RESPONSE TO REQUEST FOR INFORMATION
BY
THE OFFICE OF SCIENCE AND TECHNOLOGY POLICY

WITH REGARD TO THE
NATIONAL PLAN FOR CIVIL EARTH OBSERVATIONS

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Prepared for the
Office of Science and Technology Policy
1650 Pennsylvania Avenue NW.
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BACKGROUND

In response to your RFI concerning a National Plan for Earth Observations, Panasonic Weather Solutions (PWS) offers this overview of its TAMDAR atmospheric observing system, which has direct application for most of the Societal Benefit Areas (SBAs) identified in the RFI. TAMDAR has been fully operational since 2004.

Some of the policy questions in the RFI are beyond the scope of PWS core competence; "*n.a.*" is entered where we believe our expertise is not applicable. These responses will be followed by general information about the TAMDAR observing system.

RFI QUESTIONS AND RESPONSES

1. Are the 12 SBAs listed above sufficiently comprehensive?

n.a.

a. Should additional SBAs be considered?

n.a.

b. Should any SBA be eliminated?

n.a.

2. Are there alternative methods for categorizing Earth observations that would help the U.S. Government routinely evaluate the sufficiency of Earth observation systems?

n.a.

3. What management, procurement, development, and operational approaches should the U.S. Government employ to adequately support sustained observations for services, sustained observations for research, and experimental observations? What is the best ratio of support among these three areas?

We believe the majority of available support should be given to cost-effective operational observing systems with documented public benefits. Research observations should come after this, and then experimental observations.

4. How should the U.S. Government ensure the continuity of key Earth observations, and for which data streams (e.g., weather forecasting, land surface change analysis, sea level monitoring, climate-change research)?

Long-term contracting is the best assurance for data quality and continuity. Data streams should be *evaluated for effectiveness, demonstrable value and sustainability, and permanent funding should be allocated to those with most favorable cost/benefit ratios.*

5. Are there scientific and technological advances that the U.S. Government should consider integrating into its portfolio of systems that will make Earth observations more efficient, accurate, or economical? If so, please elaborate.

We believe the TAMDAR atmospheric observing network described below is one such technological advance, given its proven impact in multiple areas:

-Immediate, significant improvement in all forecast model skill

-TAMDAR provides improved quality control of satellite data, thereby increasing the impact of satellite data

-In-situ TAMDAR data supports a host of important industries from aviation to renewable energy

This data is readily available but is not currently being acquired by the U. S. Government.

6. How can the U.S. Government improve the spatial and temporal resolution, sample density, and geographic coverage of its Earth observation networks with cost-effective, innovative new approaches?

The TAMDAR atmospheric observing system is a new approach that can provide superior spatial and temporal resolution, density and geographic coverage without significant Government investment in infrastructure. Approximately $100 M and 15 years of development/ validation time has been invested, eliminating the need for government investment and a decade of R&D.

7. Are there management or organizational improvements that the U.S. Government should consider that will make Earth observation more efficient or economical?

Contracting with the private sector for Earth observation data is a cost-effective solution that is available immediately, with no increase in Government capital expense and modest operating expense.

8. Can advances in information and data management technologies enable coordinated observing and the integration of observations from multiple U.S. Government Earth observation platforms?

Panasonic Weather Solutions is managing and integrating observations from multiple global and regional observing systems now. These techniques are scalable and can be extended PWS and others.

9. What policies and procedures should the U.S. Government consider to ensure that its Earth observation data and information products are fully discoverable, accessible, and useable?

Establish a policy of consistent, predictable funding for cost-effective observation and information sources both public and private, to ensure their sustainability.

10. Are there policies or technological advances that the U.S. Government should consider to enhance access to Earth observation data while also reducing management redundancies across Federal agencies?

Expand public-private partnerships that push data management to the private sector and establish an intra-agency authority to create standards and coordinate capabilities to reduce redundancy.

11. What types of public-private partnerships should the U.S. Government consider to address current gaps in Earth observation data coverage and enhance the full and open exchange of Earth observation data for national and global applications?

The data is available now and is intended to be used by the global community (government and commercial) to improve productivity of commerce, and the improved safety of people and property. If the U.S. government wants to make this data available through one of its agencies, PWS is open to engaging in this dialogue

12. What types of interagency and international agreements can and should be pursued for these same purposes?

If the economics support allowing the data to be shared publicly PWS is open to this strategy. Per point 11. above, TAMDAR has been developed to support the global community, and PWS continues to aggressively expand the TAMDAR observing system throughout the world. The investments are sizable, and life cycle system and data management demanding. PWS believes the most efficient strategy is "one global system" versus regional competing systems, since a global system can provide consistency in data quality and bias/errors, making it easier to use with confidence. Additionally, it is more economical to have "one" end-to-end global data management system than a network of regional systems.

The TAMDAR System

Since the first use of the radiosonde (weather balloon) in 1937, the U.S. government has grown to depend on a small network of these devices as the backbone of our nationwide weather forecasting system. The resulting legacy program has been the bedrock of meteorological forecasting ever since. The efficacy of the program is inherently limited, however, by the number of daily balloon launches and their enormous geographic displacement (each of the 69 weather balloons covering approximately 45,000 square miles).

Over the past ten years, Panasonic Weather Solutions (formerly AirDat LLC), a private company, has pioneered a state-of-the-art system designed to greatly enhance both the radiosonde and satellite programs. Observations collected by a multi-function in-situ atmospheric sensor on commercial aircraft, called the Tropospheric Airborne Meteorological Data Reporting (TAMDAR) sensor, contain measurements of humidity, pressure, temperature, winds aloft, icing, and turbulence, along with the corresponding location, time, and altitude from built-in GPS are relayed via satellite in real-time to a ground-based network operations center. One crucial component of NextGen is the integration of more accurate products, as the paradigm shifts to a more probabilistic approach. The network of TAMDAR sensors meets the future integration enhancements and operational needs of NextGen Weather Concept of Operations (CONOPS), but is operational today.

TAMDAR supplements the well-documented shortage in RAOB data by using airborne aircraft as platforms for capturing real-time, high resolution atmospheric observations. With a significantly higher resolution meteorological data set, TAMDAR fills the spatial and temporal "data gaps", thereby producing a more reliable weather forecast and predictive capability. The result is a new tool set for managing the NAS in ways that illustrate the most basic concept behind NextGen (i.e., the use of satellite-positioned aircraft as nodes in a broad, dynamic and data-dense network).

In April 2013, the TAMDAR network and related system was acquired by Panasonic Avionics Corporation (PAC). Within the Panasonic organization, the former AirDat operates under the name Panasonic Weather Solutions (PWS). When current contracted installations are completed, more than 7000 daily soundings will be produced globally at more than 450 locations. Additional expansion is underway in the Antilles, Iceland, Central America, the Middle East, the Far East and the Central/Western US as well as expanded European coverage. *Emphasis has been placed on regional carriers where possible, as these tend to (i) fly into more remote and diverse locations, and (ii) make shorter flights that produce more daily vertical profiles (soundings) and remain in the boundary layer for longer durations.*

Engineering Development Background

In response to a government aviation safety initiative, NASA, in partnership with the FAA and NOAA, sponsored the early development and evaluation of a proprietary multi-function in-situ atmospheric sensor for aircraft. AirDat LLC, now PWS, located in Morrisville, North Carolina, was formed to develop and deploy the TAMDAR system based on requirements provided by the Global Systems Division (GSD) of NOAA, the FAA, and the World Meteorological Organization (WMO).

TAMDAR sensors can be installed on most fixed-wing aircraft from large commercial airliners to small unmanned aerial systems (UAS), where they continuously transmit atmospheric observations via a global satellite network in real time as the aircraft climbs, cruises, and descends. The TAMDAR sensor (pictured on an ERJ-195, Figure 1) offers a broad range of airborne meteorological data collection capabilities, as well as icing and turbulence data that is critical to both aviation safety and operational efficiency.

In addition to atmospheric data collection, the customizable system can also provide continuous GPS aircraft tracking, a global satellite link for data, text and voice communication, real-time TAMDAR-augmented forecast products, mapping of icing, turbulence and winds aloft, a multi-function antenna for both satellite communications and GPS, and the ability to integrate satcom with Electronic Flight Bags (EFBs) for potential display of cockpit weather.

TAMDAR observations not only include temperature, pressure, winds aloft, and relative humidity (RH), but also icing and turbulence. Additionally, each observation includes GPS-derived horizontal and vertical (altitude) coordinates, as well as a time stamp to the nearest second. With a continuous stream of observations, TAMDAR provides much higher spatial and temporal resolution compared to the Radiosonde (RAOB) network, as well as better geographic coverage, and a more complete data set than Aircraft Communication Addressing and Reporting System (ACARS), which lacks RH, icing, and turbulence.

Current upper-air observing systems are also subject to large latency based on obsolete communication networks and quality assurance protocol. TAMDAR observations are typically received, processed, quality controlled, and available for distribution or model assimilation in less than one minute from the sampling time. The sensor requires no flight crew involvement; it operates automatically, and sampling rates and calibration constants can be adjusted by remote command from the PWS operations center in Morrisville, NC.

Figure 1. The TAMDAR sensor (left) and as installed on aircraft (right)

Icing Observations

PWS icing data provides the first high volume, objective icing data available to the airline industry. Ice reporting is currently performed via pilot reports (PIREPs); while helpful, these subjective reports do not provide the accuracy and density required to effectively manage increasing demands on the finite airspace. High-density real-time TAMDAR icing reports fill this information void, creating a significantly more accurate spatial and temporal distribution of icing hazards, as well as real-time observations where icing is not occurring. The icing data can be viewed in raw observation form, or it can be used to improve icing potential model forecasts.

Turbulence Observations

The TAMDAR sensor provides objective high-resolution eddy dissipation rate (EDR) turbulence observations. These data are collected for both median and peak turbulence measurements and are capable of being sorted on a much finer (7-point) scale than current subjective pilot reports (PIREPs), which are reported as light, moderate, or severe. The EDR turbulence algorithm is aircraft-configuration and flight-condition independent. Thus, it does not depend on the type of plane, nor does it depend on load and flight capacity.

This high-density real-time in-situ turbulence data can be used to alter flight arrival and departure routes. It also can be assimilated into models to improve predictions of threatening turbulence conditions, as well as being used as a verification tool for longer-range numerical weather prediction (NWP)-based turbulence forecasts. As with the icing observations, potential utility of this data in air traffic control decision making for avoidance and mitigation of severe turbulence encounters is extremely significant.

The screenshot from PWS' AirMap tool in Figure 2 (next page) shows aircraft in the vicinity of New York City and their respective TAMDAR observations. Holding the mouse over a flight produces a "call out" of the most recent observations. This particular flight is currently reporting no icing or turbulence at a pressure altitude of 11,220 ft and GPS altitude of 11,920 ft. The relative humidity is 100%, and the temperature is 5.0°C with a wind speed of 22 kts at 261°, and a ground speed of 252 kts. Other TAMDAR-equipped planes can be seen lined up on the taxiway at LGA, while approach and takeoff patterns are visible for both LGA and JFK.

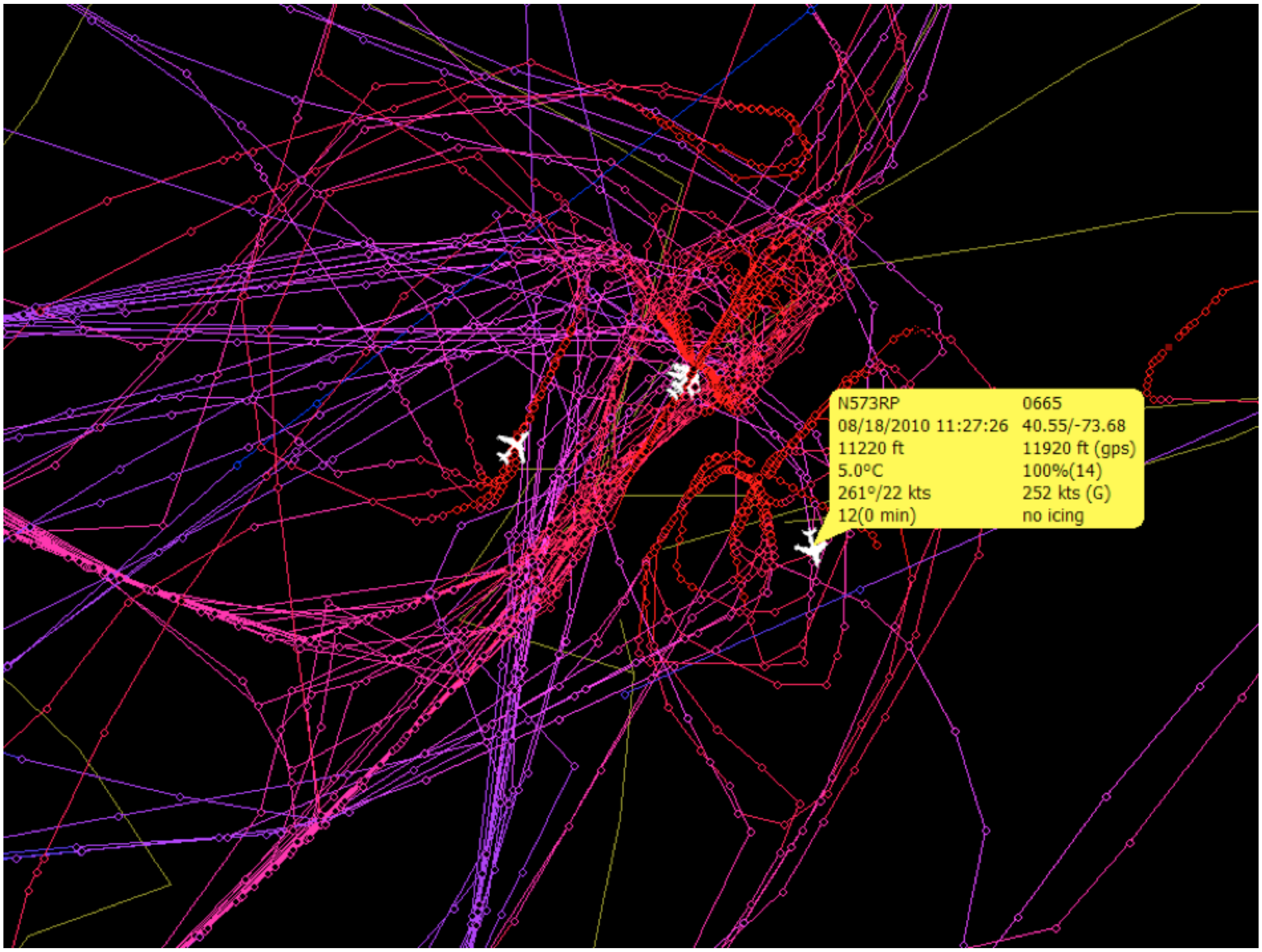

Figure 2. Example Of A TAMDAR Point Observation From Flight Out Of LGA. Other Planes Can Be Seen On The LGA Taxiway, While Approaches To LGA And JFK Are Also Visible.

The TAMDAR sensor, combined with the PWS satellite communications network, data center, quality filtering algorithms, and atmospheric modeling, provides unique operational benefits for participating airlines. Some of these benefits include real-time global tracking and reporting of aircraft position, real-time delivery of aircraft systems monitoring data, and airline operational support such as automated Out-Off-On-In (OOOI) times and satcom voice communications.

The TAMDAR installation includes a multi-function antenna, which can be used for receiving cockpit weather display information, as well as transmitting or receiving text messaging, email, aircraft data, and satellite voice communication to and from the cockpit and cabin to the ground and back. Since the communication link is satellite based, the coverage is global and seamlessly functional for any location and altitude with a sub-60 second latency. Since TAMDAR is independent of the existing aircraft communication systems, it offers additional layers of redundancy, as well as carrier-defined data stream flexibility.

Forecast Models and Validation

Numerous third-party studies have been conducted by NOAA-GSD, the National Center for Atmospheric Research (NCAR), and various universities, to verify the accuracy of TAMDAR against weather balloons and aircraft test instrumentation, as well as quantifying the TAMDAR-related impacts on NWP (e.g., Benjamin et al. 2010; Moninger et al. 2010; Gao et al. 2012). Ongoing data denial experiments show that the inclusion of TAMDAR data can significantly improve forecast model accuracy with the greatest gains realized during more dynamic and severe weather events.

Upper-air observations are the single most important data set driving a forecast model. Fine-scale regional forecast accuracy is completely dependent on a skillful representation of the mid and upper-level atmospheric flow, moisture, and wave patterns. If these features are properly analyzed during the model initialization period, then an accurate forecast will ensue.

Forecast models that employ a 3-D variational assimilation technique (3D-Var or GSI), which weights observations based on their observed time are limited in their ability to extract the maximum value from a high resolution asynoptic data set. This method greatly reduces the effectiveness of observations not taken at the precise synoptic hour (e.g., 00, 06, 12, and 18 UTC).

Recent advancements in computational power have enabled 4-D variational assimilation techniques to become an operationally feasible solution. This method is far superior when initializing a forecast model with a data set such as TAMDAR because the observations are assimilated into the numerical grid at their proper space-time location (Huang et al. 2009).

TAMDAR data has been shown to increase forecast accuracy over the US on the order of 30-50% for a monthly average, even for 3D-Var (GSI) models (Moninger et al. 2010). For specific dynamic weather events, it is not uncommon to see the improvement in skill more than double this value.

FAA Validation Summary

The FAA funded a 4-year TAMDAR impact study that was concluded in January 2009. The study was conducted by the Global Systems Division (GSD) of NOAA under an FAA contract to ascertain the potential benefits of including TAMDAR data to the 3D-Var Rapid Update Cycle (RUC) model, which was the current operational aviation-centric model run by NCEP. Two parallel versions of the model were run with the control withholding the TAMDAR data. The results of this study concluded that significant gains in forecast skill were achieved with the inclusion of the data despite using 3D-Var assimilation methods (Benjamin et al. 2010, 2009; Moninger et al. 2009; Szoke et al. 2008). The reduction in 30-day running mean RMS error averaged throughout the CONUS domain within the boundary layer for model state variables were:

- Up to 50% reduction in moisture error
- 35% reduction in temperature error
- 15% reduction in wind error

This study was conducted using a 3D-Var model on a 13 km horizontal grid. Likewise, the nature of the 30-day mean statistics dilute the actual impact provided by TAMDAR's higher resolution data during critical weather events. The forecast skill gain during dynamic events is typically much greater than what is expressed in a CONUS-wide monthly average. In other words, the increase in model accuracy is greatest during dynamic weather events where air traffic impacts are greatest.

The PWS RT-FDDA-WRF forecast runs on a North America domain with 4 km grid spacing and can include multiple nested 1 km domains. A 4-year collaborative study with NCAR has shown that the FDDA/4D-Var assimilation methodology can nearly double the improvement in forecast skill over an identical model running a 3D-Var configuration (Childs et al. 2010; Liu et al. 2007). Results from this study are summarized below using the same 30-day running mean verification statistics as employed by NOAA. TAMDAR impact using FDDA/4D-Var resulted in:

- Reduction in humidity forecast error of 74%
- Reduction in temperature forecast error of 58%
- Reduction in wind forecast error of 63%

To put this type of statistical improvement into an operational forecast perspective, successive forecast run output is presented in Figure 3. This convective frontal event produced a record number of tornadic cells over the southeast US on 16 April 2011. When using a forecast model as a decision-making tool, the two most important aspects are consistency and accuracy. In Figure 3, there are 11 consecutive forecast cycles, which all show predicted reflectivity for 18Z April 16. The forecasts begin 72 h prior to the event, and each successive cycle (i.e., 66 h, 60 h, etc.), valid at the same time, is shown up to the 12 h forecast. The bottom right image is the actual radar imagery of the event. From a consistency perspective, the space-time propagation, as well as the intensity, change very little from run to run. From an accuracy perspective, the model does very well with resolving the frontal boundary and storm cell intensity, while the timing and position are nearly perfect almost 60 h prior to the event.

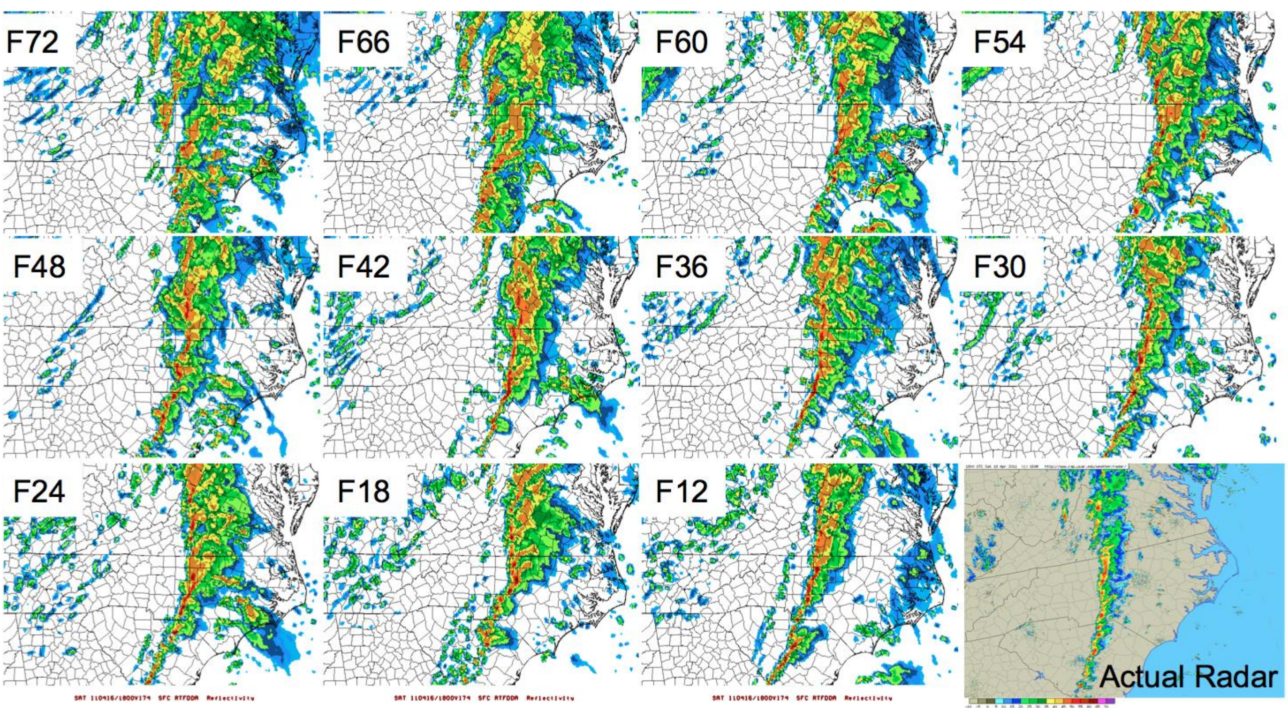

Figure 3. Eleven consecutive forecast cycles beginning 72 h prior to the event showing predicted reflectivity for 18Z April 16. The actual radar imagery of the event is shown in the lower right panel.

Forecast skill, like the example presented above, is made possible by having (i) an asynoptic in-situ observing system like TAMDAR that streams continuous real-time observations to (ii) a forecast model (deterministic or probabilistic) that has the ability to assimilate asynoptic data in four dimensions.

Auto-PIREP Utility

TAMDAR real-time icing data has the potential to improve pilot situational awareness. For example, we will consider the data in the vicinity of the Colgan Air icing accident near Buffalo, NY on February 13, 2009. Figures 4 and 5 are graphical output of raw TAMDAR observations from flights into and out of Buffalo within a 3 h window spanning the crash around 10 pm EST. The solid triangles (Figure 4) indicate icing, and the hollow triangles indicate icing with heaters activated (to melt the ice and reset). The fact that the TAMDAR heater remains activated throughout the descent suggests that the ice accretion rate is greater than 0.02" per minute, and in some cases (based on observation times) it could have been significantly greater.

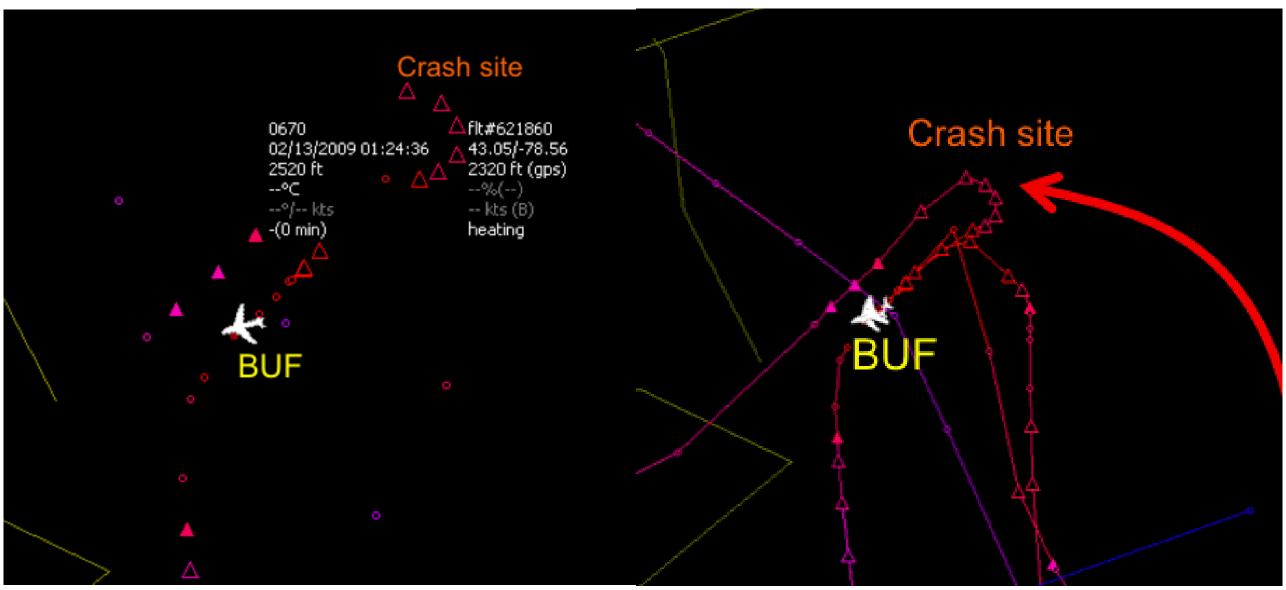

Figure 4. Flight Tracks And Icing Observations From TAMDAR-Equipped Planes Within A 3 h Window Spanning The Crash. Triangles Indicate Icing.

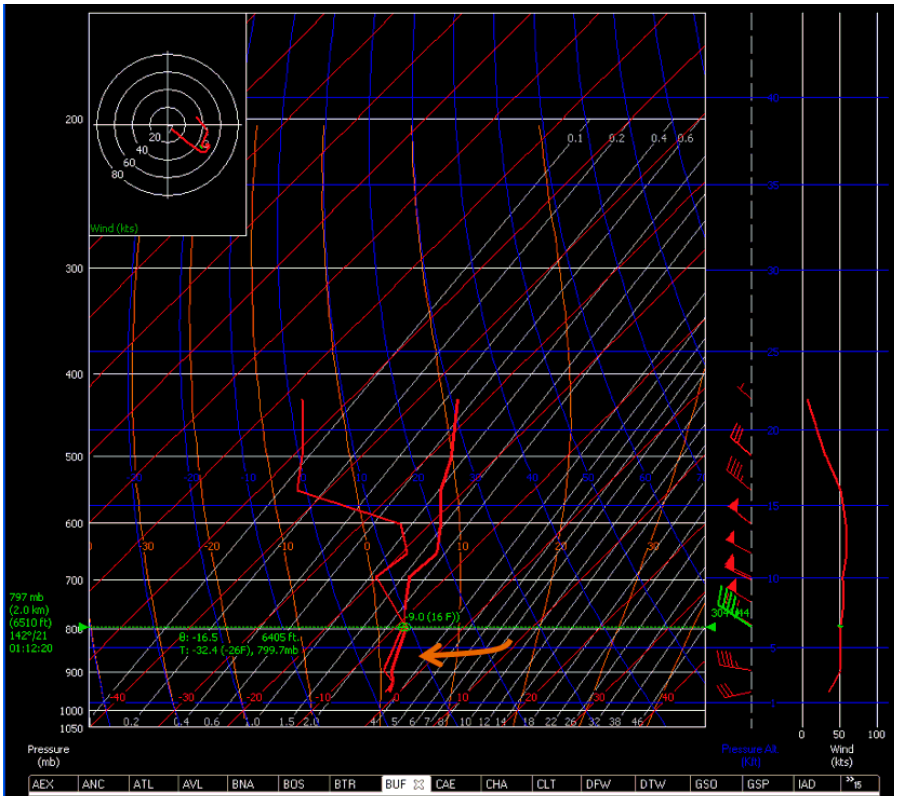

Figure 5. TAMDAR Sounding Valid 9 pm EST. Layer Below 6510 ft (Green Line) Shows Saturated Atmosphere With Temperatures Between -9 And -1 C.

The sounding in Figure 5, which is valid around 9 pm (local time), shows a substantial layer of saturated air below 6500 ft between -9 and -2 C, which is the temperature window that most supports the existence of supercooled water. TAMDAR soundings at KBUF continued to show this layer of icing well past 11 pm EST. During this window, the top of the layer dropped from 7000 ft to 3000 ft, but the temperature profile remains the same. All the soundings depict favorable conditions for supercooled water to freeze upon airframe contact. Also, the vertical profiles indicate winds between 25 and 45 knots within this layer throughout the duration of the sampling.

There is a small window of sub-freezing temperatures in which water can remain in liquid form (about 0 to -9 C). It is known as supercooled water, and as soon as it comes into contact with an object (like an aircraft wing), it instantly freezes to ice. Temperatures below -10 C are usually considered too cold for aircraft icing because the water will be in crystal (snow) form, which will not stick to the surface. TAMDAR was reporting large ice buildup rates all the way down to the surface because the entire layer was in the supercooled liquid zone.

The TAMDAR data suggests that the rates were high enough that the internal probe heater was running continuously to keep up with the accretion rate. The raw observations showing this were coming in as early as 4 to 5 hours before the crash, and were a key component of the NTSB investigation. These real-time observations can enhance decision-making for users and managers of the NAS.

Summary

Lower and middle-tropospheric observations are disproportionately sparse, both temporally and geographically, when compared to surface observations. The limited density of observations is likely one of the largest constraints in weather research and forecasting. Since December 2004, the TAMDAR system has been certified, operational, and archiving observations from commercial aircraft. This real-time data is available for operational forecasting both in forecast models and in raw sounding format that included the additional metrics of icing and turbulence, and can enable immediate forecast benefits. A TAMDAR system overview is presented in Figure 6, and provides the following along with customizable communication solutions:

- Moisture observations
- Better spatial and temporal sampling
- Real-time (15 seconds versus 2 hour latency)
- New safety-critical data metrics not captured by RAOBs or otherwise available to the FAA including icing and turbulence (measured by objective ICAO/FAA EDR standard)
- GPS stamp on each observation including latitude, longitude, altitude, date and time
- Additional winds aloft and temperature data, which have been shown to improve situational awareness, forecast accuracy, and continuous descent approaches.

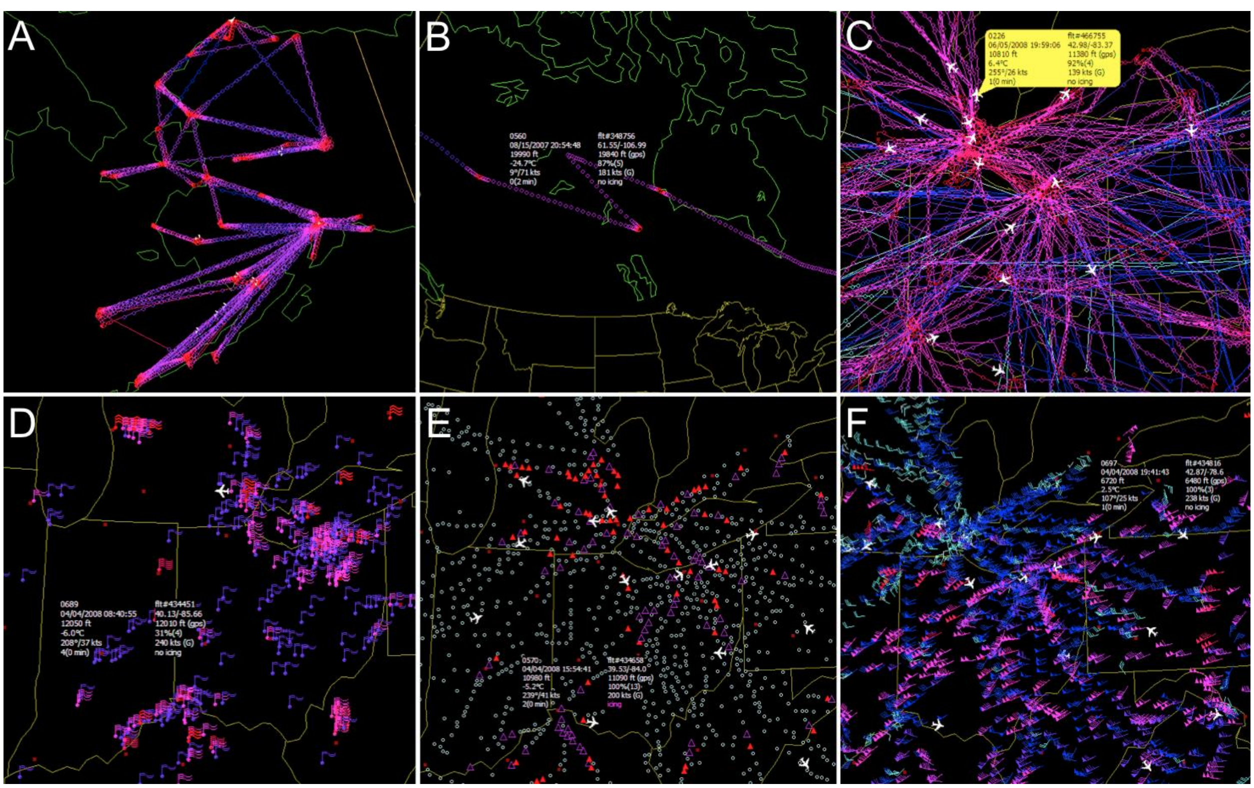

Figure 6. TAMDAR Coverage In Alaska (A); SATCOM In Remote Locations (B); High Density In Domestic Urban Areas (ORD and MSP; C). Real-time Turbulence Observations (D), Icing (E), And Winds, Temperature, and RH (F).

In addition to all of the data parameters provided by the NOAA weather balloon (radiosonde) program, the TAMDAR sensor network also detects various parameters not available from any other observing system (Table 1), yet necessary for the improvement of the NOAA/FAA NextGen Weather National Air Space (NAS) safety and efficiency.

Table 1)

	TAMDAR	RAOBS	ACARS
Icing	X		
Turbulence (EDR)	X		X (a)
Relative humidity	X	X	X (b)
Temperature	X	X	X
Pressure	X	X	X
Winds	X	X	X
GPS stamp	X		
Real-time	X		
Global communication network	X		
Sea-level pressure	X	X	
Real-time adjustable sampling rate	X		
Boundary layer data density	X		
Upper-air data density	X		X
Geographic diversity	X		
Temporal diversity (4D)	X		X
High vertical resolution	X	X	
Requires remote ground-based receivers		X	X

a) Very limited. Only a handful of planes with advanced avionics.
b) WVSS2, which is still in the development phase for major airlines only.

An End-to-End Solution

The TAMDAR network is more than a collection of sensors. It involves administration of a satellite communications network to support not only the operation of the TAMDAR sensors but also support of voice and data satellite communications for the host airlines. It includes data processing systems, database management and archiving, data monitoring, QA, life cycle management and high-speed computing and specialized atmospheric modeling operations. Panasonic Weather Solutions performs all of these activities in house, beginning with the design, manufacturing, and installation of the TAMDAR sensor. Panasonic also manages the recruitment of selected host airlines and manages the integration, certification and installation of the equipment on their aircraft.

See list of technical papers on TAMDAR in the appendix.

For additional information and documentation, please contact Panasonic Weather Solutions (next page).

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APPENDIX: A PARTIAL LIST OF **TAMDAR TECHNICAL PAPERS**

NASA:

Daniels, T. S., W. R. Moninger, R. D. Mamrosh, 2006: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Overview. 10th Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface (IOAS-AOLS), AMS, Atlanta, GA.

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Nguyen, L., J. J. Murray, P. Minnis, D. P. Garber, J. K. Ayers, D. A. Spangenberg, and M. L. Nordeen, 2006: Comparison of TAMDAR GLFE Icing Reports with NASA Advanced Satellite Aviation-weather Products (ASAP) In-flight Icing Parameters. 10th Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface (IOAS-AOLS), AMS, Atlanta, GA.

Smith, W. L., P. Minnis, C. Fleeger, D. Spangenberg, R. Palikonda, L. Nguyen, 2012: Determining the Flight Icing Threat to Aircraft with Single-Layer Cloud Parameters Derived from Operational Satellite Data. *J. Appl. Meteor. Climatol.*, **51**, 1794–1810.

GSD (ESRL/NOAA)

Benjamin, Stanley G., Brian D. Jamison, William R. Moninger, Susan R. Sahm, Barry E. Schwartz, Thomas W. Schlatter, 2010: Relative Short-Range Forecast Impact from Aircraft, Profiler, Radiosonde, VAD, GPS-PW, METAR, and Mesonet Observations via the RUC Hourly Assimilation Cycle. Mon. Wea. Rev., 138, 1319–1343.

Benjamin, S. G., B. D. Jamison, W. R. Moninger, S. R. Sahm, B. E. Schwartz, and T. W. Schlatter, 2010: Relative short-range forecast impact from aircraft, profiler, radiosonde, VAD, GPS-PW, METAR and mesonet observations within hourly assimilation in the RUC, (IOAS-AOLS), AMS, Atlanta, GA.

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