STUDIES OF THE EFFECTIVENESS OF THE WATER VAPOR SENSING SYSTEM, WVSS-II, IN SUPPORTING AIRLINE OPERATIONS AND IMPROVED AIR TRAFFIC CAPACITY

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1.0 Introduction:

- The Water Vapor Sensing System (WVSS-II) provides in-situ measurement of atmospheric water vapor from aircraft in support of U.S. and Global programs
- Tunable Diode Laser Absorption Spectroscopy (TDLAS) is used to measure water vapor in real-time from air samples collected along the aircraft flight path
- WVSS-II supports the U.S. NWS MDCRS program and the WMO AMDAR program
- Moisture information has always been the missing data element from AMDAR and MDCRS reports, but is now available through WVSS-II
- WVSS-II has been in operational use by the U.S. NWS since Oct 2009
  - United Parcel Service (UPS) operates WVSS-II on 25 aircraft
  - Southwest Airlines (SWA) is equipping 31 aircraft with WVSS-II, with plans for an additional 36 installations by 2012
- Here we provide information on WVSS-II use in operations including:
  - An overview of the WVSS-II End-to-End processing through MDCRS
  - Summary of technical evaluations and intercomparisons with other platforms
  - Examples of comparison methods in an operational environment
  - Examples to highlight the *support to aviation operations*

2.0 Overview of WVSS-II End-to-End Processing:

- Sample collection begins with the UCAR patented Air Sampler, (Figure 1), which draws the sample into the System Electronics Box analyzer where the Water Vapor concentration is determined

Figure 1 – Air Sampler Flow through the WVSS-II

- Data is communicated to the aircraft ARINC 429 bus, for onboard processing and formatting for downlink as an ACARS message via the GlobalLink network
- Ground processing at ARINC transforms the data into standard BUFR formats and routes the ACARS and BUFR forms to appropriate end users

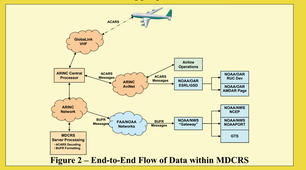

Figure 2 – End-to-End Flow of Data within MDCRS

- Data is collected during Ascent, Descent, and high altitude Cruise with 24 hours of operation represented in Figure 3
- As many as 11 flights per day have been reported from a single aircraft, resulting in the equivalent of 22 traditional radiosonde soundings

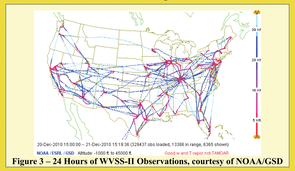

Figure 3 – 24 Hours of WVSS-II Observations, courtesy of NOAA/GSD

- Data used in forecast operations is displayed in a standard Skew-T/Log-P format, with multiple aircraft or radiosonde soundings per chart (Figure 4)

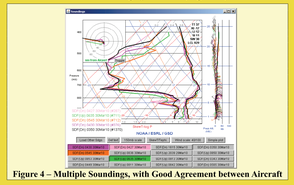

Figure 4 – Multiple Soundings, with Good Agreement between Aircraft

3.0 Summary of Technical Evaluations and Intercomparisons:

- Multiple independent verifications of WVSS-II performance have been done
- Climate Chamber tests, Field Intercomparisons with radiosondes (e.g. Figure 5), Comparisons to Operational models, Comparisons to GPS-Met IPW

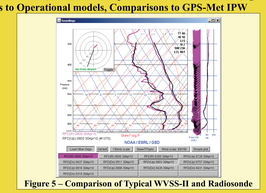

Figure 5 – Comparison of Typical WVSS-II and Radiosonde

- Results have been well documented (NOAA Sterling Test Facility 2009; Hoff, 2009; Helms et al., 2010; and Petersen, et al, 2010), supporting use in Operations
- An example of such analysis is provided in Petersen, et al, 2010, showing Consistency between WVSS-II Sensors (Figure 6)

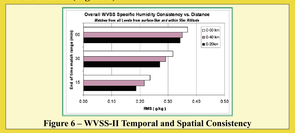

Figure 6 – WVSS-II Temporal and Spatial Consistency

- Ongoing Long Term testing provides evidence of Calibration Stability over Extended Periods similar to routine Aircraft Maintenance (Figure 7)

Figure 7 – Interim Results of 24 Month Stability Evaluation

4.0 Examples of Methods in an Operational Environment:

- With increasing use of WVSS-II in Operations, many examples have become available demonstrating the use of WVSS-II in operations and the value to aviation operations

4.1 Examples from March 30, 2010 Intercomparison at Rockford, IL

- Only one aircraft arriving at RFD from southwest detects moisture between 5Kft and 14Kft (Figure 8)

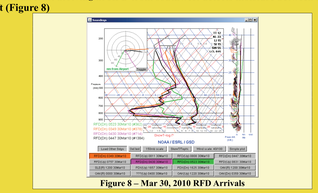

Figure 8 – Mar 30, 2010 RFD Arrivals

- Subsequent Departures of these aircraft Confirms that Moisture has now covered the entire Rockford area at those levels (Figure 9)

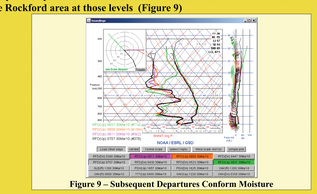

Figure 9 – Subsequent Departures Conform Moisture

4.2 Examples from July 14, 2010 at Rockford, IL:

- Conditions at Rockford (RFD) were clear as six aircraft began arrivals from various directions between 0400Z and 0600Z
- Three aircraft arriving from west detect a moisture layer between 11Kft and 15Kft, approximately 40 nm range, while three aircraft arriving from the east show dry air (Figure 10)
- Aircraft with similar profiles show very good correlation between water vapor observations

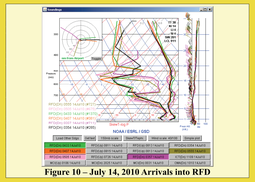

Figure 10 – July 14, 2010 Arrivals into RFD

- The 0400Z GOES Water Vapor imagery (Figure 11) confirms drier air to the south and east (salmon and yellow colors) with higher *moisture to the west at that range*

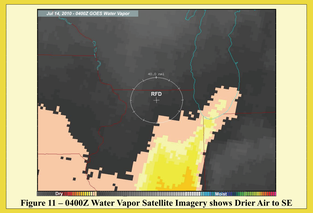

Figure 11 – 0400Z Water Vapor Satellite Imagery shows Drier Air to SE

- Subsequent east and west departures of these aircraft, beginning around 0730Z, show good correlation of all observations, regardless of direction (Figure 12)
- All profiles indicate the moisture layer at those levels now covers the entire Rockford area at the 40 nm range

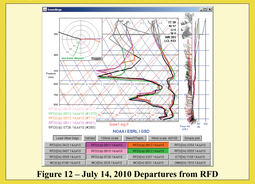

Figure 12 – July 14, 2010 Departures from RFD

- This moist layer over Rockford corresponds well with the 0800Z GOES Water Vapor imagery (Figure 13), which reveals moist air throughout the region 40nm from RFD

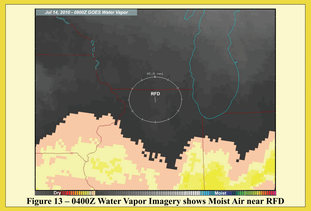

Figure 13 – 0400Z Water Vapor Imagery shows Moist Air near RFD

4.3 Examples from August 25, 2010 at Rockford, IL:

- Two aircraft arriving at RFD, GSD #285 from west and GSD 287 *from the east*, show differences in moisture profiles in the layer between 20Kft and 30Kft (Figure 14)

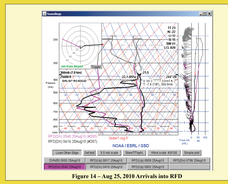

Figure 14 – Aug 25, 2010 Arrivals into RFD

- These observations are consistent with the moistures observed on satellite Water Vapor imagery at a range of 93nm from RFD, with moist conditions to the east and dry conditions to the west (Figure 15)

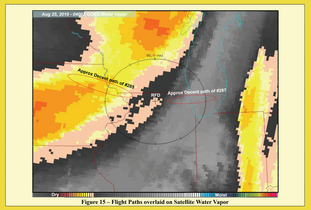

Figure 15 – Flight Paths overlaid on Satellite Water Vapor

- These observations are also consistent with the location of cloud bands observed on the composite satellite IR / Radar product at a range of 93nm *from RFD (Figure 16)*

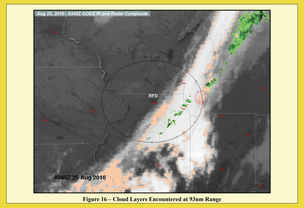

Figure 16 – Cloud Layers Encountered at 93nm Range

- By the time of their departure from RFD shortly after 0800Z, conditions had become dry through the full sounding of both aircraft departing in nearly opposite direction (Figure 17)

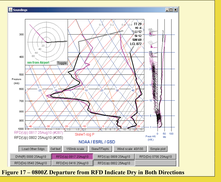

Figure 17 – 0800Z Departure from RFD Indicate Dry in Both Directions

5.0 Examples of WVSS-II Support to Airline Operations:

- The direct benefits of improved water vapor observation to aviation operations are difficult to quantify at this early stage of the implementation process; however, evidence to date indicates that the benefits will be significant
- The main operational decisions are typically made at least 6-24 hours in advance and are based primarily on forecast model data output and the interpretation of that output by the forecast operations support team
- Therefore, in most cases only minor changes to operational plans can be made based on current observations and 1-5 hour forecasts
- But with increasing availability and operational knowledge of WVSS-II data, that is expected to change as this new data becomes more widespread and the understanding of its uses in longer term aviation products, such as TAFs and models, increases
- NOAA plans to begin assimilating WVSS-II data into operational forecast models in May 2011, and with this significant step the larger benefits are expected to become more evident to aviation operations as well as all other sectors
- While quantifying benefits is difficult and can only be accomplished over long periods of well organized study, the following examples provide growing evidence that WVSS-II observations do provide benefits to operations and capacity in the short term

5.1 WVSS-II Use by NWS Forecast Operations for Aviation Support:

- AMDAR/WVSS-II data are routinely available to NWS WFO and Aviation Weather Center (AWC) meteorologists for issuing warnings and short-term predictions, such as Terminal Aerodrome Forecasts (TAF), critical to the operation of the ATM
- WVSS-II observations are made available to NWS meteorologists through AWIPS and the NOAA AMDAR website: http://amdar.noaa.gov/docs/fest-disc/?O=D
- A few examples of AMDAR/WVSS-II data used in forecast operations are provided:

AREA FORECAST DISCUSSION, NWS COLUMBIA SC, 904 AM EST FRI DEC 31 2010
NAM FORECAST SOUNDING GAVE IFR CIGS THIS MORNING BUT BOTH MET AND MAV GUIDANCE WENT VFR THIS MORNING. ALSO LOCAL *AMDAR* SOUNDING INDICATED JUST SCATTERED LOW LEVEL CLOUDS. SO WILL GO VFR ACROSS FORECAST AREA TODAY.

AREA FORECAST DISCUSSION, NWS CHICAGO/ROMEOVILLE IL, 1017 AM CST WED DEC 29 2010
WE CAN SEE THAT THE FOG IS WATER DROPLETS WHEN WE ARE OUTDOORS. THE *AMDAR* SOUNDING AT RFD SHOWS VERY HIGH WATER VAPOR CONTENT UP TO 1000 FT. THE DROPLET COULD FREEZE ON SURFACES...SO WE WILL ISSUE A FREEZING FOG ADVISORY THIS MORNING

AREA FORECAST DISCUSSION, NWS CHICAGO/ROMEOVILLE IL, 153 PM CST TUE DEC 28 2010
TODAY...THE HIGH OVER TENNESSEE WILL GIVE A SOUTH WIND TODAY. THE SOUNDINGS FROM *AMDAR* AT ROCKFORD SHOW AN INVERSION UP TO 5540 FEET. THE AIR IS ALSO VERY MOIST AS THE DEWPOINT IS VERY CLOSE TO THE TEMPERATURE UP TO 1600 FT. THE FOG WILL BE PATCHY THROUGH THE FORECAST AREA OF NORTH CENTRAL ILLINOIS.

AREA FORECAST DISCUSSION, NWS NORTHERN INDIANA, 632 AM EST MON DEC 27 2010
UPSTREAM *AMDAR* DATA CONFIRMS CLOUD BEARING PROFILES ARE WARMER THAN -10C WHICH COULD SUPPORT A FZDZ THREAT IN THE CLOUD BAND. OPTED TO LEAVE OUT ANY FZDZ MENTION AT SBN GIVEN INCREASINGLY UNFAVORABLE SUPPORT FOR LAKE EFFECT PRECIP PER WARMING/DRYING LL PROFILES/FALLING INVERSION BASES/AND AN INCREASINGLY WESTERLY FETCH FAVORING MID-LAKE BAND BREAKDOWN.

AREA FORECAST DISCUSSION, NWS MOUNT HOLLY NJ, 929 PM EST WED DEC 22 2010
1800 UTC NAM MODEL SOUNDINGS SHOW THIS MOISTURE AT JUST ABOUT ALL TERMINALS THROUGH THE OVERNIGHT. THIS MOISTURE IS SHOWING UP IN THE FORM OF VFR CEILINGS (NEAR 3500 FEET) AT KABE...AND SHOULD AFFECT KRDG AND KTTN IN THE NEXT TWO HOURS. MOST 0000 UTC SOUNDINGS AND *AMDAR* SOUNDINGS FROM KPHL SHOW THE MOISTURE ABOUT 3000 FEET. FOR NOW MVFR CEILINGS WERE NOT ADDED TO THE FORECAST, HOWEVER... MVFR CEILINGS ARE NOT THAT FAR AWAY...AND MAY HAVE TO BE ADDED TO KABE AND KRDG IN THE NEXT COUPLE OF HOURS.

AREA FORECAST DISCUSSION, NWS SACRAMENTO CA, 420 AM PST THU DEC 23 2010
QUITE A BIT OF IFR CONDITIONS HAVE DEVELOPED ACROSS THE SAC AND NORTHERN SAN JOAQUIN VALLEYS IN FOG THIS MORNING. *AMDAR* SOUNDINGS SHOW AN INVERSION NEAR FL035-040. WHERE CLOUDS HAVE FORMED AT THIS LEVEL...SURFACE GROUND FOG IS LESS DENSE. WHERE THIS LAYER HAS CLEARED...DENSE FOG IS DEVELOPING. IFR 1/2SM FG OVC005 MAY IMPACT SAC INTERNATIONAL AIRPORT THRU 18Z THIS MORNING.

AREA FORECAST DISCUSSION, NWS LOUISVILLE KY, 953 AM EST WED NOV 24 2010
AMDAR SOUNDINGS SHOW DECENT WETBULBING OCCURRING AS THE PRECIPITATION FALLS...AND WITH LOW LEVEL ATMOSPHERIC TEMPS NEAR FREEZING...WE HAVE RECEIVED NUMEROUS REPORTS OF SLEET MIXING IN. THIS TREND WILL CONTINUE FOR THE NEXT 1-2 HOURS UNTIL TEMPERATURES WARM INTO THE UPPER 30S.

AREA FORECAST DISCUSSION, NWS ST LOUIS MO, 153 PM CST THU NOV 25 2010
AS DRIER AIR ENTRAINS AT THE SURFACE...VSBYS AND CIGS SHOULD LIFT TO MVFR...BUT A BIG QUESTION PRESENTS ITSELF IF WHETHER THIS WILL RESULT IN COOLING OF LOWCLVLS AND FZDZ/PL DEVELOPMENT FOR THE 19-21Z TIMEFRAME. LATEST *AMDAR* SOUNDINGS OUT OF KSTL PRESENT SUCH A POSSIBLE SITUATION

AREA FORECAST DISCUSSION, NWS CHICAGO/ROMEOVILLE IL, 519 PM CDT MON SEP 20 2010
THERE IS A LOW PROBABILITY THAT ISOLATED THUNDERSTORM DEVELOPMENT MAY OCCUR ALONG THE WARM FRONT ITSELF IN THE NEXT COUPLE OF HOURS...GIVEN LOW LEVEL CONVERGENCE ALONG THE BOUNDARY...MID LEVEL SPEED MAX LIFTING ACROSS UPPER MIDWEST...AND OBJECTIVE ANALYSIS AND MODIFIED ORD *AMDAR* ASCENT SOUNDINGS INDICATING 2000-2500 J/KG MLCAPE PRESENT.

5.2 WVSS-II Use in Support of Airport Fog Forecasting:

- WVSS-II supplements standard upper air rawinsondes to fill temporal and spatial gaps in observations beneficial to Airline operations
- MDCRS/WVSS –II can be of short/near term value in forecasting airport fog conditions
- WVSS-II data combined with enhanced satellite imagery can help forecast and detect marine layer fog events especially prevalent along the west coast
- These events often occur at night or early morning hours, when satellite imagery determination of marine layer thickness can be limited, or obscured by higher clouds
- Most importantly, in-situ WVSS-II reports through the marine layer easily detect the moisture content and thickness, providing an early warning of fog potential before it forms, whereas satellite imagery observes the onset of fog after it develops
- Such fog events are common at locations such as San Diego's Lindberg Airport where high landing minimums are required, and where marine layer fog can be advected quite rapidly over the airport causing significant operational impacts to aviation
- With the Early Warning of fog onset enabled by WVSS-II, significant improvements in operational decision making can lead to reduced fuel consumption, reduced emissions, and the maintenance of maximum capacity

5.3 Confirmation of UPS Forecast Supports Continuation of Maximum Flow:

- Based on their forecast of moisture decreasing with height in the boundary layer, which reduces the risk of dense fog, UPS Met Ops team forecast conditions at SDF to stay above minimums, in spite of other indicators that there was a reasonable chance of fog
- That forecast resulted in a flight operations plan for arrivals into SDF using both runways, even though one runway was undergoing construction at the time and had higher visibility minimums required for operations
- During early arrivals, observed real-time WVSS-II data verified moisture was decreasing with height, validating the forecast made 12 hours earlier by UPS Met Ops
- This event provided a definite boost of confidence in the forecast made by the UPS meteorological staff, and enabled arrivals to continue at the planned flow rate without compromising safety concerns, or slowing the flow of arrivals

5.4 Data Shared with CCFP on Mid-Level Cap Inhibiting Thunderstorms:

- Morning arrivals of AMDAR/WVSS-II equipped aircraft into SDF provided data to UPS Met Ops that indicated a stronger mid-level cap than previously forecast
- Such a cap inhibits afternoon thunderstorm development, so this was used to reduce the expected thunderstorm risk for SDF and storm coverage in the area
- UPS shared this in the daily Collaborative Convective Forecast Product process, CCFP, extending the benefits to the entire aviation community
- This use of AMDAR/MDCRS data to determine convective inhibition due to mid-level capping inversions not forecast by models is now well recognized by the NWS, and has been integrated into the 2nd Distance Learning Aviation Course (DLAC2)

5.5 Warm Moist Air Observed Aloft Improves UPS Forecast of Rain to Snow Transition at SDF:

- MDCRS data, including WVSS-II, observed by UPS Met Ops during evening arrivals into SDF indicated warmer and moister air aloft than models had previously forecast
- Based on that information, UPS Met Ops moved back their estimated time for the transition of rain to snow by one hour, impacting fewer departing aircraft that night
- This improved information helped to increase preparedness and efficiency of the UPS aircraft deicing operations and UPS pilots

5.6 UPS Benefits to De-Icing Operations at SDF on Nov 18th, 2010:

- One small example of how WVSS-II data directly benefited UPS deice operations at SDF was recorded on Nov 18th, 2010
- Models and satellite imagery showed clearing conditions approaching SDF from the northwest, thus the official forecast at SDF was for low clouds to clear, leading to frost
- The clearing was expected to reach SDF at the end of UPS arrivals, and therefore all 80+ UPS departures would be expected to require pre-treating with Type IV deice fluid
- During arrivals, UPS Met Ops noticed that AMDAR winds at 3,000 ft were turning to the west and southwest, and WVSS-II data showed moisture saturation at that layer
- These observations revealed that the cloud layer was trapped below an inversion and surging in a few hours earlier than forecast, preventing the cloud clearing over SDF
- UPS Met Ops evaluated this difference from forecasted conditions and notified deicing operations to suspend pre-treating the aircraft because frost was no longer expected
- Even though much of the fleet had already been sprayed, this avoided about 30 aircraft from being treated
- This small event directly saved UPS operations approximately $4500 in cost of deice fluid, and allowed UPS staff to return to other critical functions, speeding up the UPS operation at SDF that night

6.0 Summary:

The implementation of a dense network of WVSS-II sensors on AMDAR/MDCRS equipped aircraft will certainly provide increased benefits to the aviation community. Currently, the measurable data needed to quantify these benefits are limited and further study is necessary. However, there is more and more evidence to indicate that the largest direct operational and overall economic benefit will be provided through more accurate initial conditions for the numerical weather prediction models. That can only be proven once there is sufficient observation coverage in time and space, the models begin assimilating WVSS-II data, and controlled model sensitivity studies are conducted comparing results with and without the WVSS-II data. As the operational use of WVSS-II data becomes more prevalent within the NWS and participating airlines, these benefits will continue to grow. There is a long way to go for WVSS-II to achieve its fullest benefit for the aviation community. But the potential for benefits to aviation operations, air traffic capacity, and safety are now very clear.

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