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# PREMATURE EXTINCTION OF THE WEATHER OBSERVER:

# HOW MUCH RISK IS THE AIR FORCE ASSUMING?



by

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A Research Report Submitted to the Faculty

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**Disclaimer**

**TABLE OF CONTENTS**

## FIGURES AND TABLES

**ABSTRACT**

This research addresses the representativeness of various fielded Automated Meteorological Observing Systems (AMOS) and the policies under which these systems are employed by the United States (U.S.) Air Force. A pool of 1791 surface weather observations were collected from various AMOS over three collection periods within the Republic of Korea and compared to human-augmented observations for the same periods to assess sky condition and visibility hit-rates and performance. Hits within this study are defined as ceilings positively identified within 1,000 feet and visibility assessed within 1 reportable value. The results indicate wide variance in performance of respective FMQ-19, FMQ-23, and TMQ-53 sensors within the same aerodrome with ceiling hit-rates ranging from 69.4%-76.5% and visibility hit-rates ranging from 19.2%-73.1%. When fair weather observations were removed from the total pool, performance dropped to 42.4%-56.5% and 8.1%-35.3% for ceilings and visibility, respectively. Additionally, surface weather observation policy was found to passively accept potentially erroneous AMOS weather reports even when the capability to augment with a human observer exists. Recommendations include modifying policy to pro-actively augment surface weather observations with a human observer in the loop, base-lining fielded AMOS sensors to reduce variability, and simplifying fielded systems toward the goal of minimizing manpower requirements.

# INTRODUCTION

The Department of Defense (DOD) relies upon the training and insights of meteorologists and weather technicians to exploit the battlefield environment and successfully complete the mission. The forecast on D-Day, June 6, 1944, for example, has been cited as the most important weather forecast in history.[1] The invasion was meticulously planned for a 3-day window with favorable high-illumination moon and morning twilight low tide, but an ill-timed low pressure weather system caused a postponement of the original June 5, 1944 execution date and threatened to cancel the mission altogether until the necessary astronomical, tidal, and weather conditions again supported mission execution. A keen forecaster, however, predicted a break in rough seas and generally unfavorable weather conditions on June 6, 1944, allowing President Eisenhower the opportunity to go forward with the English Channel crossing and invasion of Normandy.[2] This forecast drew much of its basis from surface weather observations collected and shared from a robust upstream manned observation network, the accuracy of which proved vital to the success of the D-Day invasion.[3]

If the U.S. Air Force is to outperform the enemy across the full spectrum of military operations, it must maintain a sharp, exploitive weather operations edge. Every military operation is impacted in some way by the weather and the forecast. DOD assets are exposed to hazardous weather conditions each year, the effects of which are mitigated daily by U.S. Air Force weather technicians through issuance of 30-hour Terminal Aerodrome Forecasts (TAF), weather

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[1] Lipman, Don. "D-Day at 70: The most important forecast in history." The Washington Post. June 6, 2014, 1.
[2] Klein, Christopher. "The Weather Forecast That Saved D-Day." History, June 4, 2014, 1.
[3] Lipman, "D-Day at 70," 1.

Watches, Warnings, and Advisories (WWA) with customer-driven desired lead times, specific Mission Weather Products (MWP) tailored to customer-defined thresholds, and transient Flight Weather Briefings to name a few.[4][5] Surface weather observations are arguably the foundation of these exploitive and mitigation efforts.

In years past, the role of the weather observer in military operations was predominately in manual collection of surface weather data which was then physically analyzed by meteorologists and forecasters to make assumptions about the current and future state of the atmosphere.[6] Technology to war-fighting application within U.S. Air Force Weather has resulted in the adoption and widespread employment of Automated Meteorological Observing Systems (AMOS) which relieve much of the physical burden of collecting and encoding surface weather data from weather observers, much like Numerical Weather Prediction (NWP) models, which came along with advances in computing technology, have relieved the burden of physical analysis and prognosis from forecasters. Meanwhile, manpower reductions and repurposing forced removal of manual weather observation as a specific specialty with the deletion of a dedicated Weather Observer School and 252X1 Weather Observer Air Force Specialty Code (AFSC) in 1981.[7]

The U.S. Air Force is a global leader in environmental exploitation; however, substantial room for improvement exists within the current surface weather observation construct. AMOS technology has known limitations, described later, and despite widespread employment,

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[4] Air Force Manual (AFMAN) 15-129 Volume 1. *Air and Space Weather Operations – Characterization*, 6 December 2011, 20, 36.

[5] Air Force Manual (AFMAN) 15-129 Volume 2. *Air and Space Weather Operations – Exploitation*, 7 December 2011, 21.

[6] Air Force Doctrine (AFD) 131104-184. *Air Force Weather, Our Heritage 1937 to 2012*, 1 July 2012, 6-11.

[7] AFD 131104-184, *Air Force Weather*, 6-14.

no known studies have been performed on their accuracy in the field since the National Weather Service's (NWS) Automated Surface Observing System (ASOS) was assessed by Jon Cornick in 1993. Practical experience indicates some margin of error among the various fielded AMOS models, specifically in the elements of visibility and sky condition, which will be explored in the pages that follow. The findings will then serve as the foundation for a policy level review on surface weather observation. Problems with AMOS data quality include marginal mission support, erroneous initial conditions supplied to NWP models, and climatological data errors. On top of data issues, other problems with the AMOS construct are increasing costs of complex equipment and support contracts, the costs of dedicated maintenance personnel to service these systems, and an array of fielded AMOS models complicating oversight and management. This research answers the question; how can the U.S. Air Force best utilize AMOS while balancing limitations and manpower constraints?



The framework for this research is *Evaluative* on two fronts: AMOS performance and surface weather observation policy. An AMOS evaluation is offered to build upon the extensive work done by Cornick[8] on the legacy ASOS and to reflect the quality of the U.S. Air Force's currently fielded AMOS inventory. The purpose of the policy-level review is to ascertain any unnecessary risk introduced into operations through implementation of AMOS. These two evaluations lead to recommendations for potential alternative methods.

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[8] Cornick, Jon. "A Comparison of Ceiling and Visibility Observations for NWS Manned Observation Sites and ASOS Sites." Colorado State University, 1993.

In the pages that follow, *Background Literature* will be introduced and discussed starting with a description of the U.S. Air Force's current AMOS inventory along with strengths and limitations. A discussion of ASOS accuracy follows and is accompanied by an assessment of surface weather observations' impacts to operations as a function of time as well as a correlation of meteorological variables to aircraft mishaps. The next section of the paper details *Methodology* of the evaluative assessments. Data collection and comparison techniques of observations from four sources in the Republic of Korea (i.e. FMQ-19, FMQ-23, TMQ-53, and human augmentation) are described. A discussion of policy evaluation methodology completes this section. *Results* of each evaluation are then discussed with *Recommandations* presented based on the results before final *Conclusions*.



## BACKGROUND AND LITERATURE REVIEW

Weather collection instruments have increased in sophistication and the use of manual, analog instruments and techniques has been almost completely replaced with digital hardware aside from some back-up techniques. This section details current knowledge of AMOS and corresponding impacts of AMOS employment.

### *Current Fielded Systems*

The U.S. Air Force's current array of fielded automated weather sensors can be captured under the umbrella term AMOS, not to be confused with the ASOS, which is a type/model of AMOS. Depending on its configuration, AMOS has the capability to collect the full suite of meteorological data including "Wind, Visibility, Precipitation/Obstructions to Vision, Cloud

Height, Sky Cover, Temperature, Dew Point, Altimeter, and Lightning."[9] AMOS models currently employed by the U.S. Air Force include the ASOS, FMQ-19, FMQ-22, FMQ-23, and TMQ-53. Of these models, the ASOS, FMQ-19, and FMQ-23 are similar in design with some variances in individual sensors, software algorithms, and communications infrastructure which affect their respective performance. The ASOS is in the process of being phased out, and the FMQ-23 is currently being phased in. The FMQ-22 is a scaled-down version of a fixed AMOS and the TMQ-53 model variant represents the latest iteration of a tactical, deployable collection unit known as Tactical Meteorological Observing System (TMOS).

AMOS employment on the airfield complex remains largely unchanged since the ASOS was first adopted from the National Weather Service (NWS) in 1995. This construct consists of one to three sensor sets per airfield depending on runway length with the U.S. Air Force's longest runways utilizing Primary, Discontinuity, and Midfield sensor groups. Shorter airfields do not have midfield sensors, and heliports may only carry a single sensor set, if anything at all. Discontinuity groups typically consist of wind, ceilometer, and visibility sensors while the midfield group consists of an additional wind sensor. The employment of additional sensors at the midfield and discontinuity end of the runway reflect the variability of weather conditions for those particular elements, and elements with less operational impact or variability including temperature, relative humidity, lightning, and pressure are not duplicated.



The U.S. Air Force currently utilizes two methods of AMOS service and upkeep specific to fixed AMOS and non-fixed TMOS. First, fixed AMOS, having become complex at costs

[9] Air Force Manual (AFMAN) 15-111. *Surface Weather Observations*, 27 February 2013, 9.

ranging from approximately $155,000 to $173,000 per sensor group[10] (discontinuity and mid-field groups increase the price from here) require dedicated Air Traffic Control and Landing Systems (ATCALS) (formerly Meteorological Navigational (METNAV)) maintenance personnel to service. The TMOS method, on the other hand, utilizes a plug-and-play maintenance scheme, and the system is trouble-shot and serviceable by the weather technician.

### *AMOS Strengths and Limitations*

The AMOS construct brings a number of benefits to any airfield sensing strategy and the U.S. Air Force weather exploitation strategy as a whole. First, AMOS enables real-time data collection and dissemination at a benefit to flight safety and mission accomplishment since AMOS sensors "live" in the elements, constantly sensing atmospheric changes. A human observer spends comparatively brief spans of time in these elements at varying intervals based on the weather occurring[11] and then must transit from the official observation point to the communications node where observations can be transmitted. AMOS also offers consistency, coding and preparing weather observations at a substantial time-savings to the weather technician. Human data-input errors are also reduced, especially in complex weather scenarios where multiple, rapidly changing criteria must be coded. Minimizing data errors in this respect positively impacts data assimilation into NWP models and improves after-the-fact data mining for climatological studies. AMOS can also be deployed and operated without a weather technician in the loop in order to provide vital weather reports back to dislocated forecasters. These stand-alone systems

[10] Mr. Todd Allen, DAFC ACC/A5WF to the author, e-mail, 30 November 2015.
[11] AFMAN 15-111, 16.

would still require preventative maintenance; however, this can be conducted by remote, centralized maintenance functions.

While this paper is concerned with the entire AMOS observing construct, special emphasis is placed on the observing and reporting limitations of sky condition and visibility due to the operational impact of these elements. Laser beam ceilometers are employed in the sensing of cloud heights and sky coverage. The laser is emitted vertically and time-phased signal returns indicate the height of obscurants. These lasers are capable of penetrating clouds and reporting multiple cloud layers. The ceilometer's software algorithms then utilize time-averages to infer current sky coverage which is defined in eights of the celestial dome as Clear (0/8), Few (trace through 2/8), Scattered (3/8 through 4/8), Broken (5/8 through less than 8/8), and Overcast (8/8).[12] This is significant as operational limitations such as Instrument Flight Rules (IFR) and Fighter/Attack Pilot Weather Categories are based on the height and coverage of clouds.[13] Furthermore, erroneously reported sky condition may lead a pilot to the false conclusion that an inaccessible airfield is accessible. The ceilometer is limited in areal scope in that it relies on a single, vertically emitted laser (or possibly two if the airfield is equipped with a Discontinuity group), and it is subject to under-reporting clouds not directly overhead and over-reporting clouds which linger overhead based on time-averaged algorithms.[14] For example, if there is one cloud in the sky at 10,000 feet covering 1/8 of the celestial dome, but it happens to remain directly over the ceilometer, the METAR will be reported as overcast skies at 10,000 feet rather

[12] AFMAN 15-111, 51.
[13] Air Force Instruction 11-202, Volume 3. *General Flight Rules – PACAF Supplement*, 7 November, 2014, 84.
[14] Cornick, *Comparison of Ceiling and Visibility*, 11.

than few clouds at 10,000 feet, assuming perfect functionality. Even this relatively minor inconsistency can have significant mission impacts ranging from Intelligence, Surveillance, and Reconnaissance (ISR) limitations to non-representative icing forecasts, and impacts compound as the cloud layer approaches the Earth's surface.

Visibility sensors detect hydrometeors (i.e. rain, fog, etc.) and lithometeors (i.e. pollutants, aerosols, dust, etc.) which act to reduce visibility in the immediate vicinity of the sensor. These sensors emit light which is scattered when it impacts airborne meteors. A separate collection function of the sensor correlates the amount of scattered light to an obscurant density and algorithms then assign a corresponding visibility. The collection function may detect forward or back-scattered light based on the configuration and model of the particular sensor in use. The average sensing volume for AMOS is approximately the size of a basketball which inhibits areal coverage.

Ceilings and visibility are not the only operationally significant elements of a surface weather observation, however, and additional concerns surround issues such as proper time-averaging of wind speeds and direction to best represent varying scales of motion[15] and temperature reporting consistency resulting from the influence of solar radiation, wind, or siting of the sensor.[16] These factors contribute to the accuracy of initial conditions ingested to NWP models.

***ASOS Accuracy***

[15] Powell, Mark. "Wind Measurement and Archival under the Automated Surface Observing System (ASOS): User Concerns and Opportunity for Improvement." *Bulletin of the American Meteorological Society*, Vol. 74, No. 4, April 1993, 615-616.

[16] Sun, B., C. Baker and T. Karl, M. Gifford. 2005. "A Comparative Study of ASOS and USCRN Temperature Measurements." *American Meteorological Society*, Vol 22: 679-686.

With any AMOS, especially one with known physical limitations such as areal coverage described above, there is some expected discrepancy between what the sensor is able to collect and what a human observer would be able to sense from the same location. Jon Cornick paved the way of comparison by validating the NWS's ASOS against human observers. In his report, "A Comparison of Ceiling and Visibility Observations for NWS Manned Observation Sites and ASOS Sites," Cornick explains how the ASOS was developed and implemented by the NWS with the intention to replace manned weather observing and reporting stations.[17] He catalogs and compares 64,000 observations against the following criteria: ceiling within 1,000 feet and visibility within one reportable category. The results appear marginally acceptable at first look with a 92.7% hit-rate for his ceiling criteria and 93.7% hit-rate for visibility. However, when fair-weather observations (i.e. no weather-type entry required) were removed from the pool (9,300 observations remaining), hit-rates dropped to 76% and 60.8% for ceilings and visibilities, respectively. The results are concerning because times when mission-limiting weather is actually occurring is when data accuracy is paramount. This data will be compared to similar assessments of the U.S. Air Force's current systems in the *Results* section to give a broader sense of AMOS accuracy.

### *Impacts to Operations*

Weather observations' impacts to operations can be sorted into three categories as a function of time: real-time or very short term on the order of seconds-to-minutes, mid-term on the order of hours-to-days, and long-term on the order of years-to-decades. Real-time surface weather observing serves flight safety and safe launch/recovery of the mission. The timeliness

[17] Cornick, *Comparison of Ceiling and Visibility*, iii.

of ceiling, visibility, and wind reports are vital in the launch/recovery process as they may provide an early indication that an alternate divert is required. Even the proper reporting of pressure is vital as it allows for calibration of the aircraft to the ground and safe descent in IFR conditions given varying atmospheric pressures. In the Republic of Korea, Air Traffic Information Service (ATIS), which broadcasts the latest weather report via radio has been seen to play a significant role in fuel management and recovery of F-16 and A-10 airframes. Inaccurate surface weather reports can contribute to mis-management of fuel while in-flight planning for a home base or alternate recovery.

Mid-term impacts of surface weather observations on operations fall more in the realm of pre-flight planning and mitigation. The farther one looks into the future from current conditions, the more heavily one weighs the insights of NWP model guidance to mitigate threats, assuming proper initialization. Forecast model guidance accuracy depends on the model's ability to resolve initial atmospheric conditions supplied to the model, partly by surface observations, in order to carry them forward to a representative future-state. As models carry initial conditions forward in time, following dynamic equations of motion, they are subject to two types of error growth: internal and external. As discussed by Danforth, "improving the estimate of the state of the atmosphere through assimilation of [accurate] observations" is one method to "tackle internal error growth."[18] It has also been shown that through application of varying techniques, it is possible to "extend [model] forecast skill up to the limits imposed by observation error."[19] Given that the future state of the atmosphere depends entirely on its initial state, misrepresented

[18] Danforth, C., E. Kalnay, M. Takemasa. 2007. "Estimating and Correcting Global Weather Model Error." *American Meteorological Society*, Vol 135, 281.
[19] Ibid, 283.

weather observations can contribute to a model's poor "handling" of weather patterns and subsequent meteorological impacts.

And lastly, weather observations impact strategic operational planning on a long-term scale via climatology. From installation planning and airfield alignment to maximizing effective use of allotted airspace in the Republic of Korea, proper consideration of climatology can have a marked impact on operations. The 14th Weather Squadron (14 WS), U.S. Air Force Combat Climatology Center (AFCCC), has begun the next phase of weather exploitation by developing and generating Climatology Modeling and Prediction (CMAP) products for strategic exploitation of regional climatology. However, as with NWP prediction, long-range climate modeling is only as good as the input data.

***Aircraft Mishaps as a Function of Weather***

In order to assess the significance of AMOS accuracy, a review of aircraft mishaps where weather was a causal factor is provided. According to a study on 235 Class A flight mishaps, 19% were directly attributable to weather and 20% were either directly or indirectly attributable to weather.[20] In terms of impacting weather criteria (i.e. thunderstorms, ceilings, visibility, crosswinds, etc.), visibility accounted for > 50% of the documented mishaps, although it is assumed that other weather criteria may be the primary causal factor in Class B and Class C mishaps. Furthermore, "nearly two-thirds [56%] of all Class A weather related mishaps were judged to be preventable with a perfect weather forecast." Averaged over time, this study purports that "weather related mishaps cause $69 million damage and produce 11 fatalities per year," and are concentrated in the terminal aerodrome or airfield complex.



[20] Cantu, Ruben, *The Role of Weather in Class A Naval Aviation Mishaps FY 90-98,* Naval Postgraduate School Thesis (Monterey, CA), March 2001.

Similarly, "an Air Force Safety Center (AFSC) FY93-02 mishap analysis reported that Class A mishaps resulted in 243 destroyed aircraft, 310 fatalities, and economic losses of $6.23 billion."[21] Of the 243 Class A incidents studied, Spatial Disorientation directly contributed to 25 mishaps, 19 fatalities, 24 aircraft lost, and a cost of over $455 million. Spatial Disorientation, a human condition characterized by lack of spatial awareness, is exacerbated by factors such as night, low illumination, and instrument meteorological conditions (IMC).

## METHODOLOGY

Methodologies of the AMOS and policy evaluations are described in this section.

### *AMOS Evaluation*

In an effort to assess AMOS ceiling and visibility representativeness within the Republic of Korea and to build upon the work done by Cornick, 1791 surface weather observations were compiled over three collection periods from multiple AMOS within the Osan Airbase terminal aerodrome and compared to surface weather observations augmented by a human observer for the same periods. Similar to Cornick, comparisons are conducted on both the total pool of 1,791 observations as well as a smaller pool which discounts fair-weather observations when no significant reportable weather was occurring. This method produces a more realistic assessment of performance. Minor differences were required in the delineation of significant weather, however. Whereas Cornick drew the line with observations that carried a weather-type identifier (i.e. mist, rain, thunderstorms, etc.), this was not practical at Osan Airbase due to the high frequency

[21] Sundstrom, Julia, *Flight Conditions Leading to Class A Spatial Disorientation Mishaps in U.S. Air Force Fighter Operations: FY93-02.* AFIT Thesis (WPAFB, OH), 16 August 2004.

of observed haze. Rather, significant weather is defined as visibility < 5 statute miles (SM) and ceiling < 5,000 feet within each of the three Study Periods.

Data collection includes 740 automated hourly Meteorological Terminal Aviation Routine Weather Reports (METAR) collected by the FMQ-19 for the 30-day period from November 13 to December 12, 2014, 990 METAR observations collected by FMQ-19 and FMQ-23 sensors from June 16 to July 8, 2015, and 61 METAR and non-routine Aviation Selected Special Weather Report (SPECI) observations collected by FMQ-23 and TMQ-53 sensors from 1 December to 2 December, 2015. Weather conditions sampled include clear days with no appreciable weather occurring, cold frontal passages, thunderstorms, rain, snow, fog, mist, and haze.

In the assessment of sky condition, which is composed of cloud cover (i.e. Few, Scattered, Broken, etc.) and cloud height, an assessment was conducted to determine whether the automated sensor produced a hit or a miss. A sky condition hit is any ceiling (lowest broken or overcast cloud layer) positively identified within 1,000 feet of the augmented report for that same time. For example, the AMOS may have indicated broken cloud cover at 8,000 feet (BKN080) while the human observer coded the sky condition as broken at 6,000 feet (BKN060). This was considered a miss for the AMOS since the ceiling was not positively identified within 1,000 feet. Alternatively, the AMOS may have indicated scattered clouds at 5,000 feet (SCT050) while the human observer coded the sky condition as broken at 5,000 feet (BKN050). This was also considered a miss as the ceiling was not positively identified. Similarly, if the AMOS reported broken at 5,000 feet (BKN050) when the augmented observation was reported as scattered at 5,000 feet (SCT050), this was also counted as a miss for that particular sensor.



In the assessment of visibility, as with the assessment of sky condition, a determination of hit versus miss ratio is quantified by comparing the respective AMOS indications of visibility to those reported by the human observer. A hit for visibility is defined by a visibility assessed within one "reportable value," as defined by AFMAN 15-111 and shown in Figure 1.[22] Reportable values range from less than 1/8 SM (M1/8SM or M0200 meters) to ten SM (10SM or 9999 meters) with 28 total reportable visibility values/categories. For example, if the AMOS indicated a visibility of 5 SM, but the observer reported 4 SM, this would be considered a hit since the visibility was assessed by the AMOS within one reportable value. Alternatively, visibility assessed by the AMOS as 1 SM which was coded by the observer as 2 SM would be a miss as this is 8 reportable categories off per Figure 1. Through this process, each AMOS visibility report was assigned a number corresponding to reportable categories off so that a fuller understanding of performance could be achieved.



**Figure 1. Current Reportable Visibility Values**

| **Reportable Visibility Values** | | | |
|---|---|---|---|
| M1/8 SM(*)<br>(M0200) | 7/8 SM(*)<br>(1400) | 1 3/4 SM<br>(2800) | 4 SM<br>(6000) |
| 1/8 SM(*)<br>(0200) | 1 SM<br>(1600) | 1 7/8 SM(*)<br>(3000) | 5 SM<br>(8000) |
| 1/4 SM<br>(0400) | 1 1/8 SM(*)<br>(1800) | 2 SM<br>(3200) | 6 SM<br>(9000) |
| 3/8 SM(*)<br>(0600) | 1 1/4 SM<br>(2000) | 2 1/4 SM(*)<br>(3600) | 7 SM<br>(9999) |
| 1/2 SM<br>(0800) | 1 3/8 SM(*)<br>(2200) | 2 1/2 SM<br>(4000) | 8 SM<br>(9999) |
| 5/8 SM(*)<br>(1000) | 1 1/2 SM<br>(2400) | 2 3/4 SM(*)<br>(4400) | 9 SM<br>(9999) |
| 3/4 SM<br>(1200) | 1 5/8 SM(*)<br>(2600) | 3(**) SM<br>(4800) | 10 SM<br>(9999) |

***Policy Evaluation***

In this evaluation, current policy is explored to identify AMOS contributions to flight safety and any direct or indirect contributions to flight risk. The hierarchy of U.S. Air Force

[22] AFMAN15-111, 39.

Weather policies, instructions, and directives, from Air Force Policy Directive (AFPD) 15-1, *Air Force Weather Operations*, Air Force Manual (AFMAN) 15-129 Volume 2, *Air and Space Weather Operations – Exploitation*, and 51st Fighter Wing Instruction (FWI) 15-101, *Weather Support to the 51st Fighter Wing*, were examined along with AFMAN 15-111, *Surface Weather Observation*, The Federal Meteorological Handbook No. 1 (FMH-1), *Surface Weather Observations and Reports*, and the World Meteorological Organization (WMO) *Manual on Codes*, Volume I.1, Part A (WMO 306, Vol I.1, Part A) which are specific to AMOS implementation.

These policies are explored through an Operational Risk Management (ORM) lens as detailed in Air Force Instruction (AFI) 90-802, *Risk Management*. Specifically, this exploration seeks to identify any "unnecessary risk," and whether policy promotes "risk decisions at the appropriate level."[23]



## RESULTS

This section details the results of the AMOS and policy evaluations.

### *AMOS Evaluation*

The results confirm that a substantial margin of variance exists, not only between AMOS reports and human-augmented reports, but also between various AMOS models. Overall AMOS performance inclusive of ceiling and visibility is assessed with 58% hits on average, ranging from 19.2% to 82.9% for individual AMOS sky condition and visibility sensors. The overall results of each Study Period are broken down by AMOS model and sensor type in Table 1.

**Table 1. Hit Rates (Total Pool)**

[23] Air Force Instruction (AFI) 90-802, *Risk Management*, 23 March 2015, preface memorandum.

| Total Pool | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ASOS | | FMQ-19 | | FMQ-23 | | TMQ-53 | |
| | CIG | VIS | CIG | VIS | CIG | VIS | CIG | VIS |
| Cornick | 92.7% | 93.7% | | | | | | |
| Study Period 1 | | | 78.3% | 82.0% | | | | |
| Study Period 2 | | | 60.5% | 64.2% | 70.1% | 59.5% | | |
| Study Period 3 | | | | | 82.9% | 25.7% | 69.2% | 19.2% |
| **Average** | **92.7%** | **93.7%** | **69.4%** | **73.1%** | **76.5%** | **42.6%** | **69.2%** | **19.2%** |

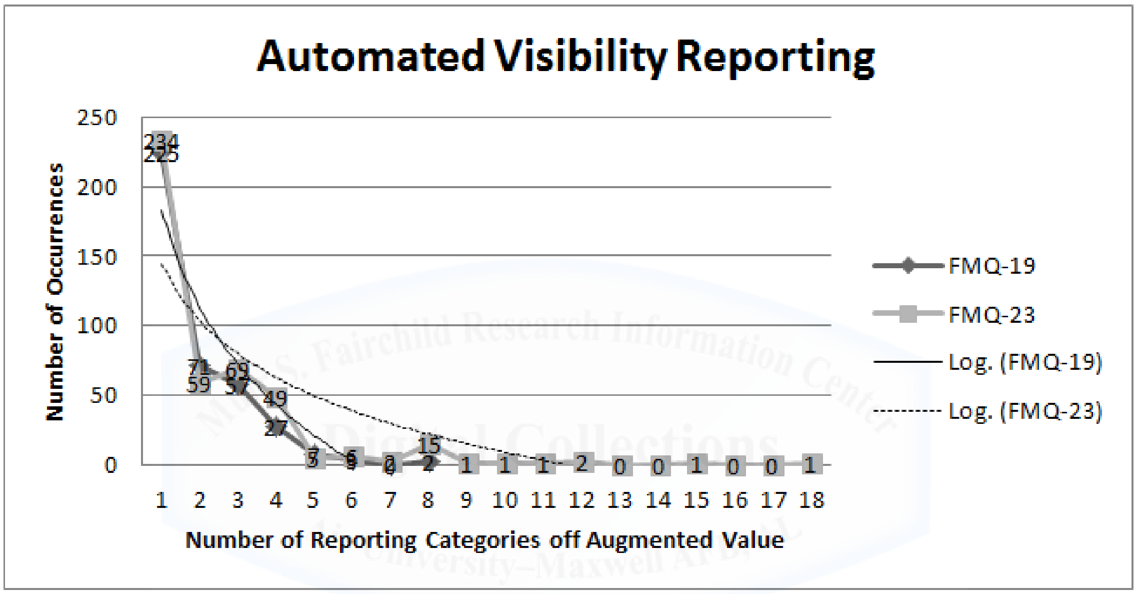
As with Cornick, a notable decrease in AMOS performance on the order of 23.5% was assessed when fair weather observations were removed from the total pool. One out of six sensors was assessed to perform better during inclement weather, the TMQ-53 visibility sensor, by a margin of 0.8%. This data is broken down by AMOS model and sensor type in Table 2.

**Table 2. Hit Rates (Fair Weather Removed)**

| Significant Weather Occurring | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ASOS | | FMQ-19 | | FMQ-23 | | TMQ-53 | |
| | CIG | VIS | CIG | VIS | CIG | VIS | CIG | VIS |
| Cornick | 76.0% | 60.8% | | | | | | |
| Study Period 1 | | | 66.7% | 52.0% | | | | |
| Study Period 2 | | | 18.0% | 18.5% | 39.0% | 11.7% | | |
| Study Period 3 | | | | | 73.9% | 4.4% | 46.7% | 20.0% |
| **Average** | **76.0%** | **60.8%** | **42.4%** | **35.3%** | **56.5%** | **8.1%** | **46.7%** | **20.0%** |

The additional reportable categories off data assigned to visibility reports as described in the *Methodology* allowed for a more in-depth assessment of AMOS visibility performance. In Study Period 2, 45% of FMQ-19 and FMQ-23 visibility observations were assessed a miss. The FMQ-19 visibility sensor's largest recorded miss was 8 categories off with 2 occurrences. The FMQ-23 on the other hand recorded misses up to 12 categories off with outliers at 15 and 18 categories off. The FMQ-23 also experienced a spike at 8 categories off with 15 occurrences. This data is presented visually in Figure 2. With trend-lines applied to the data, it is apparent that the FMQ-19 visibility sensor was more representative through this trial period. The FMQ-23's 15 occurrences of 8 categories off appear causal in this sensor's shallow trend-line. Interestingly, 13 of these 15 occurrences were due to the FMQ-23 reporting 7 SM visibility while the augmented observation was reported as 2 SM, highlighting a trend of over-reporting visibility with the FMQ-23. One other trend identified during this particular study was for the FMQ-19 to report clear skies (CLR) when cloud layers were present.

**Figure 2. Automated Visibility Reporting Performance (Study Period 2)**

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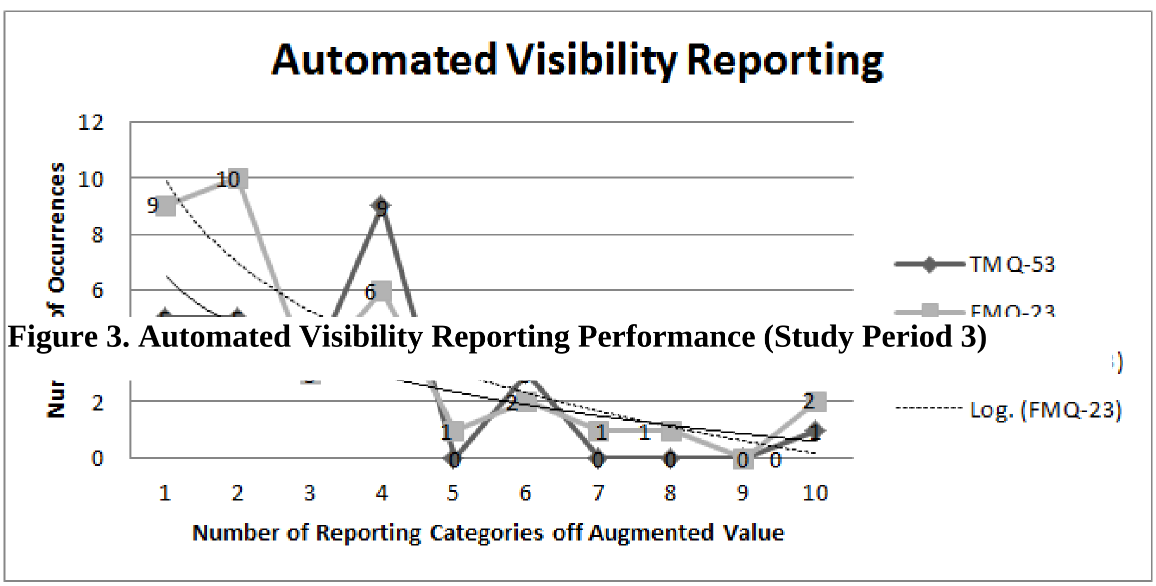


**Figure 3. Automated Visibility Reporting Performance (Study Period 3)**

Approaching data differently, AMOS visibility hits during Study Period 2 with fair weather observations removed were assessed 15% of the time on average, and cumulative AMOS performance topped 85% by 4 reportable categories off as presented in Table 3.

**Table 3. Automated Visibility Reporting Performance (Study Period 2)**

| 16 June - 8 July 2015 Collection Period // VIS with Fair Weather Removed | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | | 0 | % | 1 | % | 2 | % | 3 | % | 4 | % |
| 205 | FMQ-19 | 13 | 6.3% | 25 | 18.5% | 71 | 53.2% | 57 | 81.0% | 27 | 94.1% |
| 239 | FMQ-23 | 9 | 3.8% | 19 | 11.7% | 59 | 36.4% | 69 | 65.3% | 49 | 85.8% |

***Policy Evaluation***

U.S. Air Force policy on surface weather observation directs that weather personnel operating airfield services perform two primary functions. The first is to observe the weather via acting as "eyes-forward" for centralized forecasting hubs which are responsible for regional Terminal Aerodrome Forecasts (TAF) and the issuance of most Watches, Warnings, and Advisories (WWA), and the second is to exploit the weather.[24] These two functions are in competition for the weather technician's time and attention, especially while mission impacting weather is occurring, as evidenced by the need for published duty priorities which detail the precedence of tasks. Generally, exploitation is prioritized higher than augmentation of weather observations.[25]

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[24] Air Force Policy Directive 15-1. *Air Force Weather Operations*, 12 November 2015, 2.
[25] AFMAN15-129V2, 8.

These two fundamental roles of the weather technician to observe and to exploit the weather were abundantly clear from the highest directive, AFPD 15-1, to AFMAN 15-129V1, and even down to wing-level policy.[26] The importance of the surface weather observation is well-captured and consistent throughout these documents. An apparent break in consistency presents itself, however, in U.S. Air Force policy specific to weather observation. AFMAN 15-111, *Surface Weather Observations*, is the authoritative source document for "basic observing fundamentals" and codes.[27] This policy directs that "Automated Meteorological Observing Systems (AMOS) will be operated in full automated mode, at Department of Defense (DoD) controlled airfields, to provide the official METAR and SPECI observations," except for conditions "that would adversely impact flight/ground operations based on documented supported unit requirements."[28] This publication breaks step with other policies reviewed in that it passively defaults to automated observation when no documented end-user requirement for augmentation supersedes the policy. This presses the decision to augment AMOS down to the lowest level where individual exploitation unit leadership must determine mission-impacting augmentation criteria. This stance has resulted in an unknown number of unit-specific policies as well as consternation by end-users regarding what constitutes a "valid observation."[29]

Upon review of the Federal Meteorological Handbook No. 1 (FCM-H1) and the World Meteorological Organization (WMO) Manual on Codes, two source documents from which the 15-111 cites source data, there is no indication that a default to automation is a Federal or WMO

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[26] AFPD 15-1, 2
[27] AFMAN 15-111, 1.
[28] AFMAN15-111, 9, 20.
[29] Col Danny R. Wolf, Operations Division Chief, to SEE DISTRIBUTION, memorandum, subject: PACAF Weather Observation Policy Memorandum, 10 September 2012, see attachment 2.7.2.1.

standard.  Rather, other concerns in automation are highlighted.  Thunderstorms, for example, "shall be reported when observed to begin," and this determination can be based on "lightning…detected by an automated sensor," yet AMOS lighting detection sensors have known limitations.[30]  Through the ORM lens, and based on the results of the AMOS evaluation above, it appears some unnecessary risk may be assumed by the U.S. Air Force through the employment of AMOS in full-automated mode where the capability exists to augment these systems.

## DISCUSSION OF THE RESULTS

Evaluation considerations worthy of further discussion are presented in this section.

### *AMOS Evaluation*

Issues including sample size, Republic of Korea air quality, sensor configurations, observer-to-sensor bias, and the lack of SPECI observations in the first two data collections are noteworthy shortfalls in the methodology of this study.  The total sample size of 1,791 is small when compared with Cornick's 64,000 observation pool, and air quality variables specific to the Republic of Korea present unique, above-average concentrations of aerosol and other pollutant lithometeors which cannot be applied across all U.S. Air Force operating locations.  On sensor configuration, it was not feasible for the collection sensors to be co-located in the exact same location.  The two FMQ-19 ceilometers were fixed approximately 75 feet from FMQ-23 ceilometers and approximately 500 feet from the single TMQ-53 ceilometer.  Given the purpose of Discontinuity group sensors presented above, this discrepancy has some impact on the final results

[30] Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM), Federal Meteorological Handbook No. 1 (FMH-1), Surface Weather Observations and Reports (Washington, DC), September 2005, 8-7.

when comparing the outputs of each respective sensor. Observer-to-sensor bias refers to the tendency of an observer to utilize sensor output on cloud height when no other data was available. Real-time AMOS data was available to the observer throughout each collection period and was considered by the observer during the augmentation process. Therefore, automated data influenced the vast majority of human-augmented observations of sky condition where no Pilot Reports (PIREPS) were available. And lastly, the exclusion of SPECI observations from the first two data collections is significant to the presentation of final results since an unknown number of additional observations were generated during inclement weather conditions. Extrapolating the trend in representativeness from total pool to the smaller, weather occurring pool suggests that the numbers presented here are optimistic for all-inclusive AMOS performance. All shortfalls considered, this study presents a useful basis from which to consider AMOS representativeness.

Additionally, the 28 reportable visibility values (Figure 1) differ from the 16 utilized by Cornick (Figure 4). For example, Cornick's visibility categories are divided in 1/4 SM increments below 1 SM, whereas today's standard is 1/8 SM increments below 1 SM. This accounts for an apparent dec [illegible] en compared to the legacy ASOS, [illegible] nt criteria.

| Conventional Range | ASOS Range[1] | Category in this Study |
|---|---|---|
| 0.00 - 0.24 | <0.25 | Cat 1 |
| 0.25 | 0.25 | Cat 2 |
| 0.26 - 0.50 | 0.50 | Cat 3 |
| 0.55 - 0.75 | 0.75 | Cat 4 |
| 0.80 - 1.00 | 1.00 | Cat 5 |
| 1.05 - 1.25 | 1.25 | Cat 6 |
| [illegible] | [illegible] | Cat 7 |
| 1.55 - 1.75 | 1.75 | Cat 8 |
| 1.80 - 2.00 | 2.00 | Cat 9 |
| 2.05 - 2.50 | 2.50 | Cat 10 |
| 2.55 - 3.00 | 3.00 | Cat 11 |
| 3.05 - 3.50 | 3.50 | Cat 12 |
| 3.55 - 4.00 | 4.00 | Cat 13 |
| 5.00 - 6.00 | 5.00 | Cat 14 |
| 7.00 - 9.00 | 7.00 | Cat 15 |
| 10.00 - 10.0+ | 10+ | Cat 16 |

**Figure 4. Cornick's Reportable Visibility Values (Reprinted from Cornick, Jon. "A Comparison of Ceiling and Visibility Observations for NWS Manned Observation Sites and ASOS Sites." Colorado State University, 1993, 31.**

## RECOMMENDATIONS

Recommendations to minimize unnecessary risk, ensure risk decisions are made at the appropriate level, and maximize AMOS utility with minimal resource expenditure are discussed in this section.

***Policy***



Surface weather observations pose impacts to operations as discussed above, and AMOS limitations have the potential to magnify those impacts. In the interest of maximizing weather exploitation, recommendations include a fundamental change in the U.S. Air Force's approach to surface weather observation. Operational impacts can be minimized by injecting the weather technician actively into the problem of AMOS accuracy rather than passively defaulting to automation and settling for the resulting data quality. Specifically, recommend the verbiage in AFMAN 15-111, *Surface Weather Observations*, be amended to direct weather technicians to augment AMOS ceiling and visibility reports where the capability exists in order to minimize unnecessary risk.

Some may counter that this change would remove the Risk Management decision from the appropriate level; however, consider the broader impacts of surface weather observation on NWP models. The U.S. Air Force announced in November, 2014 the decision to transition all

NWP modeling efforts into the Unified Model (UM) of the United Kingdom Met Office (UKMO) in an effort to promote globalized weather forecasting.[31] The potential benefits in terms of "successfully bring[ing] in data from different sources" with its "proven data assimilation package" prompts now as an opportune time for the U.S. Air Force to re-address its stance on surface weather observation to the desired outcome of maximizing the capability and accuracy of this new, authoritative model.[32] As detailed by Danforth above, internal error growth is one limitation of NWP guidance that the U.S. Air Force can take an active role in minimizing through effective observation policy. Not only would this renewed approach improve usefulness of product, but it would also promote the weather technician's connection with the atmosphere, a state-of-the-art skill threatened by excessive reliance on technology.



***The Future of AMOS***

In planning the next generation of AMOS toward the goals of improving data accuracy and operational safety and maximizing the weather technician's ability to exploit the weather through improved NWP reliability while minimizing resources, the following recommendations are provided. First, based on the wide variability of performance of respective AMOS systems, it is recommended that the U.S. Air Force program for surface weather observation validate the value of a base-line AMOS which could be maintained by the weather technician in order to quantify manpower and cost savings potential. When considering the implications of an AMOS overhaul of this magnitude, it becomes apparent that this endeavor would best be implemented

[31] Samenow, Jason. "Air Force's plan to drop U.S. forecast system for U.K. model draws criticism." The Washington Post. 20 April 2015, 1.
[32] Samenow, Jason. "Air Force's plan to drop U.S. forecast system for U.K. model draws criticism." The Washington Post. 20 April 2015, 1.

nationally through the National Weather Service, or even internationally among coalition partners in order to set a World Meteorological Organization (WMO) standard which could be adopted for the betterment of globalized Numerical Weather Prediction (NWP) initialization and forecasting.

In terms of cost savings to the U.S. Air Force, the advantages of a full-scale baseline across both tactical and fixed systems are numerous. While fixed systems may still incorporate more substantial infrastructure (i.e. concrete pads, masts, and communications), the visibility sensor, for example, utilized on the next-generation fixed AMOS should be the same sensor employed on the next-generation TMOS, maximizing economies of scale. Additionally, pulling lessons learned from years of tactical TMQ-53 operation and maintenance, it has been verified that weather technicians are capable of maintaining their own equipment under the proper construct. The TMQ-53 utilizes a plug-and-play service methodology which is both troubleshot and fixed by the weather technician via communicating with a centralized help-desk. Applying this model to the entire AMOS inventory could allow a number of ATCALS billets to be retrained to weather flights or removed all-together at a substantial cost savings. AMOS replacement costs under a base-line construct would also be cut substantially. Today, when an ASOS or FMQ-19 is replaced, an entirely new system consisting of new concrete pads, new masts/towers, and new sensors is installed. A base-line would allow for incremental hardware improvements to be fielded utilizing the same plug-and-play methodology, re-utilizing existing infrastructure.

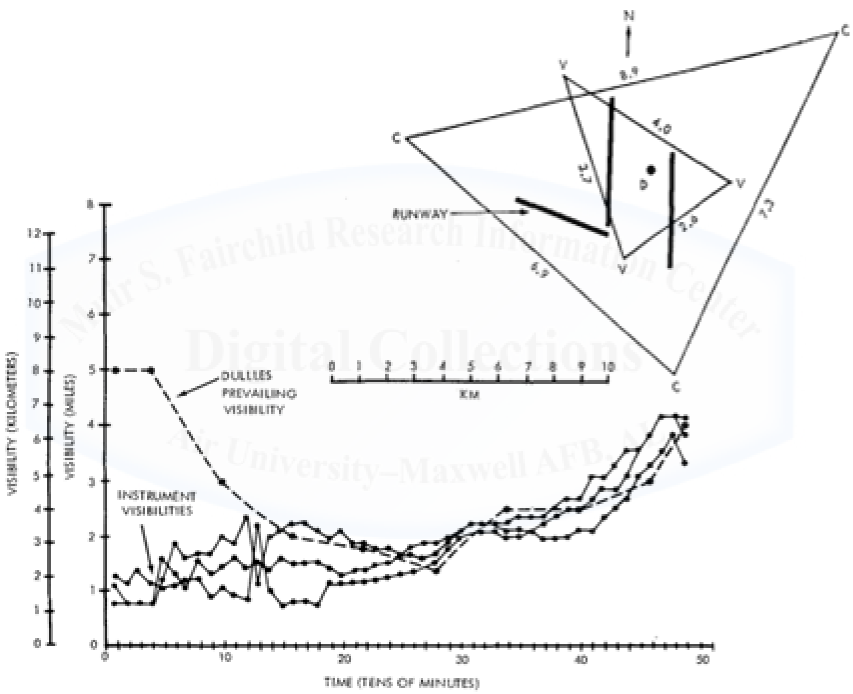
U.S. Air Force Weather is actively pursuing a software baseline which is a significant step forward in consolidating and simplifying the plethora of algorithms supplied with each AMOS down to one base-line algorithm. The benefits of this endeavor include centralizing algorithm development and support away from multiple contracts and may offer cost savings and improved performance of currently fielded systems. While AMOS software algorithms are required to conform to federal standards,[33] engaging weather flight staffs for specific tailoring of algorithms to the local environment, as in the Republic of Korea, may further improve accuracy of fielded systems. Furthermore, this centralized software effort is significant as it is a mandatory precursor to a hardware base-line, should the U.S. Air Force adopt this as a COA.

Even more savings stand to be gained upon a successful hardware base-lining by simplifying sensors and increasing competition among contracts for individual sensors rather than entire AMOS systems. Handheld sensors used for backup operations cost $250 off the shelf and can measure/report barometric pressure, temperature, dew-point, relative humidity, and wind speed, among other readings. These handhelds are not as survivable as an AMOS or TMOS, but demonstrate the point that simple, inexpensive alternatives exist. This competition may also promote innovation which rivals current sensor-types. In the past, for example, a more expansive areal visibility set was utilized as opposed today's basketball-sized sensing volume. Figure 5 demonstrates such a layout previously tested at Dulles International, where the triangle (V) represents the placement of visibility emitting/collecting points and the three bold lines indicate Dulles' three runways. This coverage resulted in impeccable handling of fog as seen in the corresponding scatter-plot.[34] Re-adopting this old idea at Osan Airbase, for example, by utilizing

[33] FMH-1, 2-4.
[34] Mandel, Eric. 1975. "An Early Look at the Development of an Unmanned Automated Surface Aviation Weather Observation System." *Bulletin American Meteorological Society*, Vol 56, No 9, September 1975, 980. Note: The discrepancy between sensor and observer in the initial 100 minutes of the scatterplot is due to the observer's heightened vantage point with this being a ground-fog development scenario. Therefore this discrepancy can be discounted.

existing FMQ-23 infrastructure which spans nearly the entire length of the parallel runways would expand areal coverage and representativeness in limited visibility scenarios.

**Figure 5. Visibility Sensor Performance with Increased Areal Coverage (Reprinted from Mandel, Eric. 1975. "An Early Look at the Development of an Unmanned Automated Surface Aviation Weather Observation System."** ***Bulletin American Meteorological Society*****, Vol 56, No 9, September 1975, 980.**





Finally, despite their many benefits, there is currently no AMOS which can serve as a full replacement for the senses of a trained human observer. Weather flights and detachments are not currently manned for augmented or manual observation based on current policy; however, practical experience and the data above indicate a necessity to produce augmented observations in order to mitigate risk and improve data quality for NWP models. While manpower cuts have been the recent trend, it is recommended that weather flights be manned to maximize weather exploitation of their supported units.

## CONCLUSIONS

The role of the U.S. Air Force Weather technician has evolved substantially as technology has been integrated into warfighting. In theory, the current surface weather observing construct has enabled a shift in focus from collection to exploitation of weather data in support of military operations. However, numerous indications highlight the fact that AMOS alone is not sufficient to support exploitive, real-time operations without a human observer in the loop.[35] The result is a weather observing construct built on optimistic expectations of AMOS accuracy which suffers from the limitations of these systems and undermines the fundamental goal of the weather technician: to positively impact mission success by enabling the war-fighter to exploit the weather. It is vitally important to habitually test/validate methods under which we operate and re-check course considering not only current operations but past lessons and future requirements. The results presented above in this quantified form are concerning, but they also present opportunities for improvement. It seems minor adjustments to course with respect to surface weather observation policy will promote habitual sharpening of the U.S. Air Force's weather exploitation edge, a necessity required to defeat a true adversary.

[35] Lt Gen Tod D. Wolters, Deputy Chief of Staff, Operations, to MAJCOM/CVs, memorandum, subject: Augmentation of Airfield Automated Weather Observation Systems, 16 April 2015.

## APPENDIX 1 – Terms and Definitions

**Augment** or **Augmentation –** The process by which a human observer supplements an observation generated by an AMOS.

**Automated Meteorological Observing System (AMOS) –** An umbrella term which refers to all automated surface weather observing systems.

**Automated Surface Observing System (ASOS) –** An early model of AMOS developed by the National Weather Service.

**Ceiling –** The lowest broken or overcast cloud layer as viewed from the ground.

**Celestial Dome –** The part of the sky visible to an observer from the official observation point.

**Initialization –** A term which refers to the initial condition of a forecast model. A model which has initialized accurately can be given more confidence in its future guidance.

**Numerical Weather Prediction (NWP) or Forecast Model –** Refers to computer forecast models such as the Global Air Land Exploitation Model (GALWEM).

**Sky Condition –** An assessment of the height and coverage of clouds.

**Tactical Meteorological Observing System (TMOS) –** A deployable version of the AMOS.

**Terminal Aerodrome Forecast (TAF) –** A point-based forecast for a specific airfield complex such as Osan Airbase.

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