J1.2 METEOROLOGICAL APPLICATIONS OF WVSS-II WATER VAPOR DATA FROM COMMERCIAL AIRCRAFT

Richard D. Mamrosh
National Weather Service, Green Bay, Wisconsin

1. INTRODUCTION

The National Weather Service has collaborated with United Parcel Service and Southwest Airlines to collect water vapor data from over 120 aircraft equipped with the Water Vapor Sensing System version 2 (WVSS-II). WVSS-II data are a subset of aircraft meteorological data known as AMDAR (Aircraft Meteorological Data Report) that are collected from over 3,000 commercial aircraft around the world. AMDAR data are currently used by national meteorological centers as input to numerical weather prediction models, and directly by meteorologists to improve forecasts and warnings.

Despite being a relatively new source of atmospheric moisture data, meteorologists at National Weather Service Forecast Offices and national centers have found many applications of these data to improve forecasts and advisories. These include forecasts of precipitation type, aircraft icing, low clouds and fog, as well as convective initiation or inhibition.

The author will first present a short historical discussion of efforts to collect water vapor data from commercial aircraft, including WVSS-I, TAMDAR, and WVSS-II. Several case studies will then follow that show WVSS-II sounding information, NWS Area Forecast Discussions that explain how the water vapor information was used in forecast decisions, and the observed weather that verified those forecast decisions. Finally, future plans to expand the number of aircraft collecting water vapor data will be discussed, as well as possible future applications of WVSS-II data.

Corresponding author address

Richard D. Mamrosh
National Weather Service
2485 South Point Road
Green Bay, Wisconsin 54313
Richard.mamrosh@noaa.gov

2. HISTORY OF THE WATER VAPOR SENSING SYSTEM

Aircraft have served as sources of weather data since the dawn of aviation. In 1919 the United States Weather Bureau began paying pilots to fly aircraft equipped with weather recording instruments. By 1937 there were regularly scheduled flights in over 30 United States cities. The program ended a few years later, when radiosonde units became available. Meteorological data from aircraft then became used primarily in weather research, until the availability of modern communications systems in the late twentieth century made automatic transmission of weather data feasible. (Moninger, et. al.,2003). Data were initially limited to air temperature and ground relative wind speed and direction.

Measurement of atmospheric water vapor by commercial aircraft began in the late 1990s, in a cooperative venture by United Parcel Service (UPS) Airlines and the National Weather Service (NWS). A sensor employing a thin film capacitor became known as the Water Vapor Sensing System (WVSS). (Fleming, 1996) It was installed on six UPS aircraft between 1997 and 1999. A two week study was conducted in the fall of 1999 in Louisville, Kentucky to compare WVSS data from UPS aircraft with radiosondes launched from a nearby mobile sounding unit. The study showed that WVSS data compared favorably to radiosondes.

The availability of sixteen WVSS aircraft in the spring of 2001 prompted a comparison of this new data source with NWS radiosondes over a several month period. Nearly 1100 data comparisons were made at various mandatory sounding levels from 925 to 250 mb in the three month period from May through July 2001 (Mamrosh, et. al., 2002). While this study also showed WVSS data to be comparable to NWS radiosondes, they sensors required maintenance at intervals unacceptable to the airline.

In response to this problem, and in an attempt to get water vapor data of superior quality, a new sensor called the Water Vapor Sensing System II (WVSS-II) was developed (Fleming, 2006) .The WVSS-II uses a diode laser to measure water vapor mixing ratio. It was installed on 25 UPS aircraft by the summer of 2005.

In order to determine how the WVSS-II compared to the WVSS (hereafter called WVSS-I), a study was conducted during the summer of 2005 that was nearly identical to the WVSS-I to radiosonde comparison. It concluded that the new WVSS-II sensor produced data superior to its predecessor. (Mamrosh, et. al, 2006). There were around 130 aircraft equipped with WVSS-II sensors by the end of 2014.

3. TAMDAR

A slightly different method of measuring atmospheric water vapor was occurring during much of the WVSS-II development. NASA sponsored an aviation safety project in the early 2000s that resulted in the development of an instrument package that could be installed on regional turboprop and jet aircraft. The Tropospheric Airborne Meteorological Data Report (TAMDAR) system collected temperature, wind, humidity, pressure, icing and turbulence data. Humidity was measured by a thin film capacitance unit similar to those used in NWS radiosondes. (Daniels, et. al, 2004).

Moisture data from TAMDAR were compared to NWS radiosondes in a study by Brusky and Luchs (2006). A field experiment was also conducted by Feltz, et. al (2006) that compared TAMDAR to radiosondes launched from a mobile sounding unit at the Memphis International Airport. The results of the two studies showed that TAMDAR humidity measurements were of a similar quality of NWS radiosondes.

TAMDAR was a proof of concept effort, and was ultimately turned over to a private sector company called AIRDAT (now Panasonic Aviation Systems), which has since expanded to Mexico and parts of Europe. As of January 2015, there was no contract for the provision of TAMDAR data to the NWS, thus this paper is limited to water vapor data from WVSS-II equipped aircraft.

4. METEOROLOGICAL APPLICATIONS OF WVSS-II DATA

The increasing number of WVSS-II soundings has resulted in many different forecast applications, including forecasts of precipitation type, aircraft icing, fog and low clouds, and convection.

a) **Precipitation Type Forecasts** - are amongst the most difficult for meteorologists, because traditional upper air data from weather balloons are often not sufficiently available in space and time to provide the detailed temperature and moisture data from the lower levels of the atmosphere. WVSS-II soundings are often available from locations 100km or more from the nearest radiosonde, and are often available at times outside the 00z and 12z radiosonde launches.

Meteorologists at the NWS in Saint Louis, Missouri used WVSS-II data in their precipitation forecasts during a snow and ice storm on December 5, 2013. The text box below shows an excerpt from their area forecast discussion issued at 1637 UTC.

> NWS ST LOUIS MO
> 1037 AM CST Thu Dec 5 2013
>
> Latest aircraft soundings and spotter reports depict an ever cooling atmosphere with freezing rain now limited to the far southern and southeastern counties of the forecast area.

Figure 1 below shows a WVSS-II sounding from Saint Louis Lambert airport at 1634 UTC, depicting an above freezing layer between 700mb and 800mb that had significantly cooled during the morning hours.

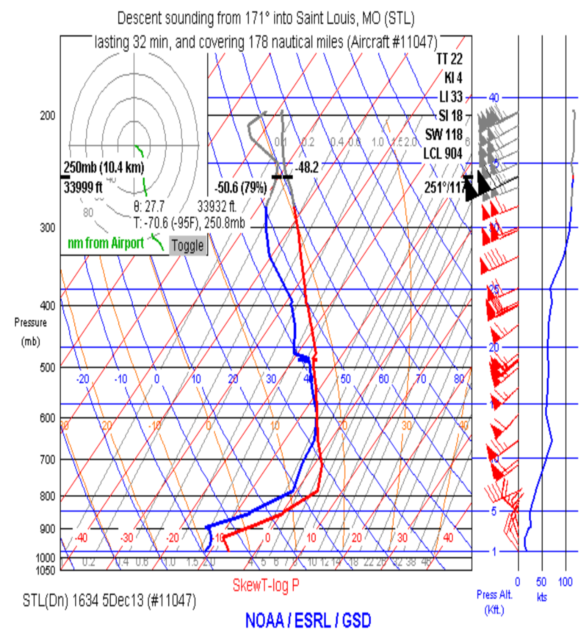


Figure 1 shows a WVSS-II sounding from STL at 1634 UTC

b) Aircraft icing – is a significant hazard to aviation, especially to smaller aircraft that cruise at altitudes that may be conducive to icing. WVSS-II equipped aircraft can provide useful data to aviation meteorologists that produce forecasts and advisories for icing.

Figure 2 below shows where advisories (dashed lines) for icing were in effect at 1500 UTC December 3, 2013, and the locations of WVSS-II soundings (denoted by stars).

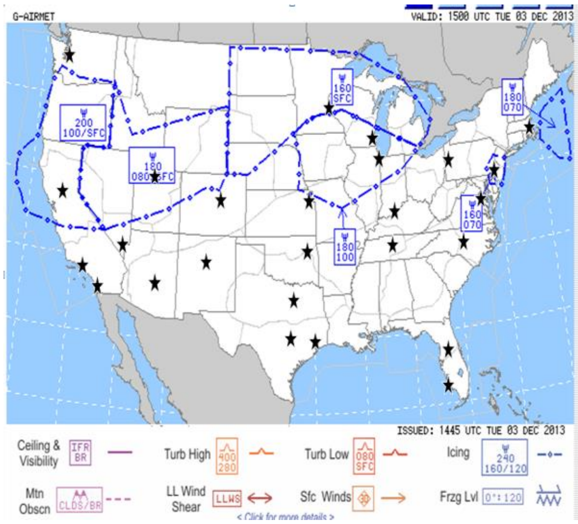


Figure 2 shows AIRMETs for icing (dashed lines) and locations of WVSS-II soundings (designated by stars) around 1500 UTC.

With only one exception, the WVSS-II soundings supported the icing advisory products, including the sounding below (figure 3) from Milwaukee, Wisconsin at 1435 UTC. The highlighted portion of the sounding shows an environment (10,000 to 16,000 feet) that is conducive to the presence of super cooled water vapor. This is within the icing advisory issued for 10,000 to 18,000 feet.

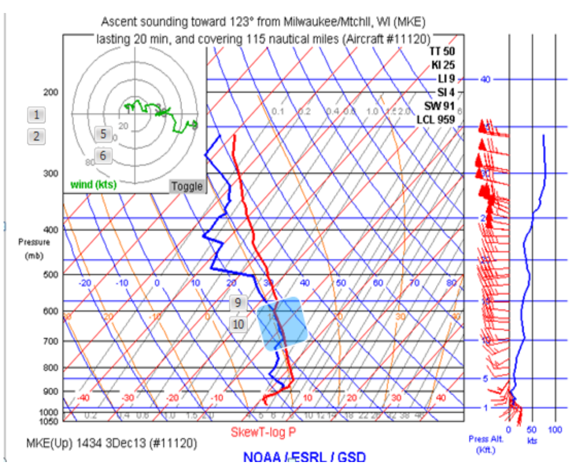


Figure 3 is a WVSS-II sounding from Milwaukee Mitchell Field at 1434 UTC 12/3/2013.

c) Low Clouds and Fog – are often difficult to forecast due to a lack of moisture data in the boundary layer. WVSS-II equipped aircraft can often supply this information.

NWS offices in southern California have relied on AMDAR temperature and wind data for many years to monitor the height of the inversion created by the marine layer that often moves in to the coastal cities. WVSS-II data now provides the moisture information to help improve low cloud and fog forecasts for aviation customers and the general public.

Marine clouds and fog often move into the coastal cities of Los Angeles (LAX) and Sand Diego (SAN) but are slowed or stopped by the range of hills Between the coast and the region called the “Inland Empire”, which includes Ontario, California (figure 4).

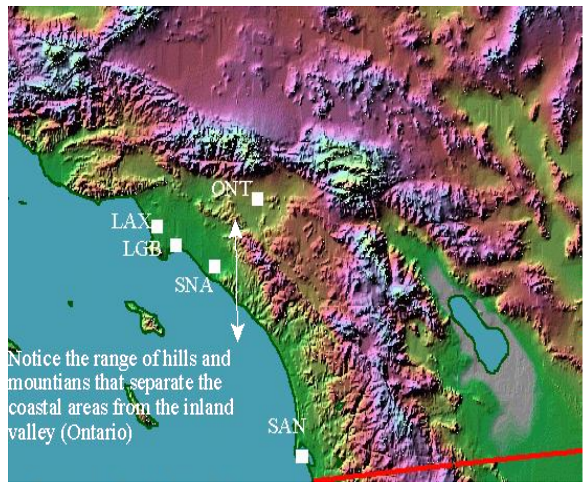


Figure 4 shows coastal southern California

Figure 5 below shows low level moisture trapped below a strong inversion at Burbank, California.

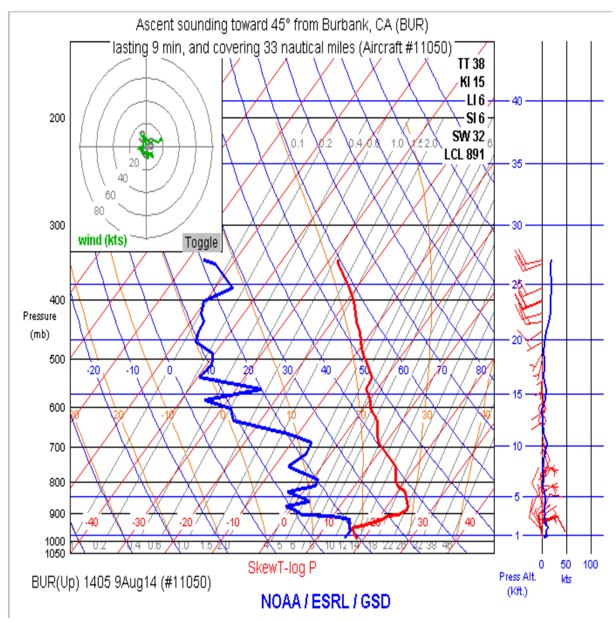
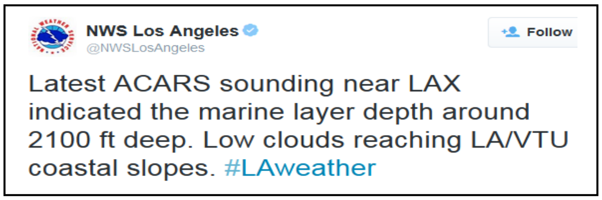


Figure 5 shows a WVSS-II sounding from Burbank, California from 1405 UTC 8/9/2014.

Meteorologists mentioned the use of WVSS-II data in the social media "Tweet" message below.



d) Convection – typically occurs on scales much smaller than a single upper air observing system can resolve. AMDAR combined with radiosonde and satellite soundings are now providing an increasingly complete data set to assist in the forecast of convection.

Temperature and wind data available from nearly all AMDAR aircraft are useful in convective forecasts, but the addition of water vapor data allows for more precise calculations of convective parameters such as convective inhibition, convectively available potential energy, total precipitable water, and other convective indices. Studies such as Brusky and Mamrosh (2006) show the value of aircraft soundings for assessing the near storm environment.

The NWS in Houston, Texas is fortunate to have many WVSS-II soundings available each day to assist in convective forecasts. Meteorologists used these soundings on July 3, 2014 to help forecast the initiation, type, and movement of expected thunderstorms later in the day. Figure 6 below shows a sounding from Houston Hobby airport modified for high temperatures (low 90s) expected that afternoon.

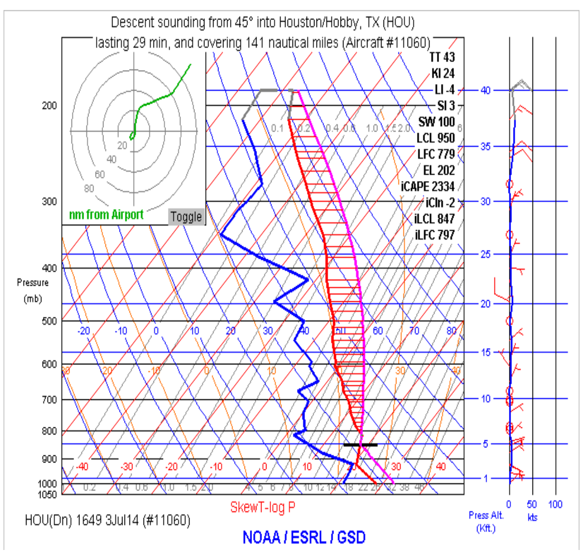


Figure 6 shows a sounding from Houston, Texas from 1649 UTC on 7/3/2014. Note stability indices in upper right hand corner of sounding

The text box below shows an excerpt from their forecast discussion; mentioning how the soundings show an unstable atmosphere capable of supporting slow moving, strong thunderstorms.

AREA FORECAST DISCUSSION
NWS HOUSTON/GALVESTON TX
1026 AM CDT THU JUL 3 2014

AMDAR SOUNDINGS SUGGEST WE WILL HAVE THUNDERSTORM DEVELOPMENT TODAY WITH LIFTED INDICES AROUND -5 AND CAPES 2000 TO 3000 J/KG ONCE CONVECTIVE TEMPS ARE REACHED (AROUND 90F). SOUNDINGS SHOW VERY LITTLE WIND OR WIND SHEAR SO WE SHOULD HAVE SLOW MOVING PULSE TYPE STORMS.

The forecast was a good one, as scattered thunderstorms began to form between noon and 1 pm local times as surface temperatures rose to around 90F. The storms were slow moving, produced very heavy rains, and some produced strong to severe winds.

5. FUTURE PLANS

The 130 WVSS-II equipped aircraft provided good coverage of most of the lower 48 states as of January 2015. Figure 7 below shows a typical twenty four hour distribution of WVSS-II soundings (blue stars) and the location of NWS radiosondes (blue text).

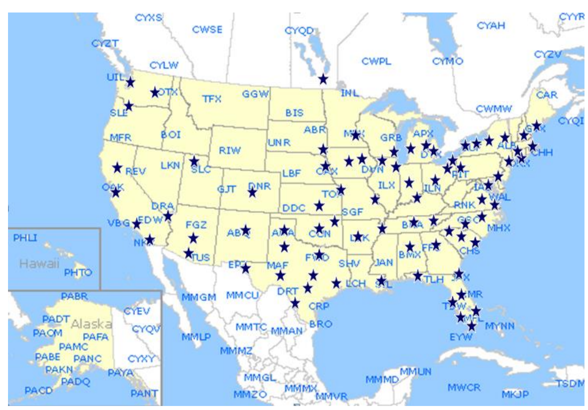


Figure 7 shows the location of WVSS-II soundings and NWS radiosonde sites.

The NWS plans to expand the number of WVSS-II equipped aircraft in the future, dependent on funding and airline participation.

Additional data are especially needed over the Northern Plains, Rocky Mountains, and other data sparse regions.

If WVSS-II should become sufficiently abundant, the data could be used as a substitute for weather balloon borne data at locations near large airports.

REFERENCES

Brusky, E. S., and S. Luchs, 2006: A Preliminary Comparison of TAMDAR Aircraft and NWS Radiosonde Sounding Data. 10th Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface (IOAS -AOLS), AMS, Atlanta, GA.

Brusky, E. S., and R. D. Mamrosh, 2006: The Utility of Aircraft Soundings in Assessing the Near Storm Environment. *23rd Conference on Severe Local Storms*, St. Louis, MO, Amer. Meteor. Soc., Paper 2.1.

Daniels, T. S., Anderson, M., Moninger, W. R., and R. D. Mamrosh, 2004: Tropospheric Airborne Meteorological Data Reporting (TAMDAR) Sensor Development. 11th Conf. on Aviation, Range, and Aerospace Meteorology, Hyannis, MA, Amer. Meteor.Soc.

Feltz, W. F., 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 Atmosphere, Oceans, and Land Surface (IOAS-AOLS), AMS, Atlanta, GA.

Fleming, R.J., 1996: The use of commercial aircraft as platforms for environmental measurements. Bull. Amer. Meteor. Soc., 77, 2229-2242.

Fleming, Rex, 2006: The WVSS-II: A commercial aircraft sensor for water vapor information, *10th Symposium on IOAS-AOLS*, Atlanta, GA, Amer. Meteor. Soc., Paper 9.4.

Mamrosh, R., Baker, R., and Jirikowic, T.: A, 2002 Comparison of ACARS WVSS and NWS Radiosonde Temperature and Moisture Data, Sixth Symposium on Integrated Observing Systems, Orlando, Florida, USA, Paper 6.14.

Mamrosh, R., Gillis, J., Petersen, R., and Baker, R.: A 2006. A Comparison of WVSS-II and NWS Radiosonde Temperature and Moisture Data, 10th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS), Atlanta, GA, 28 January–2 February 2006,

Moninger W.R., Mamrosh R.D., Pauley P.M.. 2003:. Automated Meteorological Reports from Commercial Aircraft. Bull. Amer. Meteorol. Soc. 84: 203 – 216.