9.1 TROPOSPHERIC AIRBORNE METEOROLOGICAL DATA REPORTING (TAMDAR) OVERVIEW

Taumi S. Daniels*
NASA Langley Research Center, Hampton, Virginia
William R. Moninger
NOAA Earth System Research Laboratory, Boulder, Colorado
Richard D. Mamrosh
NOAA National Weather Service, Green Bay, Wisconsin

1. INTRODUCTION

This paper is an overview of the Tropospheric Airborne Meteorological Data Reporting (TAMDAR) project, giving some history on the project, various applications of the atmospheric data, and future ideas and plans. As part of NASA's Aviation Safety and Security Program, the TAMDAR project developed a small low-cost sensor that collects useful meteorological data and makes them available in near real time to improve weather forecasts.

This activity has been a joint effort with FAA, NOAA, universities, and industry. A tri-agency team collaborated by developing a concept of operations, determining the sensor specifications, and evaluating sensor performance as reported by Moosakhanian et. al. (2006). Under contract with Georgia Tech Research Institute, NASA worked with AirDat of Raleigh, NC to develop the sensor. The sensor is capable of measuring temperature, relative humidity, pressure, and icing. It can compute pressure altitude, indicated and true air speed, ice accretion rate, wind speed and direction, peak and average turbulence, and eddy dissipation rate. The overall development process, sensor capabilities, and performance based on ground and flight tests is reported by Daniels (2002), Daniels et. al. (2004) and by Tsoucalas et. al. (2006).

An in-service evaluation of the sensor was performed called the Great Lakes Fleet Experiment (GLFE), first reported by Moninger et. al. (2004) and Mamrosh et. al. (2005). In this experiment, a Mesaba Airlines fleet was equipped to collect meteorological data over the Great Lakes region during normal revenue-producing flights.

---

* Corresponding author address: Taumi Daniels, taumi.daniels@nasa.gov, phone: 757-864-4659, fax: 757-864-7891, Mail: NASA MS-473, 8 North Dryden, Hampton, VA 23681 USA

These aircraft make over 400 flights daily to 75 airports, providing more than 800 soundings for a total of over 22,000 daily observations of wind and temperature. This number can be compared with the approximately 100,000 observations of only wind and temperature over the entire contiguous U. S. from aircraft that currently provide Meteorological Data Collection and Reporting System (MDCRS) data. While originally funded by NASA for six months, more funding from the FAA was provided to perform an additional six months of the GLFE.

The automated collection, processing, and dissemination of meteorological data from aircraft are referred to as MDCRS in the U.S. and as Aircraft Meteorological Data Relay (AMDAR) throughout the rest of the world. The role of TAMDAR within this wider scheme is described by Moninger et. al. (2006a).

2. TAMDAR TEAM

The guiding principle of the GLFE is to make the data freely available to researchers for evaluation purposes. As a result, a large team of atmospheric modelers and forecasters has banded together to characterize the sensor performance through application to their particular research. This paper provides an overview of the known research activities at specific organizations and is presented in alphabetical order.

2.1 AirDat

The TAMDAR sensor was developed with input from NOAA Earth System Research Laboratory (ESRL), the FAA, and the WMO to achieve both improved mesoscale modeling and aviation safety. As part of the development, numerous ground and flight tests were conducted. Sensor performance on various aircraft is provided by Mulally (2006). For the GLFE, AirDat equipped 63 Mesaba Airlines Saab 340 aircraft with the TAMDAR sensor, interface circuitry, and Iridium satellite modem. AirDat has built a network operations center to receive and process the atmospheric observations, to format and relay the data to end users, and to provide ongoing lifecycle management of the TAMDAR network including sensor quality monitoring. A description of the data quality system that AirDat uses to process the data is provided by Anderson (2006). The overall system for collecting, processing, and disseminating weather observations is described on the company website http://www.airdat.com/.

The company also has a mesoscale modeling capability in use at their network operations center. This mesoscale model uses real-time four-dimensional data assimilation to compare parallel 12-hour simulations. Data denial data sets are generated for case studies of interest. This work is detailed in Jacobs (2006).

Deployment of TAMDAR sensors on other commercial aircraft is under negotiation. AirDat plans to equip a minimum of 600 aircraft with TAMDAR sensors to provide adequate coverage of the continental U.S. for model ingest. The focus is on regional aircraft flying at lower altitudes and providing ascent/descent profiles into several hundred airports, though some larger commercial jets may also be equipped.

2.2 Aviation Weather Center

At the Aviation Weather Center, forecasters issue warnings of hazardous conditions within the domestic and international airspace, operational aviation forecasts, and analyses of relevant atmospheric variables. The AWC prepares all NWS domestic and international aviation products, except for terminal forecasts and transcribed weather broadcasts, which are produced by the Weather Forecast Offices. In-situ observations from aircraft are used indirectly through forecast model output. Recently, AWC forecasters have started an evaluation of TAMDAR data. In particular, the data is being evaluated for use in helping AWC forecasters properly assess the Great Lakes region environment, resolve differences in model output, and improve convection forecasts. This research will analyze particularly interesting case studies of significant weather and is reported by Fischer et. al. (2006).

2.3 Canadian Meteorological Center

As part of a larger Canadian AMDAR project, 15 TAMDAR sensors are planned to be installed on First Air Airlines DHC-8 aircraft. This research has similar goals as the GLFE, in collecting real-time aircraft observations for improving weather forecasts and is described in Fournier (2006). Researchers have been receiving and monitoring the GLFE data for quality and eventual ingest to their global and regional numerical weather prediction models. This research is detailed by Zaitseva et. al. (2006).

2.4 Cooperative Institute for Meteorological Satellite Studies

As part of the GLFE, a team of researchers from the Cooperative Institute for Meteorological Satellite Studies at the University of Wisconsin collected ground truth data at Memphis International Airport. During these deployments, they collected much needed ground truth or reference data. The team made extra radiosonde launches from their mobile sounding facility. Two 2-week deployments were completed by the team in March and June 2005 as described by Feltz et. al. (2006). The data is available online at the website: http://cimss.ssec.wisc.edu/tamdar/.

The team also collected temperature and moisture profiles using an automated ground-based passive infrared interferometer. This instrument is described in Feltz et. al. (1998). Using these profiles along with the rawinsonde data, the team performed an analysis of parameter errors. These experiments were conducted to assess the accuracy of the TAMDAR instruments by comparing the temperature, moisture, and wind profiles to collocated radiosonde data. This work is described by Bedka et. al. (2006).

The team fielded a similar campaign as part of the Water Vapor Sensing System II (WVSSII) evaluation at Louisville, KY in June 2005. A comparison between TAMDAR, WVSSII, and the reference data is presented in Peterson (2006).

2.5 Earth System Research Laboratory / Global Systems Division

NOAA ESRL Global Systems Division (GSD) (formerly Forecast Systems Laboratory) is playing a central role in the distribution and evaluation of TAMDAR data. GSD's efforts are described by Moninger et. al. (2006b) and include the following.

- Ingesting TAMDAR data from AirDat, LLC, performing additional quality control checks, and distributing the data to authorized users via our MADIS program. This work is described in Miller et. al. (2006).
- Providing documentation and consultation to NWS offices that have chosen to ingest TAMDAR data into their AWIPS workstations.

- Making the TAMDAR data available to authorized users on FSL's aircraft display at http://amdar.noaa.gov/

- Ingesting and displaying radiosonde soundings gathered by the University of Wisconsin CIMSS group for comparison with TAMDAR (and other aircraft) soundings.

- Evaluating the TAMDAR data on a case-study basis, such as by comparing TAMDAR soundings with nearby radiosondes and wind profilers.

- Hosting a NWS survey for operational weather forecasters on their use of TAMDAR data (http://amdar.noaa.gov/TAMDAR/survey/).

- Working with scientists at National Center for Atmospheric Research (NCAR), comparing TAMDAR observations with written reports of turbulence, clouds, and icing generated by the pilots of the TAMDAR-equipped aircraft.

- Generating and making publicly available on the web (http://amdar.noaa.gov/ruc_acars/) statistics (bias, rms error) for wind, temperature, and relative humidity for TAMDAR and other aircraft with respect to co-located 1h forecasts from various Rapid Update Cycle (RUC) models. This work is described in Moninger et. al. (2006).

- Running in real-time parallel versions of the RUC model, one with TAMDAR (called "dev") and one without (called "dev2"). Plan view analyses and forecasts from these models are available (http://rapidrefresh.noaa.gov/), as are soundings (http://www-frd.fsl.noaa.gov/soundings/java/). The latter may be compared with actual aircraft soundings by users authorized to view the aircraft data. Results from this research are provided in more detail by Benjamin et. al. (2006a, 2006b) and Szoke et. al. (2006).

In brief, these results of these comparative RUC studies are the following:

- TAMDAR improves forecasts of temperature and winds in the lower troposphere, and during the summer months, relative humidity at 850 mb.
- The key areas of improvement have been in low clouds, precipitation, frontal zones, and convective forecasts.
- Through close interaction between GSD and AirDat, some systematic observation problems have been identified and fixed.
- However some problems remain which AirDat is actively working to fix. The data suggest that TAMDAR will have a larger impact on RUC forecasts once these problems are corrected.

2.6 National Aeronautics and Space Administration

A long-standing need to automate pilot reports was the original impetus for the TAMDAR project. While NASA's initial role was development of the sensor, this role has changed to project management. Over the past year, NASA has taken the lead in organizing the research, providing funding, setting goals, and measuring progress. The project culminates with the GLFE, after which, NASA's role will be limited.

NASA provided the genesis for the development of TAMDAR and has been an active tester, integrator and advocate for its deployment. NASA Langley researchers have assisted the TAMDAR project in the independent validation and verification of various types of TAMDAR data. These collaborative efforts, though not all published, include a number of stand-alone validation efforts of temperature, relative humidity, wind, and icing. Of note are comparisons of TAMDAR icing sensor performance with satellite derived cloud microphysical properties and icing severity indices produced by NASA's Advanced Satellite Aviation-weather Products. This research is described in Murray et al (2005), and more recently in Nguyen et al (2006).

Following the effort to modify the ARINC 620 standard used by MDCRS in order to accommodate TAMDAR data including the addition of icing and turbulence reports, the TAMDAR team of researchers are now engaged in the interagency Joint Planning and Development Office (JPDO) for the Next Generation Air Transportation system (NGATS) to significantly augment the MDCRS system by facilitating the transition of TAMDAR data to operations through efforts such as the GLFE.

2.7 National Center for Atmospheric Research

Other researchers at NCAR will analyze the potential for improvement in the Current Icing Potential (CIP) algorithm with inclusion of TAMDAR data during the GLFE. They will be comparing in-situ aircraft measurements of temperature, humidity and icing against various RUC model fields such as temperature, dewpoint and liquid water content. Results of this work are provided in Landolt et. al. (2006). Other researchers are working to test if the use of TAMDAR data in the CIP algorithm will improve the accuracy of the CIP output using standard verification methods. This work is described by Braid et. al. (2006b).

To determine the impact on short-term forecasts, other researchers have the goal of incorporating TAMDAR data into a short-term forecast system which includes: International H_2O Project (IHOP) instability analyses, NCAR Auto-Nowcaster short-term (0-2 hour) forecast system, and Variation Doppler Radar Assimilation System (VDRAS) explicit forecast system. Details about the NCAR Auto-Nowcaster can be found in Mueller et. al. (2003). The VDRAS technique is described in Sun (2001). They will analyze TAMDAR soundings, modify stability fields within Auto-Nowcaster to include TAMDAR data, and assimilate TAMDAR soundings into explicit VDRAS forecast. Some results of this effort are reported in Cai et. al. (2006).

An in-depth evaluation of precipitation forecast skill will be performed by other researchers. They will perform this evaluation and will take into account temporal and spatial offsets in the predicted values. While doing so, they intend to provide new verification approaches for evaluating TAMDAR impacts on mesoscale quantitative precipitation forecasts. At issue is the fact that traditional forecast verification approaches provide limited information about forecast quality and differences between forecast systems. Their goal is to apply new diagnostic approaches that provide more meaningful information about differences between forecasts and forecasting systems. This approach is described by Brown et. al. (2004).

For impacts to turbulence products, other researchers will perform an evaluation of the TAMDAR turbulence algorithm and make any recommendations for algorithm improvement. The use of eddy dissipation rate as a measure of turbulence is described by Cornman et. al. (1995).This final study will require a modified TAMDAR sensor for high turbulence data rate output, installed on the University of North Dakota Cessna Citation along with updated data recording capability on the aircraft. The results of this research are reported by Cornman et. al. (2006).

During the GLFE, Mesaba pilots will be completing PIREP forms for each phase of flight, take-off, cruise, and landing. The forms are being collected and analyzed by researchers at the National Center for Atmospheric Research (NCAR) as part of the FAA's Aviation Weather Research Program Quality Assessment Product Development Team. This team will use the PIREP forms as part of their Real Time Verification System, as described in Mahoney et. al. (2002). Among the data annotated by the pilots are time, flight mode, altitude, location, temperature, icing state, cloud tops, turbulence, in/out of cloud, and precipitation type. Results from the PIREP efforts are detailed by Braid et. al. (2006a).

2.8 National Weather Service Weather Forecast Offices

NOAA NWS Weather Forecast offices in much of the central and eastern United States are evaluating the TAMDAR data in several ways, such as through daily use by operational forecasters. The GLFE data are used as plan views of aircraft tracks and sounding displays to keep close track of changes in weather conditions. NWS forecasters will document those cases in which the GLFE data make a notable difference in their forecast decisions. Documentation will be provided in Area Forecast Discussions and special reports. The NWS Green Bay office hosted and maintained a website for the GLFE, http://www.crh.noaa.gov/tamdar/, and produced a training presentation for NWS WFOs and CWSUs

Meteorologists at many NWS Forecast Offices found TAMDAR data to be valuable in their forecasts and warnings. In addition, these data were also used by the NWS Storm Prediction Center in their severe thunderstorm monitoring and forecasting. Several examples are presented to demonstrate how TAMDAR was used in forecasting precipitation type of winter storms, cloud and fog formation, convective initiation, etc. The forecast utility of regional TAMDAR aircraft sounding data in assessing short-term (0-12 hour) convective potential is described by Brusky (2006a, 2006b).

Meteorologists at many National Weather Service Forecast Offices and Center Weather Service Units found TAMDAR to be valuable in forecasting ceilings, visibilities and turbulence in Terminal Forecasts and Center Weather Advisories. Several examples are presented to demonstrate how TAMDAR was valuable in forecasting different weather phenomena important to aviation. For a description of these aviation examples, refer to Mamrosh et. al. (2006a, 2006b).

One notable use of GLFE data is the incorporation of TAMDAR data into real-time local modeling on a workstation version of ESRL's Local Analysis & Prediction System (LAPS) at the NWS Marquette office. Model output is available online at:
http://www.crh.noaa.gov/mqt/data/wrf_html/laps_wrf_info.html

The model ingests data from Meteorological Assimilation Data Ingest System (MADIS) & Advanced Weather Interactive Processing System

(AWIPS) netCDF files. The LAPS is cycled hourly with 1-hour Weather Research and Forecasting (WRF) Advanced Research WRF (ARW) forecast used as first guess in LAPS analysis (and subsequent LAPS analysis used to initialize WRF-ARW). Boundary conditions are obtained from North American Meso model (NAM) (32 km files).

There are two runs per day (03 UTC & 15 UTC) to 30 hours (hourly cycling restarted every 12 hours, using operational RUC for initial first guess). Other details include: 15 km grid spacing, 31 vertical layers, and a 50 mb model top. As noted on the website above, to request a model re-run with/without particular datasets in the analysis (particularly TAMDAR) contact Tom Hultquist within two weeks of the event.

Output images are updated hourly (with looping possible through JavaScript). A variety of basic fields can be displayed as well as a few aviation specific fields and Skew-T diagrams for select locations. Model implementation details are provided by Hultquist (2005).

2.9 UK MET OFFICE & ECMWF

As part of the European AMDAR research, the United Kingdom Meteorological Office and the European Center for Medium-Range Weather Forecasts (ECMWF) are evaluating TAMDAR data. Both groups plan to develop, test, and apply tools to filter the suspect data to create 'clean' datasets. The next step is to compare observation minus model values to those produced by other systems such as AMDAR, radiosonde, etc.

Data denial studies may follow depending on the results of the earlier work. They also plan to look at the quantity / nature of the filtered or removed data. Assuming the data are found to be of sufficiently high quality, the schedule for running Observing System Experiments will depend on competing priorities for other studies. Results of these experiments will determine future operational use of the data. This information was provided by Truscott (2005).

3. FUTURE RESEARCH

The TAMDAR project successfully met the initial design criteria as evidenced by sensor performance statistics. However to take full advantage of TAMDAR as well as any other systems that may in the future measure upper air characteristics on the mesoscale, the infrastructure that assimilates and distributes these data must be improved and upgraded. These suggestions are made with the goal of improving the system's features to address aviation weather needs in the National Aerospace System. Specific research endeavors include:

- Development and implementation of an algorithm to prevent data loss during de-icing.
- Development and evaluation of new or improved mesoscale models that feature reduced grid spacing and cycle time and use of metadata.
- Development and evaluation of uplinked weather products for both tactical and strategic flight deck display. This would entail flight deck display studies, human factors research on pilot utilization, resolution of data display issues, and collaborative weather decision making studies.
- Development and evaluation of new and/or updated aviation weather products derived from mesoscale upper-air data such as TAMDAR. The FAA Aviation Weather Research Program develops new weather products, some of which could benefit from the inclusion of mesoscale upper-air data.
- Development of Flight Service Station user requirements and evaluation of enhanced displays for collaborative decision-making. Also, the evaluation of Electronic PIREPS disseminated to flight service stations and weather briefers.

This future research will require significant funding, possibly beyond current budgetary levels. As a result, the government must work in partnership with industry to enhance the upper-air observing systems. While an immediate goal is CONUS-wide deployment, future observation systems based on aircraft platforms must cover a global domain. Together, this partnership must improve predictive models and methods of dissemination to gain efficiencies in the operation of the National Air Space. Mesoscale reports of in-situ water vapor will significantly improve weather model forecasts and forecast products generated at local offices. Future observation systems must incorporate effective controls or mechanisms to manage and limit the collection of data within specified temporal and spatial requirements.

These needs necessarily fall into categories based on end-user requirements. In particular, numerical weather prediction model requirements for meteorological accuracy are more stringent than those of the NWS local forecasters. The concept of "good enough" as a criterion for observation acceptance should be considered. Ultimately, measurement accuracy versus cost will be a key driver in this decision.

4. SUMMARY

The GLFE has shown that the use of TAMDAR data makes a positive and significant impact on local forecasting and on model forecast output. While this success is significant, additional work is required to realize the full potential of TAMDAR. Improved weather forecasts have a major impact on all industries. Transportation, agriculture, and energy are just three of many that will benefit from the more accurate and timely weather forecasts. The societal benefits that can and must be attained will be determined by how well the FAA and NOAA can develop a partnership to acquire data such as that available from AirDat. The TAMDAR team has led the way through initiating this public/private partnership.

Acknowledgement

The authors would like to express their gratitude to the entire TAMDAR team for their dedication to the project. Also, we would like to thank everyone at AirDat for their numerous contributions.

REFERENCES

Alan K Anderson, 2006: AirDat system for ensuring TAMDAR data quality. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

American Meteorological Society Council, Support for Automated Observations from U.S. Commercial Aircraft, Bull. Amer. Met. Soc., 84, 515—517, Adopted by AMS Council on 9 February 2003.

Sarah Bedka, W. F. Feltz, E. R. Olson, K. M. Bedka, R. A. Petersen, and R. T. Neece, 2006: TAMDAR thermodynamic state validation using radiosonde data from TAVE. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Jamie T. Braid, R. S. Collander, P. Boylan, W. R. Moninger, and B. G. Brown, 2006a: Overview of the Great Lakes Fleet Experiment Supplemental PIREP Program. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Jamie T. Braid, C. A. Wolff, A. Holmes, and M. K. Politovich, 2006b: Current Icing Potential (CIP) Algorithm with TAMDAR Data – A Verification Analysis. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Stan Benjamin, W. Moninger, T. L. Smith, B. Jamison, and B. Schwartz, 2006a: Impact of TAMDAR humidity, temperature, and wind observations in RUC parallel experiments. 12th Conference on Aviation Range and Aerospace Meteorology, Atlanta, GA, Amer. Meteor. Soc.

Stan Benjamin, W. Moninger, T. L. Smith, B. Jamison, and B. Schwartz, 2006b: TAMDAR aircraft impact experiments with the Rapid Update Cycle. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Ben C. Bernstein, F. McDonough, M. K. Politovich, B. G. Brown, T. P. Ratvasky, D. R. Miller, C. A. Wolff and G. Cunning. 2005: Current Icing Potential: Algorithm Description and Comparison with Aircraft Observations. Journal of Applied Meteorology: Vol. 44, No. 7, pp. 969–986.

Barbara Brown, R. R. Bullock, C. A. Davis, J. H. Gotway, M. Chapman, A. Takacs, E. Gilleland, J. L. Mahoney, and K. Manning, 2004: New Verification Approaches for convective weather forecasts, 11th Conference on Aviation, Range, and Aerospace, Hyannis, MA, American Meteorological Society, October 2004.

Eugene S. Brusky, P. Kurimski, 2006a: The Utility of TAMDAR Regional Aircraft Sounding Data in Short-term Convective Forecasting. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Eugene S. Brusky, S. Luchs, 2006b: A Preliminary Comparison of TAMDAR Aircraft and NWS Radiosonde Sounding Data. 10th Symposium on Integrated Observing and Assimilation

Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Huaqing Cai, R. Roberts, C. Mueller, T. Saxen, D. Megenhardt, M. Xu, S. Trier, E. Nelson, D. Albo, N. Rehak, S. Dettling, and N. Oien, 2006: Enhancements of NCAR Auto-Nowcast System Using NRL, ASAP, MM5 and TAMDAR Data. 12th Conference on Aviation Range and Aerospace Meteorology, Atlanta, GA, Amer. Meteor. Soc.

Larry B. Cornman, C.S. Morse, and J. Cunning, 1995: Real-time estimation of atmospheric turbulence severity from in-situ aircraft measurements. Journal of Aircraft, Vol. 32 (1), pp. 171-177.

Larry B. Cornman, M. Poellot, D. Mulally, and P. Schaffner, 2006: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Sensor Eddy Dissipation Rate Performance in UND Citation II Flight Tests. 12th Conference on Aviation Range and Aerospace Meteorology, Atlanta, GA, Amer. Meteor. Soc.

Taumi S. Daniels, Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Sensor Development. SAE Paper 2002-01-1523, April 2002.

Taumi S. Daniels, Tsoucalas, G.; Anderson, M.; Mulally, D.; Moninger, W.; and Mamrosh, R., 2004: Tropospheric Meteorological Data Reporting (TAMDAR) Sensor Development. 11th Conference on Aviation, Range, and Aerospace Meteorology, Hyannis, MA, American Meteorological Society, October, 2004.

Wayne F. Feltz, W.L. Smith, R.O. Knuteson, H.E. Revercomb, H.M. Woolf, and H.B. Howell, 1998: Meteorological applications of temperature and water vapor retrievals from the ground-based atmospheric emitted radiance interferometer (AERI). Journal of Applied Meteorology, Vol. 37, No. 9, pp. 857-875.

Wayne F. Feltz, E. Olson, S. Bedka, K. Bedka, J. Short, and T. S. Daniels, 2006: Highlights of the TAMDAR AERIbago Validation Experiment (TAVE) in Memphis, Tennessee. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Gilles Fournier, 2006: Development of the Canadian aircraft meteorological data relay (AMDAR) program and plans for the future. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Thomas Hultquist, 2005: GLFE planning meeting, April 2005 personal communication.

Neil A. Jacobs, 2006: Evaluation of temporal and spatial distribution of TAMDAR data in short-range mesoscale forecasts. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Scott D. Landolt, M. K. Politovich and B. C. Bernstein, 2006: TAMDAR icing data comparisons against RUC model fields. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Jennifer L. Mahoney, J. K. Henderson, B. G. Brown, J. E. Hart, A. Loughe, C. Fischer, and B. Sigren, 2002: The Real-Time Verification System (RTVS) and its Application to Aviation Weather Forecast, 10th Conference on Aviation, Range, and Aerospace Meteorology, Portland, OR 13-16 May, 2002.

Richard D. Mamrosh, E. S. Brusky, J.K. Last, W. R. Moninger, T. S. Daniels, 2005: The Great Lakes Fleet Experiment, Ninth Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, American Meteorological Society Annual Meeting, San Diego, CA, January 2005.

Richard D. Mamrosh, E. S. Brusky, J. K. Last, E. J. Szoke, W. R. Moninger, and T. S. Daniels, 2006a: Applications of TAMDAR Aircraft Data Reports in NWS Forecast Offices. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Richard D. Mamrosh, T. S. Daniels and W. R. Moninger, 2006b: Aviation Applications of TAMDAR Aircraft Data Reports. 12th Conference on Aviation Range and Aerospace Meteorology, Atlanta, GA, Amer. Meteor. Soc.

Patricia A. Miller, M. F. Barth and L. A. Benjamin, 2006: A update on MADIS emphasizing observations added to support advances in transportation weather. 22nd International Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology, Atlanta, GA, Amer. Meteor. Soc.

William R Moninger, Daniels. T. S., Mamrosh, R. D., Barth, M. F., Benjamin, S. G., Collander, R. S., Ewy, L., Jamison, B. D., Lipschutz, R. C., Miller, P. A., Schwartz, B. E., Smith, T. L., and E. J. Szoke: TAMDAR, The Rapid Update Cycle, and the Great Lakes Fleet Experiment. 11th Conf. on Aviation, Range, and Aerospace Meteorology, Hyannis, MA, American Meteorological Society, October 2004.

William R. Moninger, T. S. Daniels and R. D. Mamrosh, 2006a: Automated Weather Reports from Aircraft: TAMDAR and the U.S. AMDAR Fleet. 12th Conference on Aviation Range and Aerospace Meteorology, Atlanta, GA, Amer. Meteor. Soc.

William R. Moninger, M. F. Barth, S. G. Benjamin, R. S. Collander, B. D. Jamison, P. A. Miller, B. E. Schwartz, T. L. Smith, and E. Szoke, 2006b: TAMDAR Evaluation Work at the Forecast Systems Laboratory: an Overview. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Alfred Moosakhanian, S. Schmidt, E. R. Dash, T. S. Daniels, and P. Stough, 2006: FAA–NASA collaboration on automated aircraft weather observations—culminating in TAMDAR. 12th Conference on Aviation Range and Aerospace Meteorology, Atlanta, GA, Amer. Meteor. Soc.

John J. Murray, L. A. Nguyen, T. S. Daniels , P. Minnis, P. R. Schaffner, M.F. Cagle, M. L. Nordeen,C.A. Wolff, M. V. Anderson, D. J. Mulally, K. R. Jensen, C. A. Grainger, and D. J. Delene, 2005: Tropospheric Airborne Meteorological Data and Reporting (TAMDAR) Icing Sensor Performance during the 2003/2004 Alliance Icing Research Study (AIRS II), AIAA-2005-0258, 43rd AIAA Aerospace Science Meeting & Exhibit, Reno, NV, 10-13 January 2005.

Cindy Mueller, T. Saxen, R. Roberts, J. Wilson, T. Betancourt, S. Dettling, N. Oien, and J. Yee, 2003: NCAR Auto-Nowcast system. *Weather Forecasting*, **18,** 545-561.

Dan Mulally, and M. Anderson, 2006: Assessment of TAMDAR System Performance on Various Aircraft Types. 12th Conference on Aviation Range and Aerospace Meteorology, Atlanta, GA, Amer. Meteor. Soc.

Louis Nguyen, J. J. Murray, P. Minnis, D. P. Garber, J. K. Ayers, D. A. Spangenberg, 2006: Comparison of TAMDAR GLFE Icing Reports with NASA Advanced Satellite Aviation-weather Product (ASAP) In-flight Icing Parameters. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Ralph A. Petersen, W. R. Moninger, 2006: Assessing two different commercial aircraft-based sensing systems. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

Juanzhen Sun, and N.A. Crook, 2001: Realtime Low-Level Wind and Temperature Analysis Using WSR-88D Data. Weather and Forecasting. 16, **117-132**.

Edward J. Szoke, B. D. Jamison, W. R. Moninger, S. Benjamin, B. Schwartz, and T. L. Smith, 2006: Impact of TAMDAR on RUC forecasts: case studies. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.

George Tsoucalas, T.S. Daniels, J. Zysko, M. Anderson, D. Mulally, 2006: Tropospheric Airborne Meterological Data Reporting (TAMDAR) Sensor Validation And Verification On National Oceanographic And Atmospheric Administration (NOAA) Lockheed WD-3D Aircraft, NASA TP (in publication), 2006.

Bruce Truscott, 2005: GLFE planning meeting, April 2005 personal communication.

Yulia Zaitseva, G. Verner and R. Sarrazin, 2006: Monitoring of GLFE TAMDAR at the Canadian Meteorological Centre. 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface, Atlanta, GA, Amer. Meteor. Soc.