed on manning CWTs accordingly. Further, we recommend an operational effectiveness study be conducted to compare the quantitative impact of having embedded weather personnel in the flying squadrons to not having embedded weather personnel.

Several of our results suggest that aviators are not familiar with many of the terms AFW personnel use. The feedback we received also suggests AFW personnel need to educate aviators better on the types of products available and when and where aviators can find these products.

Results indicate AFW forecasts have the ability to provide positive mission impacts when aviators follow forecasts and make mission plan changes accordingly. It appears PWFs can make a difference in whether or not aviators achieve their primary mission. So we recommend that aviators better incorporate weather products earlier in their planning process, at least 12-24 hours prior to takeoff .

C.   FUTURE WORK

Work already in progress at the NPS is adapting this web-based, near-real time system for collecting and analyzing METOC and aviator data from U.S.

Navy aircraft carriers. The same system being adapted across U.S. military service lines will improve joint service cooperation.

Feedback from CWTs and NPS aviators stressed the large number of different agencies wanting feedback from aviators after mission execution. Thus, it would be useful to incorporate weather data collection forms into other existing pilot debrief systems. Perhaps airfield flight and weather could combine their data collection efforts into one database. Semi-automated feedback needs to continue, but will not be successful unless it is tied into an automated system that is already established. Evidently, such a system is already setup at Whiteman AFB called Patriot Excalibur. Unfortunately, the system is not accessible from a non-".mil" website therefore limiting usage.

Adapting our prototype system to combat operations, such as Operation Iraqi Freedom, would provide valuable "war-time" information. This would need to be accomplished over a secure network which would involve a lot more time due to limited availability to communicate with the data collectors in theater, but would be extremely valuable.

The biggest challenge we faced was getting data. The fast-paced aviator environment proved to be a challenging one to tap into. Unless aviators can be provided qualitative and quantitative justification as to why it is advantageous for them to provide feedback, it will continue to be the most challenging part of operational verification for the AFW community.

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APPENDIX   FIGURES

Schematic Timelines Linking
Aviation Operations and Weather Support

Figure 1. Schematic timeline linking aviation operations to weather support. Timeline begins on left with long range planning that occurs three months prior to mission takeoff to the actual mission execution on the right. Linkage provides framework for determining data collection opportunities.

Operations Process

WING SCHEDULING

-Climatology provided by base weather

-3 months prior, wing scheduler checks climatology (solar/lunar data, etc.) to hand down to squadrons

SQUADRON SCHEDULING

-Long range forecast provided by base weather

-3 weeks prior, squadron scheduler checks long range weather forecast

MISSION PLANNING

-24 hours prior, planning mission execution forecast (MEF) provided by weather office

-24 hours prior, aircrew checks planning weather forecast

MISSION EXECUTION

-6 hours prior to take-off, base weather provides MEF to customer

-4 hours prior to take-off, aircrew checks MEF

SOF & SQDN TOP 3

-MEF and current observations seen on weather terminals in control tower and squadrons

-Supervisor of Flying (SOF) in control tower and squadron leadership continuously check weather prior to take-off, during flight, and for landing

-SOF and TOP 3 (senior operations officers) have direct phone links to forecaster in base weather station

EVENT FLOWN

- Lasts 1 1/2 to 2 1/2 hours

EVENT DEBRIEF

- 1 to 2 hours after flight ends

- Get weather impacts feedback from aircrew that flew mission

- Get tactical weather (TAWS) feedback from aircrew that flew mission

Data to be Collected

Collect data on:

• climate forecast and verifying observations

• scheduling changes due to climate forecasts

Not collected in this project

Collect data on:

• long range forecasts and verifying observations

• scheduling changes due to long range forecast

Collect data on:

• planning forecasts and verifying observations

• mission changes due to planning MEF

Collect data on:

• MEF, TAWS forecast, and verifying observations

• mission changes due to MEF

Collect data on:

• verifying observations

• mission changes due to changing observations

Collect data on:

• verifying observations

• mission changes during flight due to weather

Figure 2. Flow chart for planning, executing, and debriefing air operations (blue boxes), and corresponding data collection needed for analyses of the performance and operational impacts of weather forecasts (yellow boxes). The operations flow chart indicates the types of weather products aviators use at different stages in their planning and execution.

Figure 3. Flow chart depicting all avenues mission planning and execution can take from receipt of a weather forecast to completion of a successful mission. Flow chart traces back the forecast-related steps that led to a successful mission. Steps are those that involve the planning weather forecast (PWF, bottom row), mission changes made in response to PWF, second row up), mission execution forecast (MEF, third row up), mission changes made in response to MEF (fourth row up), and actual weather experienced during the mission (fifth row up).

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Figure 4. Flow chart depicting all avenues mission planning and execution can take from receipt of a weather forecast to completion of an unsuccessful mission. Flow chart traces back the forecast-related steps that led to an unsuccessful mission. Steps are those that involve the planning weather forecast (PWF, bottom row), mission changes made in response to PWF, second row up), mission execution forecast (MEF, third row up), mission changes made in response to MEF (fourth row up), and actual weather experienced during the mission (fifth row up).

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Generic Data Collection Form

Mission Identification

Mission #/Call Sign:

MO/DA/YR_____   **Take-off Time (Zulu)**_____

PLANNING

1. How many hours prior to your flight did you first check the Combat Weather Team (CWT) weather?
48, 36, 24, 12, 6, 0

2. How many hours prior to your flight would you have checked the CWT weather if it were available?
72, 60, 48, 24, 12, 0

3. What negative mission impacts were forecasted in the <u>planning weather</u>?
Won't see target
Won't be able to lock-on target
Won't be able to do air-to-air training
Won't be able to take-off or land
Won't be able to refuel
Won't be able to do instrumentation training
Won't be able to do touch and gos
Won't be able to do low-level training
None

4. What weather phenomena led to these forecasted negative impacts?
Cloud Ceiling
Cloud Layers
Thunderstorms
Rain
Visibility at Surface
Visibility Aloft
Turbulence
Icing
X-wind
None

5. What <u>changes </u>in mission plans were made <u>due to planning weather</u> forecasting negative impacts?
Aircrew
Weapon
Schedule (i.e. time of mission)

EXECUTION

6. How many hours prior to your flight did you check the Mission Execution Forecast (MEF)?
6, 5, 4, 3, 2, 1, 0

7. What negative mission impacts were forecasted in MEF?
Won't see target
Won't be able to lock-on target
Won't be able to do air-to-air training
Won't be able to take-off or land
Won't be able to refuel
Won't be able to do instrumentation training
Won't be able to do touch and gos
Won't be able to do low-level training
None

8. What weather phenomena led to these MEF negative impacts?
Cloud Ceiling
Cloud Layers
Thunderstorms
Rain
Visibility at Surface
Visibility Aloft
Turbulence
Icing
X-wind
None

9. What underline additional changes underline in mission plans were made underline due to MEF underline negative impacts?
Aircrew
Weapon
Schedule (i.e. time of mission)
Type (i.e. high alt, instrumentation, strike, low-level)
None

10. What negative impacts due to weather underline actually occurred underline during mission?
Couldn't take-off
Couldn't see target
Couldn't refuel
Couldn't perform low-level training
Couldn't perform air-to-air training
Couldn't perform instrumentation flight
None

11. What weather phenomena led to these negative impacts <u>during your mission</u>?
Cloud Ceiling
Cloud Layers
Thunderstorms
Rain
Visibility at Surface
Visibility Aloft
Turbulence
Icing
X-wind
None

12. How are you using Target Acquisition Weapons Software (TAWS)?
Not using (skip to question #21)
Mission planning
Execution
Both

13. Does TAWS have your weapon sensor modeled?
Yes
No

14. What are you using TAWS for?
IR
TV
Laser
NVG predictions

15. Did you change your weapons load or tactics based on TAWS predictions?
Yes
No

16. How were the TAWS predictions?
Pessimistic
Optimistic
Accurate

17. Did you download weather from AFWA or get a TAWS file from your CWT?
AFWA
CWT

18. Was the TAWS weather accurate?
Yes
No

19. Would you use TAWS again?
Yes, but it could be improved by __(insert your suggestions)_____
No

20. Rate the prediction software in the areas below using the following scale:
1-not useful, 2-somewhat useful but not required, 3-useful, 4-mission essential

Pre-mission:
a. Route selection	1	2	3	4
b. Target viewing azimuth	1	2	3	4
c. Target area tactics	1	2	3	4

Inflight:
a. Low level navigation	1	2	3	4
b. Target area tactics	1	2	3	4
c. Target identification	1	2	3	4
d. Threat avoidance	1	2	3	4
e. Sensor cross-check techniques	1	2	3	4

21. What did you intend to accomplish on your mission?
Low-level training
High-altitude training
Instrumentation training
Air-to-Air Combat training
Air-to-Air Refueling
Strike Target on Ground

22. What did you actually accomplish on your mission?
Low-level training
High-altitude training
Instrumentation training
Air-to-Air Combat training
Air-to-Air Refueling
Strike Target on Ground
Nothing

23. What was your overall impression of the actual mission?

a. ☐ **Mission successful** ☐ **Mission unsuccessful**

b. ☐ **Changed mission due to planning weather** ☐ **No change in mission due to planning weather**

c. ☐ **Changed mission due to MEF** ☐ **No mission change due to MEF**

d. ☐ **No negative weather impacts forecasted**

☐ **Negative weather impacts forecasted accurately**

☐ **Negative weather impacts forecasted inaccurately**

e. ☐ **No WX impact to mission** ☐ **Negative WX impact to mission**

Figure 5.   Generic data collection form used to gain feedback on planning, execution and TAWS data from aviators after mission execution.

IRTSS Questionnaire

Nellis AFB is the lead ACC unit for software that creates Sensor Prediction Products (SPP). Infrared Target Scene Simulation (IRTSS) is the latest and greatest SPP tool. Thanks for your time and for helping make the program better.

Which sensor[s] did you employ on your mission?

Was the IRTSS prediction helpful in your mission planning?

Was the IRTSS prediction a realistic representation of what you saw on your cockpit display?

Did IRTSS represent 'feeder features' (roads, rivers, etc) into the target area correctly?

Did IRTSS represent the target area correctly?

Did the IRTSS prediction influence you to adjust/alter tactical decisions before mission execution?

What is one enhancement that if made to IRTSS would make the product more useful to you?

Figure 6.   Infrared target scene simulation (IRTSS) data collection form used to gain feedback from aviators after mission execution.

Naval Postgraduate School Aviation Survey Form

1. **Please provide a brief history of your flying experience to include airframes flown and number of hours in that airframe.**

2. **In general, how many days prior to a mission did you first look at the weather? How did you receive this weather? (internet, base weather station, weather channel) What were you looking for? (general sky coverage, thunderstorms, precipitation, fog, solar/lunar data)**

3. **In general, how flexible were you at making changes to the mission plan? Please elaborate on how maintenance and perhaps airfield operations play into this. Discuss weapons, targets, scheduling ranges, refueling, scheduling low-level routes, different category pilots.**

4. **In your opinion, what are the most important parts of the MEF? (Mission Execution Forecast issues by the Combat Weather Team at your installation) Which weather phenomena (icing, turbulence, visibility at surface, etc.) in your opinion, caused the most mission planning changes on your part?**

5. **From your flying experiences, what does Air Force Weather (AFW) do well and what could AFW stand to put time and effort into?**

6. **In general, how much faith have you had in the weather forecasts you've received? Did you find the quality of the weather support you received changed based on weather flight leadership? Person to person?**

7. **When you first get to a new location, do you tend to pay more attention to the weather forecast versus having been at a location for a year where you've experienced all four seasons and in the back of your mind can picture what you'll see based on a satellite photo? Seems like common sense, but just want to confirm.**

8. **How well is weather integrated into operations? Long range climate forecasts? Planning weather? MEF?**

Figure 7.   Naval Postgraduate School aviator survey form. Information from this survey was used to validate and interpret results of ACC and PACAF data analyses.

Ave # Msns/day / Ave length of Msn / Mission Type	A-10 Thunderbolt II	B-1B Lancer	B-2 Spirit	F-16 Fighting Falcon	U-2	UAV (Unmanned Aerial Vehicle)
Beale AFB, CA					5 Ave Msns/day 5 Hrs/Msn S&R	
Creech AFB, NV						9 Ave Msns/day 8 Hrs/Msn S&R
Dyess AFB, TX		10 Ave Msns/day 6 Hrs/Msn B				
Kunsan AB, ROK				18 Ave Msns/day 1.8 Hrs/Msn AA, AG		
Nellis AFB, NV	8 Ave Msns/day 2 Hrs/Msn AA, AG, CAS			8 Ave Msns/day 2 Hrs/Msn AA, AG		
Osan AB, ROK	10 Ave Msns/day 3 Hrs/Msn AA, AG, CAS			15 Ave Msns/day 1.5 Hrs/Msn AA, AG		
Whiteman AFB, MO			9 Msns/day 4 Hrs/Msn B			

S&R=Surveillance and Reconnaissance
AA=Air-to-Air
AG=Air-to-Ground
B=Bombing
CAS=Close Air Support

Figure 8. Summary of missions flown during data collection timeframe, categorized by air base (rows) and air frame (columns). Information on missions describes: average number of missions flown per day, average length of mission (hours), and mission type (see key at bottom of table).
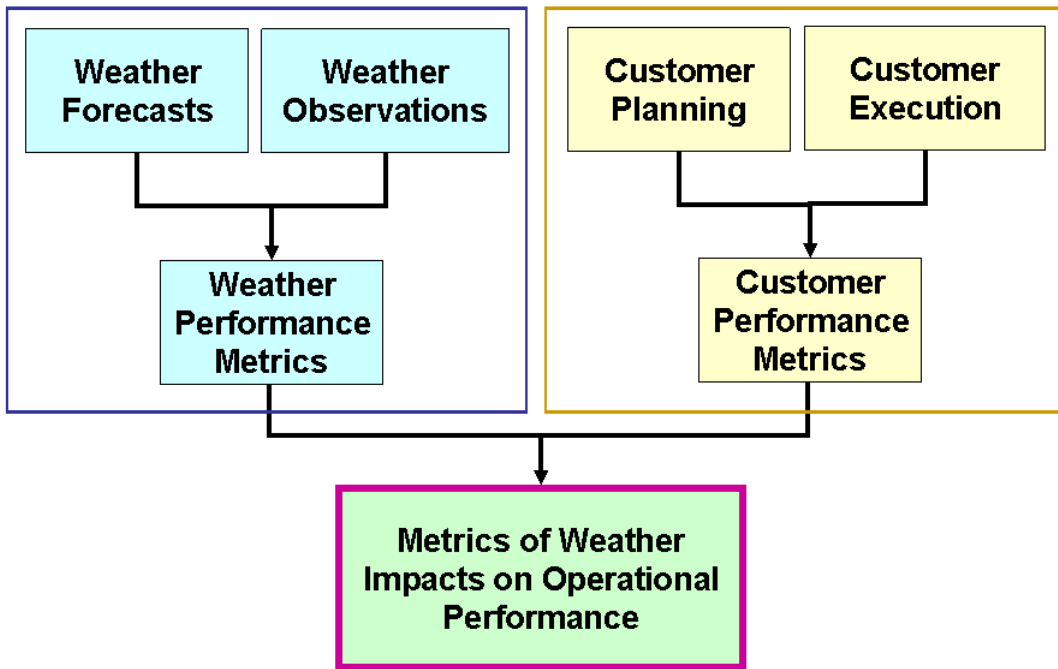
Figure 9.   Schematic data and methods flow chart showing the data collected (top row), performance analysis (middle row), and assessment of operational impacts (bottom row).

Data Analyses Calculations
(Based on Kunsan, Nellis, and Osan data collection form)

A. Number of total missions, successful missions and unsuccessful missions analyzed
    1. Count the number of total missions entered into the database, the number of missions deemed successful in #23a, and the number of missions deemed unsuccessful in #23a
    2. Display results in numeric form showing total missions, successful missions, and unsuccessful missions

B. Percentage of missions where aviator would have checked the planning weather earlier had it been available.
    1. If #2 is greater than #1, then divide the number of times this exists by the total number of missions analyzed and multiply by 100
    2. Display results in a bar graph with time (in hours) increments (72, 60, 48, 24, 12, 0) on the x-axis and frequency of occurrence on the y-axis

C. Percentage of missions deemed unsuccessful and the aviators would have checked the planning weather earlier had it been available.
    1. If #23a shows mission unsuccessful and #2 is greater than #1, then divide the number of times this exists by the total number of missions analyzed and multiply by 100
    2. Display results in a pie chart with the total number unsuccessful missions as the total pie and the missions where aviators would have checked the planning weather earlier had it been available as a piece of the pie

D. Percentage of missions considered successful even though aviators did not actually accomplish what they intended to.
    1. If #23a shows mission successful and #21 and #22 do not have the same answers, then divide the number of times this exists by the total number of missions analyzed and multiply by 100
    2. Display results as a pie chart with total number of successful missions as the total pie and the missions where aviators didn't accomplish what they intended to as a piece of the pie

E. Percentage of missions that were successful even though negative weather impacts were forecasted in MEF, but aviators did not make any mission changes due to the MEF.

    1. If #23a shows mission successful and #7 shows anything but "None" and either #9 shows "None" or #23c shows "No mission change due to MEF", then divide the number of times this exists by the total number of successful missions and multiply by 100

    2. Display results as a pie chart with the total number of successful missions being the total pie and the piece of the pie representing missions where negative weather impacts were forecasted in the MEF, but no mission plans were changed

F. Correlation between weather phenomena and negative mission impacts

    1. Match responses to #3 and #7 to the corresponding responses other than "None" for #4 and #8.

    2. Display results as a chart with the mission impacts on one axis, weather phenomena on the other axis, and frequency of occurrence in the corresponding square

G. Percentage of missions the aircrew checked the MEF 6, 5, 4, 3, 2, 1, 0 hours prior to takeoff

    1. Count each response to #6 and divide it by the total number of missions

    2. Display results as a bar graph with the hours on the x-axis and percent of missions on the y-axis

H. Percentage of missions successful where there were changes in mission plans due to planning weather and aviators actually accomplished what they intended to (Positive Mission Contribution due to PWF)

    1. If #23a shows "mission successful" and #5 shows anything other than "None" and #22 has at least the same options as #21 and #23b shows "Changed mission due to planning weather", divide the number of times this exists by the total number of missions analyzed and multiply by 100

    2. Display results as a pie chart with letter I, where the whole pie is the total number of successful missions analyzed and a piece of the pie is the PMC due to PWF

I. Percentage of missions successful where there were changes in mission plans due to MEF and aviators actually accomplished what they intended to (Positive Mission Contribution due to MEF)

    1. If #23a shows "mission successful" and #9 shows anything other than "None" and #22 has at least the same options as #21 and #23c shows "Changed mission due to MEF", divide the number of times this exists by the total number of missions analyzed and multiply by 100

    2. Display results as pie chart with letter H, where the whole pie is the total number of successful missions analyzed and a piece of the pie is the PMC due to MEF

J. Correlation between weather phenomena forecasted and resulting mission plan changes

    1. Most frequent responses other than "None" to #4 and #8 and the corresponding responses to #5 and #9

    2. Display results as a chart with the mission plan changes on one axis, weather phenomena on the other axis, and frequency of occurrence in the corresponding square

K. Weather phenomena in MEF resulting in the most unsuccessful missions

    1. Identify the correlation between a response of "Mission unsuccessful" in #23a and the corresponding answer to #8 other than "None"

    2. Display each weather phenomena on x-axis and # of unsuccessful missions on y-axis

L. Percentage of missions a negative impact due to weather actually occurred when MEF did/didn't forecast it

    1. If #10 shows anything other than "None" then see if #7 shows a corresponding response and if it does, then it "was forecasted"; if it does not, it "was not forecasted." Divide both the "was forecasted" and the "was not forecasted" responses for each impact by the total occurring and multiply by 100 to get percentages

    2. Display each negative mission impact on x-axis and the percentage of missions in which it corresponded to the #7 response on the y-axis

M. Percentage of missions a particular mission plan was changed due to planning weather and then <u>changed again</u> due to MEF

    1. Responses in #5 other than "None" that correspond to the same response in #9

    2. Display mission plan changes on x-axis and on y-axis show three separate percentages: # changed due to planning weather, # changed due to MEF, # plan was changed both due to planning weather and then again due to MEF

N. Percentage of missions where mission was unsuccessful and operator felt the MEF was inaccurate.
  1. If #23a shows "Mission unsuccessful" and #8 responses do not match #11 responses and #23d shows either "No negative weather impacts forecasted" or "Negative weather impacts forecasted inaccurately". Divide the number of times this exists by the number of unsuccessful missions and multiply by 100
  2. Display results numerically

O. The most common weather phenomena actually occurring that resulted in mission being successful/unsuccessful.
  1. #11 responses other than "None" that correspond to #23a "mission successful/mission unsuccessful"
  2. Display the weather phenomena on the x-axis and number of missions on the y-axis. Display successful missions in one color and unsuccessful missions in another color on the bar graph

P. Percentage of each weather phenomena negatively impacting the mission, but was/wasn't forecasted in MEF
  1. If response to #11 is anything other than "None" and it wasn't in #8 responses
  2. Display the weather phenomena on the x-axis and number of MEFs on the y-axis. Display both when they correspond and when they do not in different colors on the bar graph

Q. Percentage of missions a weather phenomena actually occurred, but wasn't in the MEF(planning weather) even though it was in planning weather(MEF) or was not in either or was in both
  1. If response to #11 is anything other than "None" and it wasn't in #8 (#4) responses, but it was in #4 (#8) or it wasn't in either #8 or #4 or it was in both #8 and #4.
  2. Display the weather phenomena on the x-axis and number of MEFs (planning weather forecasts) on the y-axis. Display each of the four situations in different colors.

Target Acquisition Weapon Software (TAWS)
R. Percentage of missions that used TAWS
  1. Count the number of responses for #13 that responded "Not using" and subtract if from the total number of forms submitted and then divide this number by the total number of missions and multiply by 100.
  2. Display results in numeric form.

S. How is TAWS being used?

    1. Responses for #13 other than "Not using" and divide each response by the total number of TAWS users and multiply by 100.

    2. Display results in a bar graph with "Mission planning", "Execution", and "Both" on the x-axis and percentage of TAWS usage on the y-axis

T. Percentage of time TAWS had the weapon sensor modeled (didn't have the weapon sensor modeled) and the TAWS predictions were accurate, pessimistic, or optimistic?

    1. Responses to #17 that matched a "Yes"("No") response to #14

    2. Display results as a bar graph with the TAWS predictions (pessimistic, optimistic, accurate) on the x-axis and the number of times these responses corresponded to the weapon sensor being modeled ("Yes") in one color and the number of times these responses corresponded to the weapon sensor not being modeled ("No") in another color

U. What is TAWS being used for?

    1. Count the number of times each response for #15 is marked and divide it by the total number of TAWS users. Multiply this by 100 to get a percentage.

    2. Display each of the responses to #15 on the x-axis and the percentage of time they are using TAWS for it on the y-axis

V. Percentage of missions TAWS weather was accurate/inaccurate when it came from the CWT versus AFWA

    1. Count the number of times each response for #18 is marked and the percentage of time each response corresponded to a #19 response of "Yes" or "No"

    2. Display the responses to #18 on the x-axis and the percentage of time they were "Yes" to #19 in one color and the percentage of time they were "No" in #19 in another color...the percentages are on the y-axis

W. Percentage of TAWS users that would use it again when their weapon sensor was/wasn't modeled

    1. Count the number of times each response for #20 is marked and the percentage of time this corresponded to either answer to #14.

    2. Display each of the responses to #20 on the x-axis and the percentage of time their weapon sensor was modeled in one color and the percentage of time their weapon sensor was not modeled in another color

X. Percentage of time the weapons load or tactics were changed based on TAWS predictions
    1. Count the number of times each response for #16 is marked and divide it by the total number of TAWS users…multiply this by 100 to get a percentage.
    2. Display each of the responses to #16 on the x-axis and the percentage of time they occurred on the y-axis

Y. Usefulness of TAWS
    1. Count the number of times each response for #21 is marked and divide it by the total number of TAWS users…multiply this by 100 to get a percentage.
    2. Display each of the responses to #21 on the x-axis and the corresponding percentage of usefulness (1-4) on the y-axis in four different colors…may need to do two bar graphs, one for "Pre-mission" and one for "In-flight"

Figure 10. Description of calculations performed to analyze ACC and PACAF data, plus instructions for displaying the results of the analyses. Based on data collected from Kunsan AB, Nellis AFB, and Osan AB.

ACC & PACAF CWTs

Data obtained by aircrews filling out paper copy of data collection form

Data entered via HTML & PHP webpage

NPS

Data written to MYSQL database

Data analyzed per NPS metrics procedures

Output reports delivered via webpage

Reports are available on demand by using embedded PHP to calculate metrics

Reports delivered by CWTs to AFW and operations leadership
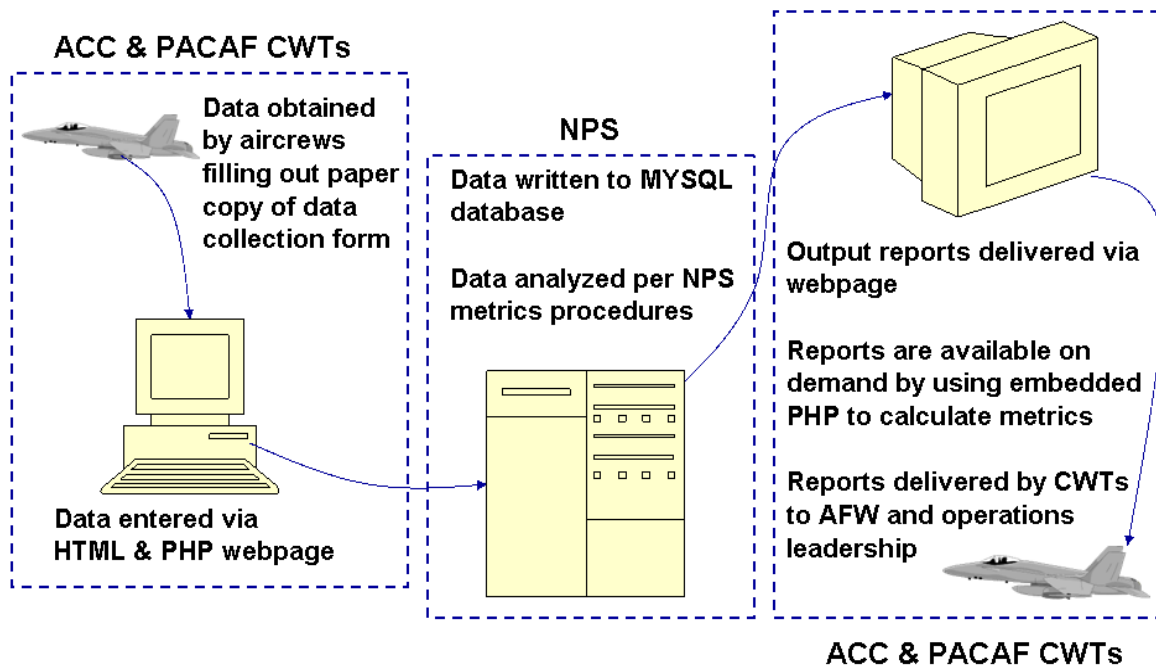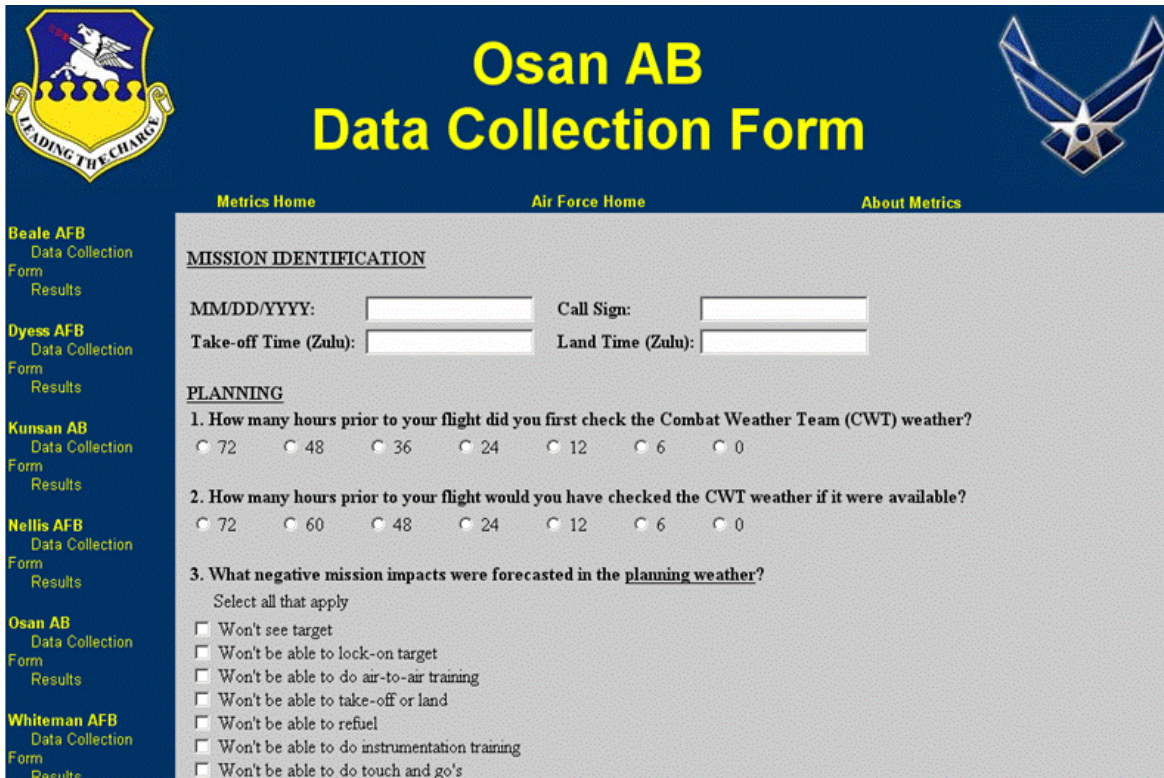
ACC & PACAF CWTs

Figure 11. Flow of data, from collection by aviators, to analyses at Naval Postgraduate School, to results reported to leadership. (Adapted from Butler 2005)

Figure 12. Online data collection form for Osan AB available online at http://wx.met.nps.navy.mil/metrics/index.html. Data collected is put into a Naval Postgraduate School database where it is then analyzed, and from which metrics reports are issued.

% of Total Missions % of Sqdn Msns MAJCOM	A-10 Thunderbolt II	B-1B Lancer	B-2 Spirit	F-16 Fighting Falcon	U-2	UAV (Unmanned Aerial Vehicle)
Beale AFB, CA					5% 30% ACC	
Creech AFB, NV						0%
Dyess AFB, TX		17% 60% ACC				
Kunsan AB, ROK				14% 35% PACAF		
Nellis AFB, NV	8% 10% ACC			0%		
Osan AB, ROK	16% 50% PACAF			24% 50% PACAF		
Whiteman AFB, MO			16% 40% ACC			

Figure 13. Summary of data collected during data collection timeframe, categorized by air base (rows) and air frame (columns). Information on missions describes: percent of total missions, percent of squadron missions completing data collection forms, and major command (Air Combat Command or Pacific Air Forces).
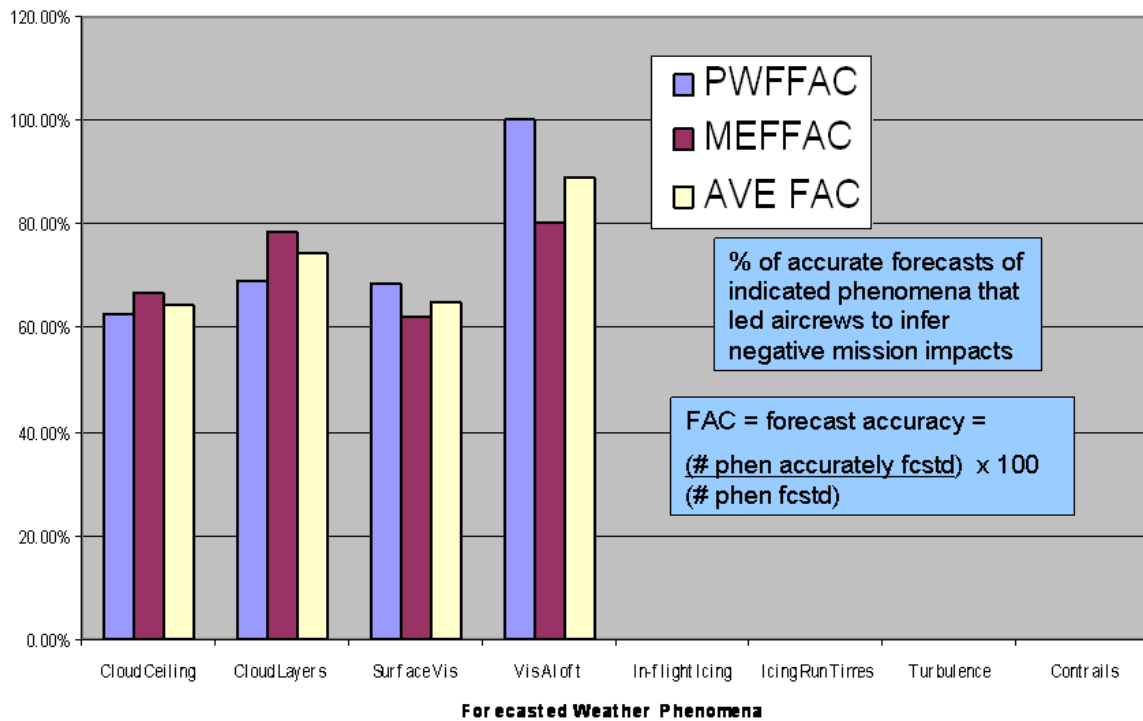
Figure 14. Forecast accuracy (FAC) for forecasts of phenomena (listed on horizontal axis) from which aviators inferred negative mission impacts. Planning weather forecast FAC (blue), mission execution forecast FAC (purple), average of PWF and MEF FAC (yellow). Note: large values of FAC for a given phenomenon are generally associated with a very small sample size.
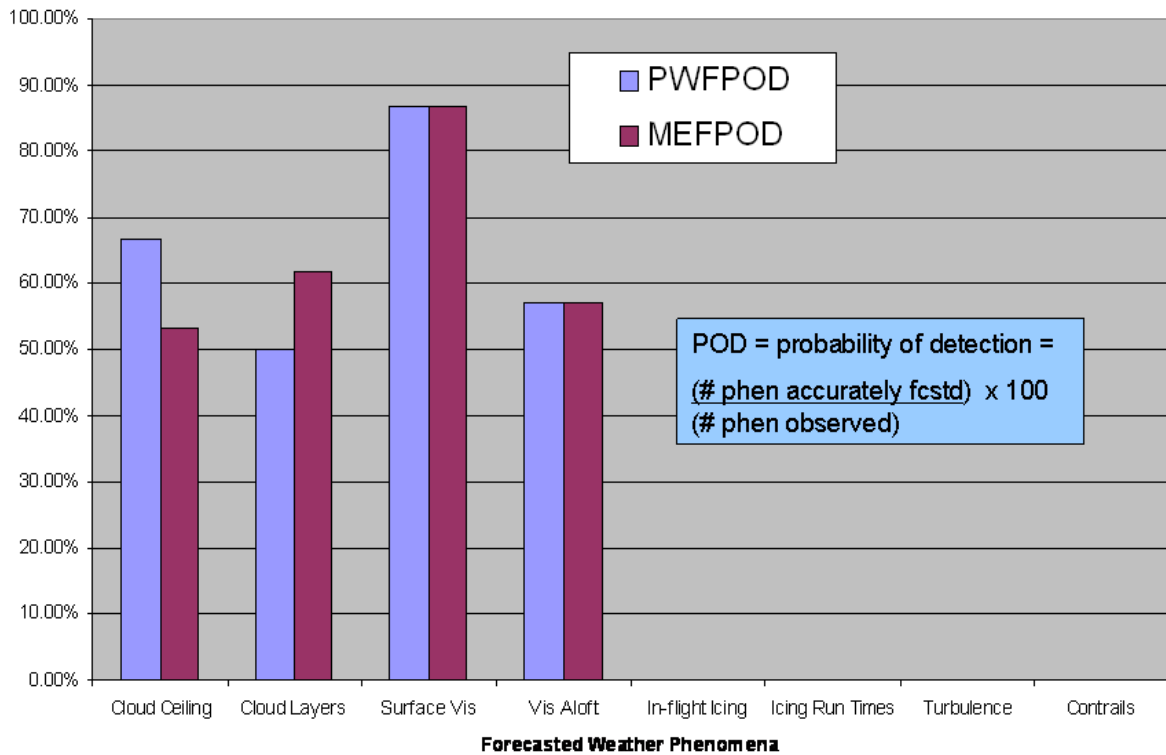
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Figure 15. Probability of detection (POD) for forecasts of phenomena (listed on horizontal axis) from which aviators inferred negative mission impacts. Planning weather forecast POD (blue), mission execution forecast POD (purple). Note: large values of POD for a given phenomenon are generally associated with a very small sample size.
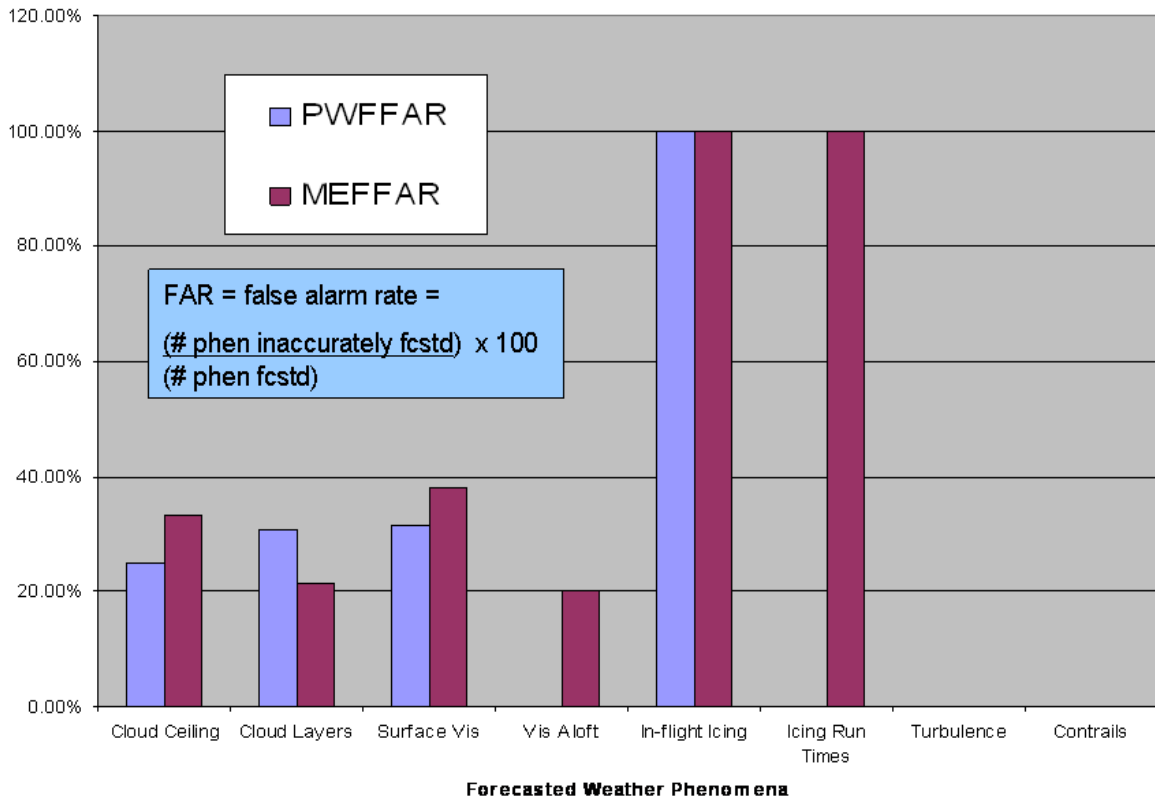
Figure 16. False alarm rate (FAR) for forecasts of phenomena (listed on horizontal axis) from which aviators inferred negative mission impacts. Planning weather forecast FAR (blue), mission execution forecast FAR (purple). Note: large values of FAR for a given phenomenon are generally associated with a very small sample size.
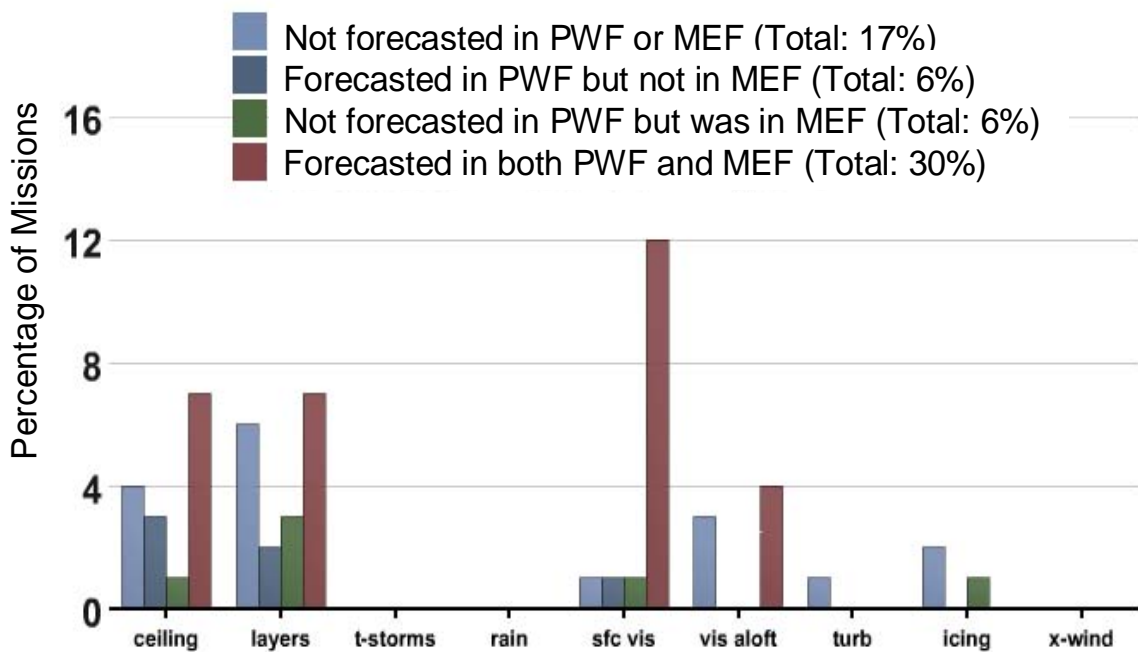
Figure 17.   Percent of missions that experienced phenomena (horizontal axis) with negative impacts that were/were not forecasted in the planning weather forecast (PWF) and/or the mission execution forecast (MEF).
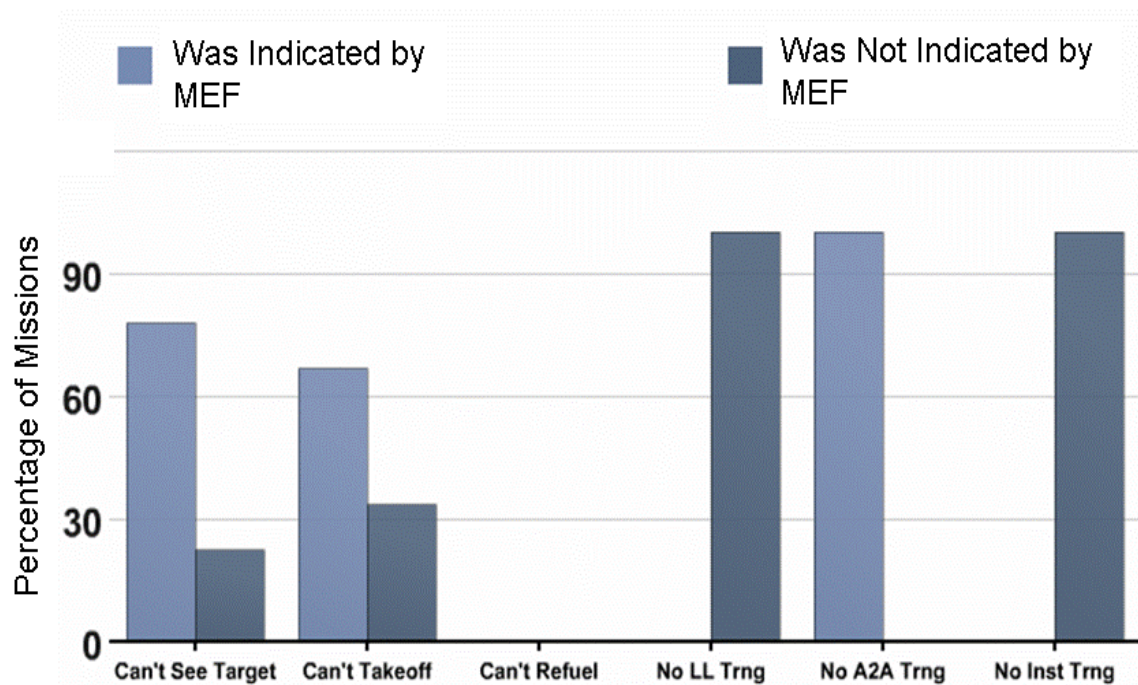
Figure 18.   Percent of missions that experienced negative impacts (horizontal axis) that were/were not indicated by the mission execution forecast (MEF).
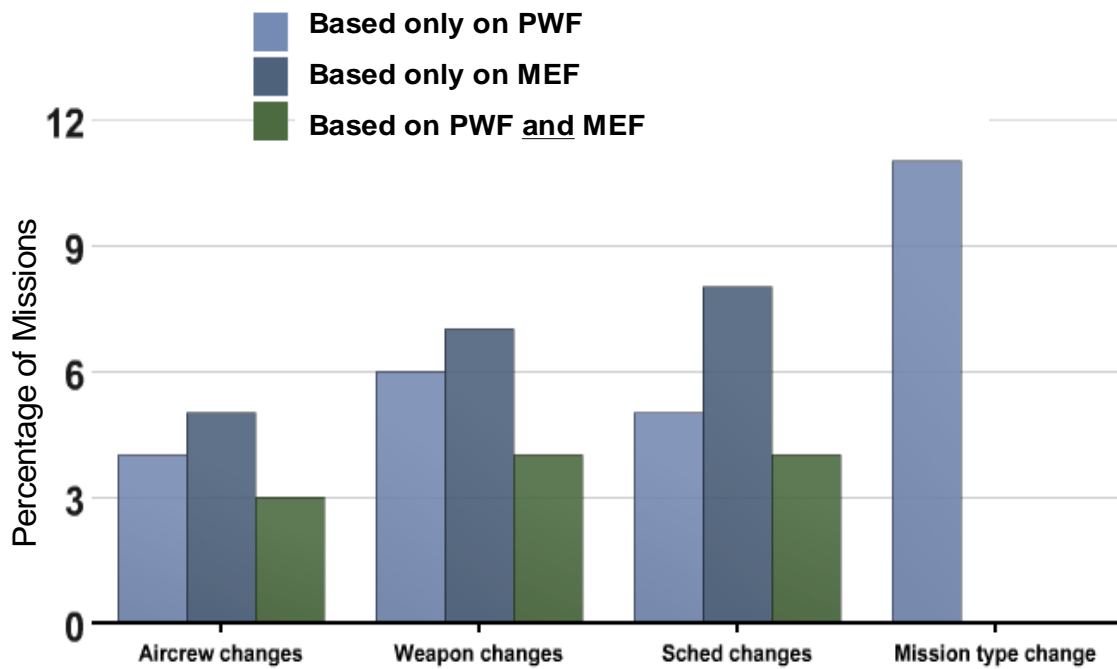
Figure 19.   Percent of missions for which mission plan changes (horizontal axis) were made by aircrews in response to negatively impacting weather phenomena indicated by planning weather forecast only (PWF, light blue), mission execution forecast only (MEF, dark blue), or both PWF and MEF (green).

Figure 20. Number of missions for which indicated negative impacts (colored symbols) were inferred by aviators from planning weather forecasts of indicated weather phenomena (horizontal axis). Note that the forecasted phenomena associated with the largest number of inferred negative mission impacts were cloud ceiling (associated with inability to see target), cloud layers (associated with inability to see target), and surface visibility (associated with inability to takeoff or land).

Figure 21. Number of missions for which indicated mission plan changes (colored symbols) were made based on planning weather forecasts of indicated weather phenomena (horizontal axis). Example: the mission schedule was changed for four missions based on the PWF forecast of surface visibility.
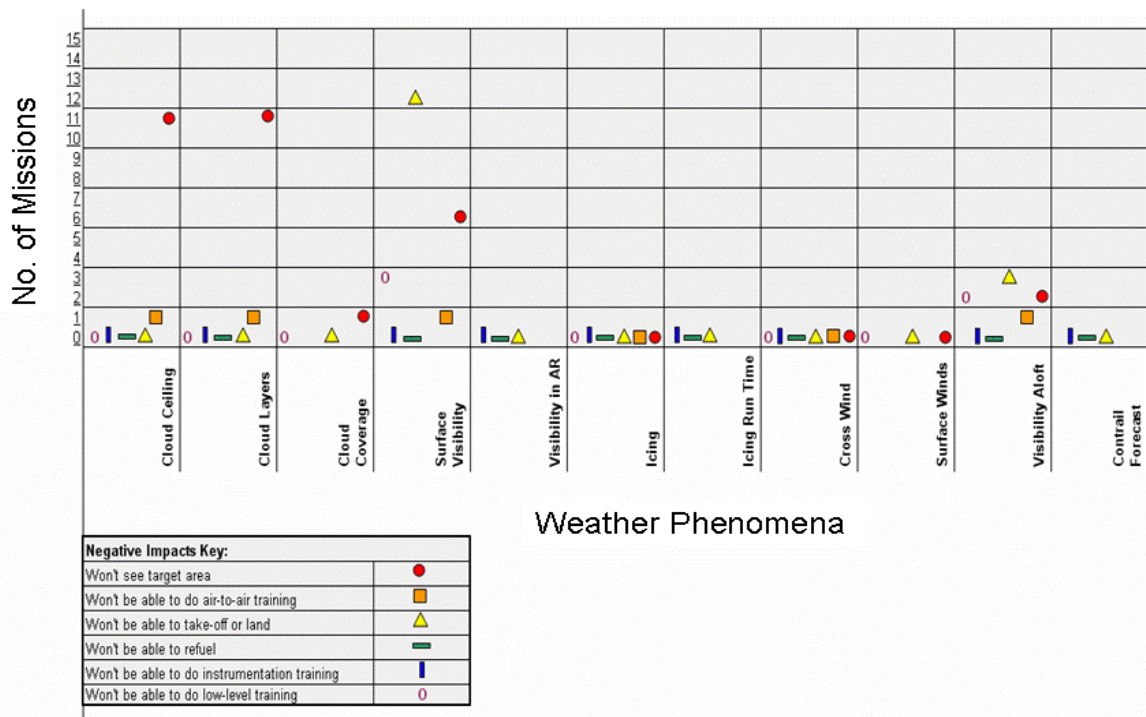
87
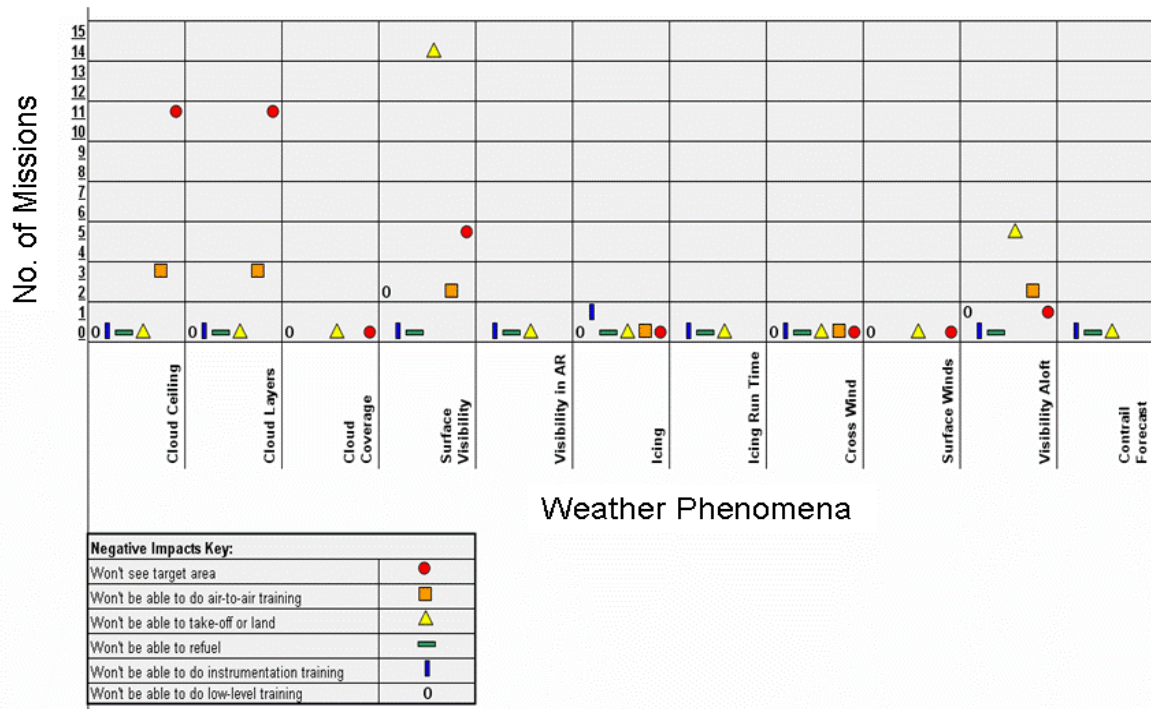
Figure 22. Number of missions for which indicated negative impacts (colored symbols) were inferred by aviators from mission execution forecasts of indicated weather phenomena (horizontal axis). Example: inability to takeoff or land was inferred for 14 missions based on forecasts of surface visibility in the MEFs for those missions.
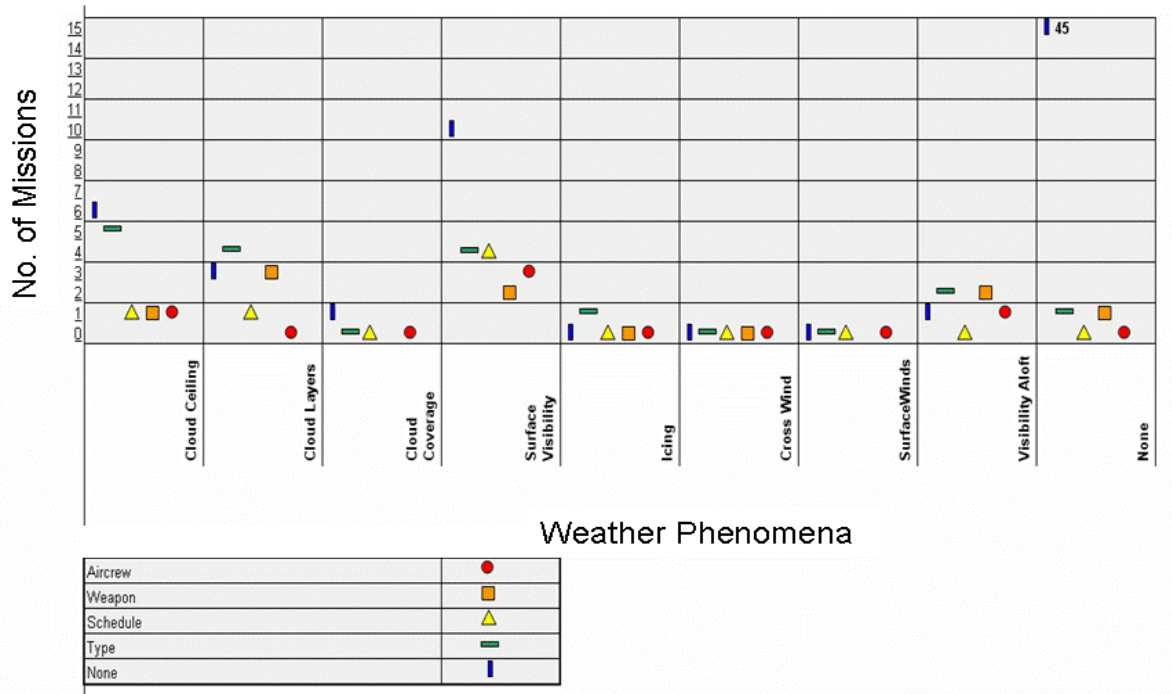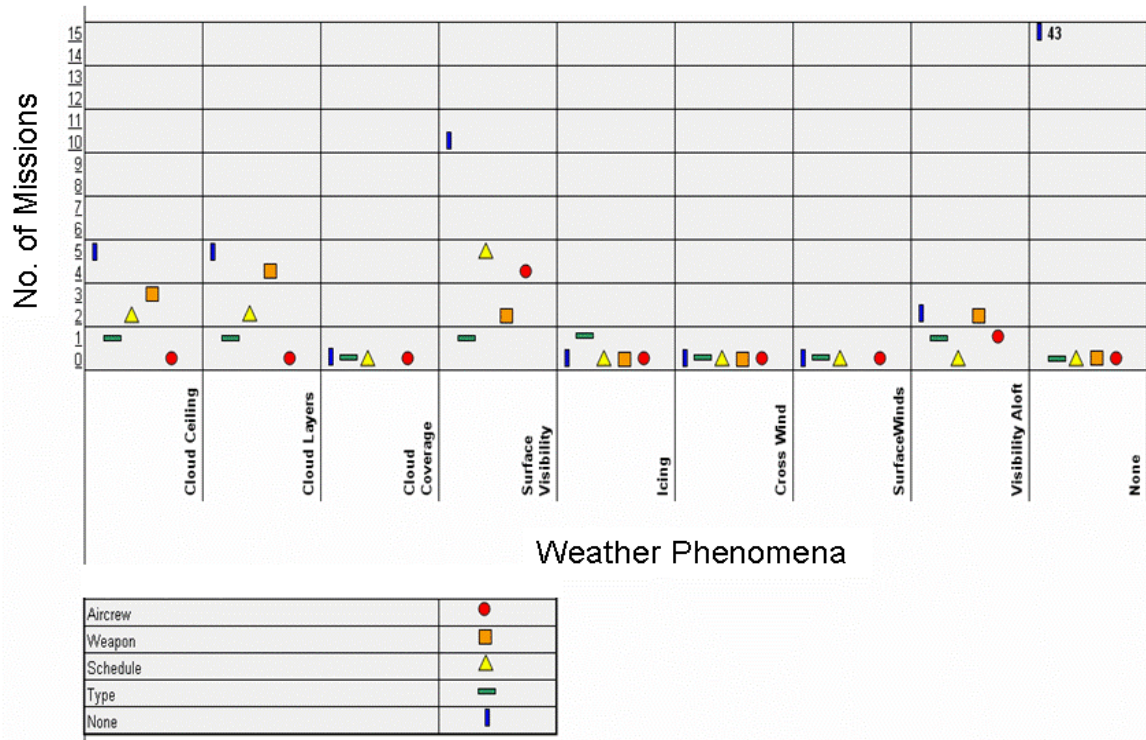
Figure 23. Number of missions for which indicated mission plan changes (colored symbols) were made based on mission execution forecasts of indicated weather phenomena (horizontal axis). Example: weapons changes were made for four missions based on the cloud layer forecasts in the MEFs for those missions.
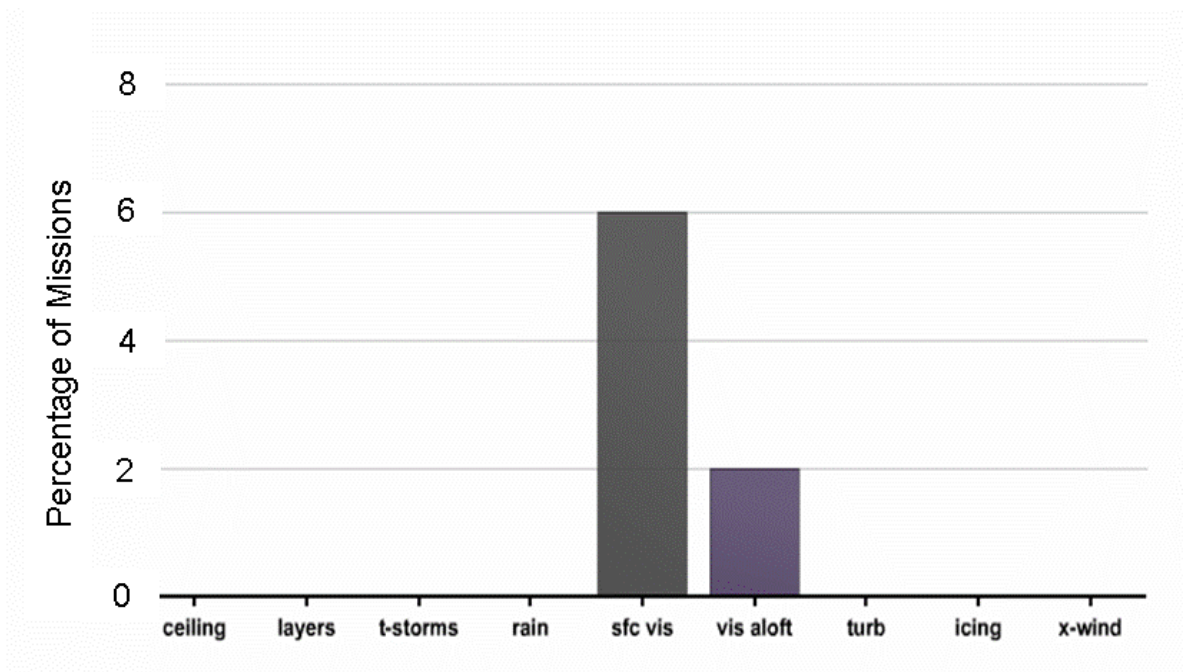
Figure 24. Percent of missions deemed unsuccessful due to negative impacts from indicated weather phenomena (horizontal axis). Seven percent of all missions analyzed were deemed unsuccessful by aviators.

The chart shows "Percentage of Successful Missions" (y-axis, 0.00% to 8.00%) for bases on the x-axis: Beale AFB, Dyess AFB, Kunsan AB, Nellis AFB, Osan AB, Whiteman AFB.

Legend:
- PWF PMC (blue/purple)
- MEF PMC (dark red)

Text box (yellow): **PWF PMC = 10.2%** / **MEF PMC = 10.2%**

Text box (blue): PMC: forecast implies negative mission impact, mission plan changes, *and* primary mission accomplished
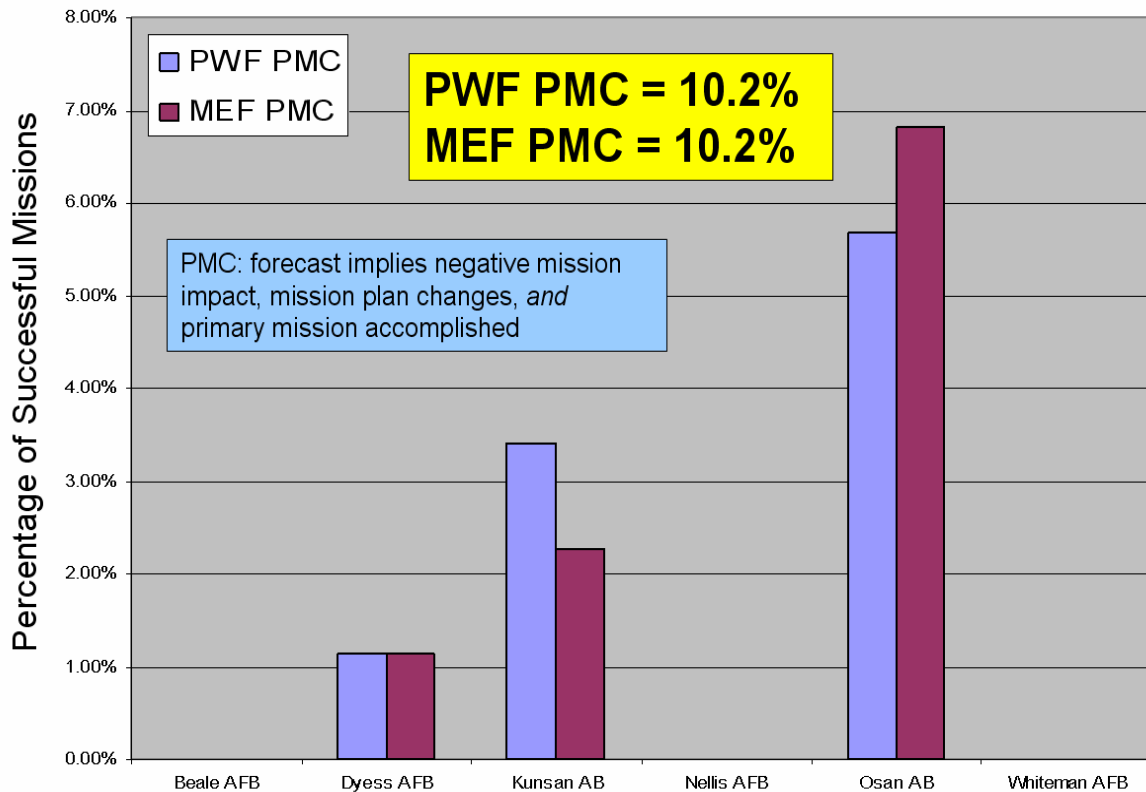
Figure 25. Percent of missions for which a positive mission contribution (PMC) was made by the planning weather forecast (PWF, blue) or mission execution forecast (MEF, purple). PMC criteria are summarized in blue text box within figure and are described in detail in Chapter II. Percentages based in part on number of missions deemed successful by aviators. For all bases, 10.2% of successful missions received a PMC from their PWFs, and 10.2% of missions received a PMC from their MEFs.
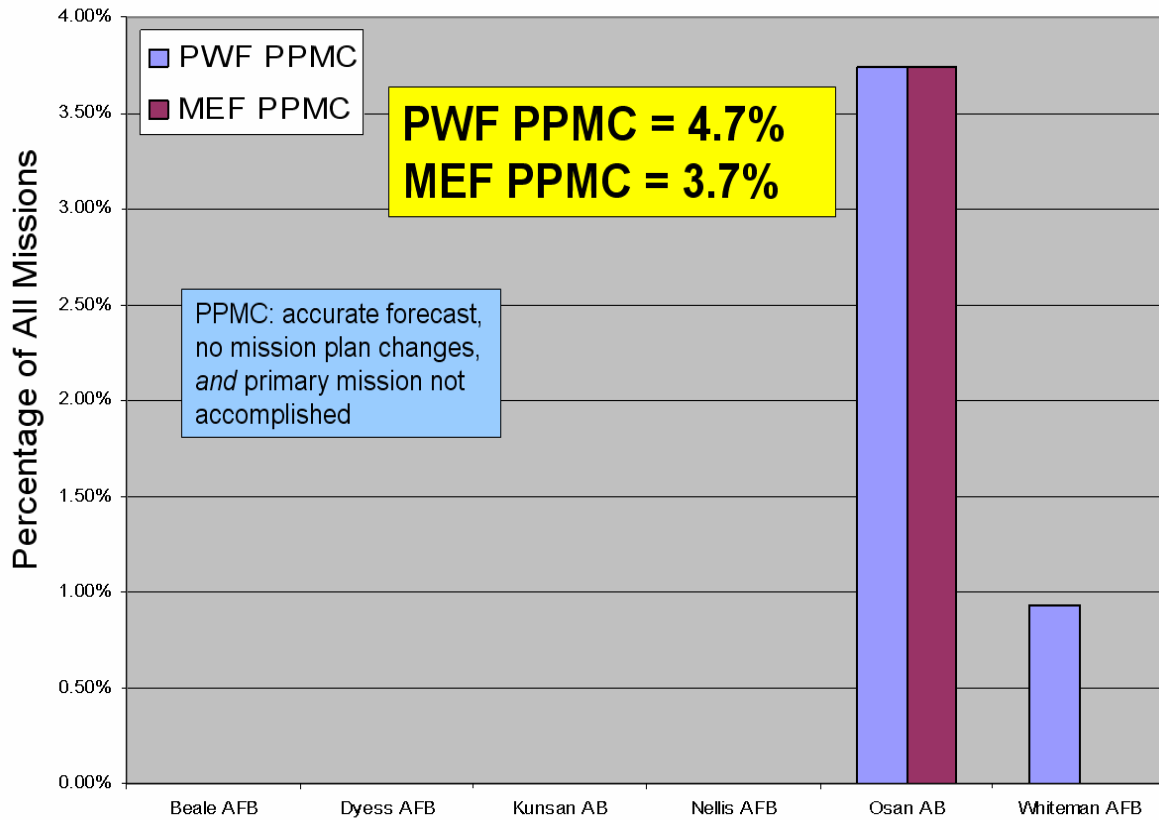
Figure 26. Percent of missions for which a potential positive mission contribution (PPMC) was made by the planning weather forecast (PWF, blue) or mission execution forecast (MEF, purple). PPMC criteria are summarized in blue text box within figure and are described in detail in Chapter II. Percentages based in part on number of missions deemed unsuccessful by aviators. For all bases, 4.7% of missions received a PPMC from their PWFs, and 3.7% of missions received a PPMC from their MEFs.

Generic Fighter Aircraft Data Collection Form

Call sign:_____Date (mm/dd/yyyy):_____Take-off time(zulu):_____Land time (zulu):_____

PRE-EXECUTION

**1. How many <u>hours</u> prior to your flight did you check the weather provided by the weather station (MEF-mission execution forecast)?**
□ 6 □ 5 □ 4 □ 3 □ 2 □ 1 □ 0

2. What <u>weather phenomena in the MEF were inferred</u> to cause negative mission impacts?

□ Surface Visibility   □ Cloud Ceiling
□ Clouds Layers   □ Visibility Aloft
□ Other_____   □ None

3. What negative mission impacts did you infer from the MEF?

□ Won't be able to take-off   □ Won't be able to refuel
□ Won't be able to strike target   □ Won't be able to do low-level training
□ Won't be able to do air-to-air training □ Won't be able to land
□ Other_____   □ None

4. What mission plan <u>changes</u> <u>due to the MEF</u> were made <u>prior to your flight</u>?

□ Aircrew change   □ Schedule (i.e. time of mission)
□ Too late to make any changes   □ Weapon
□ Type (e.g. low-level, refueling) □ Other_____
□ None

EXECUTION

5. What negative impacts due to weather <u>actually occurred during the mission</u>?

□ Couldn't take-off   □ Couldn't refuel
□ Couldn't strike target   □ Couldn't do low-level training
□ Couldn't do air-to-air training □ Couldn't land
□ Other_____   □ None

6. Was the MEF accurate?

□ Yes   □ No, what was inaccurate?
□ Surface Visibility   □ Cloud Ceiling
□ Clouds Layers   □ Visibility Aloft
□ Other_____   □ None

7. What did you <u>intend to accomplish</u> on your mission?

□ Low-level training   □ Air-to-air combat training
□ Strike target on ground   □ Air-to-air refueling
□ Instrumentation training   □ Other_____

8. What did you <u>actually accomplish</u> on your mission?

□ Low-level training   □ Air-to-air combat training
□ Strike target on ground   □ Air-to-air refueling
□ Instrumentation training   □ Other_____
□ Nothing

9. **What was your overall impression of the mission?**

   a) ☐ **Mission successful**
        ☐ **Mission unsuccessful**

   b) ☐ **No negative impacts forecasted**
        ☐ **Negative impacts forecasted <u>inaccurately</u>**
        ☐ **Negative impacts forecasted accurately**

   c) ☐ **No weather impact to mission**
        ☐ **Weather negatively impacted mission**

   d) ☐ **<u>Changed</u> mission <u>due to MEF</u>**
        ☐ **<u>No mission change</u> due to <u>MEF</u>**

   e) ☐ **<u>Changed</u> mission due to <u>planning weather</u>**
        ☐ **<u>No mission change</u> due to <u>planning weather</u>**

<u>PLANNING WEATHER</u>
10. How many days prior to your flight did you first check the planning weather provided by the base weather station?
☐ 6 ☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 ☐ 0

11. Would you have checked the weather earlier if it were available?
☐ Yes ☐ No

12. What mission plan <u>changes due to planning weather</u> were made >12hrs prior to your take-off?

☐ **Aircrew change**	☐ **Schedule (i.e. time of mission)**
☐ **Weapon**	☐ **Type (e.g. low-level, refueling)**
☐ **Other_____**	☐ **None**

<u>TAWS</u>
13. How are you using Target Acquisition Weapon Software (TAWS)?
☐ **Not using (you are finished with data collection form…thanks for your feedback)**
☐ **Mission planning**
☐ **Execution**
☐ **Both**

14. Does TAWS have your weapon sensor modeled?
☐ Yes ☐ No

15. What are you using TAWS for?
☐ IR ☐ TV ☐ Laser ☐ NVG predictions

16. Did you change your weapons load or tactics based on TAWS predictions?
☐ Yes ☐ No

17. How were the TAWS predictions?
☐ Pessimistic ☐ Optimistic ☐ Accurate

18. How did you get your weather for TAWS?
☐ Download from AFWA ☐ File from the CWT

19. Was the TAWS weather accurate?
□ **Yes**   □ **No**

20. Would you use TAWS again?
□ **Yes**   □ **No**

21. Rate the prediction software in the areas below using the following scale:
1-not useful, 2-somewhat useful but not required, 3-useful, 4-mission essential

Pre-mission:
a. Route selection	1	2	3	4
b. Target viewing azimuth	1	2	3	4
c. Target area tactics	1	2	3	4

Inflight:
a. Low level navigation	1	2	3	4
b. Target area tactics	1	2	3	4
c. Target identification	1	2	3	4
d. Threat avoidance	1	2	3	4
e. Sensor cross-check techniques	1	2	3	4

Figure 27.   Proposed generic fighter data collection form for future studies.

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