Actions on Formats, Software, and Quality Control for the Water Vapor Sensing System (WVSS): With Implications for Accessing other Environmental Data from Commercial and General Aviation Aircraft

Report

June 19, 2000

Rex J. Fleming[1]

A publication of the University Corporation for Atmospheric Research pursuant to National Oceanic and Atmospheric Administration Award No. NA87GPO105.

---

[1]Visiting scientist at the University Corporation for Atmospheric Research

---

Table of Contents

Acknowledgements

This work was supported by the FAA's Aviation Weather Research Program and NOAA's Office of Global Programs through the GEWEX Continental-Scale International Program (GCIP). The engineering contributions of John W. Kowles of BF Goodrich Aircraft Sensors division (fomerly Rosemont Aerospace) are greatly acknowledged. The support of the United Parcel Service for providing their aircraft and the help of Randy Baker, their chief meteorologist, are greatly appreciated. Mike Russo of ARINC was a valuable aid in implementing ARINC 620.

1. INTRODUCTION

The use of real-time meteorological data flowing from commercial aircraft as the measuring platform down to users via the Aeronautical Radio Inc. (ARINC) Communications Addressing and Reporting System (ACARS) first occurred in 1979 and was briefly described in Fleming, et al (1979) as part of the Global Weather Experiment. Since then, there has been a remarkable growth of this additional component of an atmospheric observing system to complement radiosondes, satellites, and other atmospheric observing systems.

The addition of water vapor as a further commercial aircraft observable (in addition to winds and temperature) was described in Fleming (1996). In early 2000, the number of wind and temperature reports over the mainland USA was over 50,000 per day, and over 1,000 per day with the additional water vapor information. The growth of water vapor reports will rise dramatically in the next few years.

There will also be an initiation and/or rise in the measurements of other atmospheric quantities from commercial aircraft as sensors and communications systems evolve. These additional measurements will include: ice/no ice, cloud/no cloud, wind profiles from flight level, water vapor profiles from flight level, various chemical species, and others. The motivation of the use of commercial aircraft is the synergistic value it provides in blending the data from satellites and other conventional and non-conventional sources. **Essential** to the effective use of the commercial aircraft as an observing platform is the wise end-to-end use of the communication systems employed within the National Airspace System (NAS).

This publication addresses the principles used in the preparation of formats, software, and in obtaining quality control procedures required for operational real-time environmental information from commercial and general aviation aircraft. These principles were required to serve the multiple needs of the users of the aircraft-supplied data and the system concerns of those who operate and fund the aircraft communications system. **These principles apply to all environmental data and to all aircraft types**. As the number of applications and end-users of this data grow, these principles must continue to be followed. The report uses the water vapor sensing system (WVSS) as a focus but provides guidance for the broader acquisition of other data from commercial and general aviation aircraft as well. For the WVSS users, it should be considered a companion document to the FAA Report of April 17, 2000 (Fleming and Braune, 2000). This document is available on the Internet at www.joss.ucar.edu/wvss/title_page.html or in hard copy from the author. The organization of this document is as follows. Chapter 2 covers the guiding principles. The specific codes (existing and evolving) will be discussed in Chapter 3. The role of the avionics manufacturers is described in Chapter 4. Discussion of further end-to-end activities and concluding remarks are provided in Chapter 5. Throughout the document, unique actions for specific organizations will be highlighted as appropriate.

2. PRINCIPLES TO FOLLOW FOR REAL-TIME COMMUNICATIONS OF ATMOSPHERIC-RELATED DATA FROM AIRCRAFT

The first major departure in the conventional use of ACARS for meteorological purposes was the addition of water vapor. This was because water vapor had been difficult to measure and was new, and because to capitalize on its value, one needed high vertical resolution ascent/descent formats to capture the vertical structure of all three fields: water vapor, winds, and temperature. In this document, we continuously follow water vapor as the primary sampled field (though it exemplifies other fields from a communications viewpoint-except where noted).

It is easy to write an overall objective of designing a communications system to "maximize information flow at a minimum of communication cost for all operational contingencies." However, in the real world of commercial aircraft operations where safety, efficiency, capacity, profitability, and unexpected developing weather events all must be accommodated, there are always tradeoffs. Principles that meet these, sometimes diverse demands, must be carefully employed. The following four guiding principles are offered-all of equal value-in designing an effective real-time communication system for conveying measured atmospheric data from commercial and general aviation aircraft to users: (i) accuracy and reliability of the data must be maintained, (ii) communications cost must be low, (iii) maximum resolution must be achieved in the vertical, and (iv) flexibility in implementation must be achieved. Each of these is covered in the following sub-sections.

2.1 Accuracy and reliability of the data must be maintained.

Given this first principle regarding accuracy and reliability, the immediate questions arise as to how accurate and how reliable? First, some facts and examples. Weather data (at least for our purposes here) has two basic uses: (i) objective information to a numerical analysis and hence to a forecast model and (ii) subjective information to a human interpreter.

The first basic class of use in numerical applications has evolved into a highly successful form of four-dimensional data assimilation (4DDA) whereby data and model output are blended according to the error characteristics of each. In this use, accuracy is easy to determine-the observed variable must be competitive with the other data sources and model sources or it simply won't be used. Error characteristics of all data sources are determined before they are allowed to enter into the 4DDA activity, or as it is also referred to, the "analysis/forecast" cycle. With regard to water vapor information, it now appears that we have ways to measure the vertical structure of this important variable via aircraft that are better than from any other observing platform. Two technologies now exist. The first generation WVSS (WVSS-I) was won in a competitive contract with the thin-film capacitor (directly measuring relative humidity) as the moisture sensor. This was our second choice as a sensor-the first choice, a diode laser for the direct measurement of water vapor mixing ratio, was too expensive at the time and was not bid. While both sensors work, there are some serious limitations with thin-film capacitors, and with measuring relative humidity directly, which are described in Section 3.2.

Given that an aircraft-based water vapor measuring technology is initially competitive because of proper calibration, it must remain in sufficiently proper calibration-else it degrades and actually harms the 4DDA process-negatively impacting other "good" data and/or model sources. Thus, both the **success** and **ease** with which calibration is maintained are important issues on what sensor flies on commercial or general aviation aircraft.

The second basic class of use of data by the human user leads to no less of concern on initial accuracy and maintained calibration. Would you be satisfied with a railroad crossing signal that worked correctly 95% of the time if your family crossed it every single day? Of course, the answer is no. A human user of data gradually learns from experience the trust he can put into a data source. If pilots or dispatchers or air traffic controllers get information that occasionally doesn't match their own experience, then the confidence factor plunges dramatically. This is why in our current mushrooming growth of air traffic in the country, one must maintain the highest possible confidence in the basic measurements of our atmosphere-in order to help fortify subsequent proper use of algorithms or human decisions in ensuring safety, efficiency, and capacity in our NAS. This principle of accuracy and reliability must be maintained in commercial and general aviation measurement concepts, and especially for general aviation, this must be the first design goal-with low cost a distant second in the list of design goals!

2.2 Communication costs must be low.

Communication systems continue to evolve and there exist some exciting options on the horizon to the long-established ACARS. Someone must pay the communication costs (whatever the system), and when one end of a communication system is a fast-moving aircraft with many potential destinations, these may not be small. The use of ACARS has evolved to many applications within the general categories of Airline Operational Control, Air Traffic Services, Communication, Navigation, Surveillance/Air Traffic Management (CNS/ATM), and Weather Support. Information on the atmosphere in real-time is absolutely vital to safety, efficiency, and capacity. At the same time, in view of all the uses of the communication system, it is imperative to keep the weather information to as few bits as possible-both for reasons of cost and for possible communication traffic congestion. Examples of how to best use the ground processing capabilities of computers dedicated to message decoding while minimizing the number of characters (or bits or bytes) actually transmitted between air and ground are given in the next chapter.

Currently in the USA, the basic information of winds, temperature, and water vapor supplied from commercial aircraft of some major carriers is provided without additional charge (there is a decoding fee paid by the FAA and the National Weather Service (NWS) to ARINC). This may change in the USA and the situation in Europe is already a bit more costly. The point is, whether it is today's ACARS, the upcoming replacement VHF Data Link (VDL) Mode 2, or a future system, the accommodation of more atmospheric information within the overall air transportation communication system will be far easier if this principle is strictly followed.

2.3 Maximum vertical resolution must be achieved.

Virtually all atmospheric phenomena that affect aviation safety, efficiency, and capacity are "mesoscale" in nature. Mesoscale implies small-scale features in the space domain and/or fine structure in the time domain. Atmospheric stability has a profound influence on mesoscale phenomena. Warm or moist air is light. Cold or dry air is heavy. Thus, the stability (or capability to overturn) of the atmosphere is determined by the detailed vertical structure of the atmospheric temperature and water vapor information. Mesoscale research scientists and mesoscale numerical modelers were consulted in the early days of developing a water vapor sensor for commercial aircraft. The consensus then was that 100-meter vertical resolution was desired as an absolute minimum, and preferably 50-meter vertical resolution. This requirement was carried over in the WVSS initial design and incorporated into the formats described in Section 3.

For some new applications (ice/no ice, cloud/no cloud, etc.) the vertical resolution **sensing** requirement may be the same or even greater-however, the communication of the null case may be avoided if the "triggered" event is always communicated-thus reducing communication costs. Vertical resolution for some atmospheric chemical parameters may vary according to application. Monitoring ozone levels for local air quality will be quite different than for global warming issues. The main point is that the commercial aircraft can provide vertical structure information far better than satellite systems and better than most ground-based remote sensing systems. As such, the vertical structure information must be communicated in an efficient way as possible.

2.4 Flexibility in implementation must be achieved.

The initial ARINC 620 formats for ascent, descent, and the enroute portions of a typical flight were initially designed to achieve the maximum utility possible based upon the three previous principles. However, there was another factor, flexibility in implementation that turned out to be more important than originally anticipated. It was immediately recognized that due to the day to day dynamic variability of the Earth's atmosphere, there might be a requirement on some occasions for even greater vertical resolution than normal. Likewise, at a busy airport under benign conditions, less vertical resolution from some aircraft might be desirable. Such a flexibility was designed into the codes described in Chapter 3 and they could be dynamically changed via a message to the aircraft.

It later became evident that further characters in the initial "header" portion of an ARINC 620 Meteorological Report were required to account for different nuances in the way avionics vendors could implement the "spirit" of ARINC 620. Header information might also be required for different ways avionics hardware might be configured, and for the way ground processing decoders might have to cope with all the above flexibility and nuances. Examples of each follow.

One avionics vendor might implement the "spirit" of ARINC 620 in a slightly different manner than another. An example might be the trigger for the descent report. If such an implementation has an impact on the ground-based decoder software, then the header must have a unique indicator in the header for the decoder. United Parcel Service (UPS) has another example of limited capability (old) ACARS units that did not support multi-block messages-for which the ARINC 620 code was designed. However, using only single block messages and a unique set of characters in the header, UPS was able to exactly reproduce the ARINC 620 timing of reports and accompanying vertical resolution. The unique header characters allowed the ground-based decoders to work. Finally, the dynamic switching of aircraft format characteristics (e.g., such as increased data coverage on descent in bad weather conditions which might feed a mesoscale forecast model designed to predict when conditions might improve) can only work if the decoder is cognizant of the change through the header field. Note that some avionics suppliers may not have their on-board software organized for all possible implementation options offered in ARINC 620. However, through the use of the header, a few primary options can be pre-programmed in the software and implemented in this manner.

An example which combines these points is one used by UPS where the first four-character field in the header is

> A3 x x
> where the A indicates ascent, the 3 indicates Format Version Number, and the third and fourth characters are used for assembling the full ascent profile on the ground.

The 3 in the above four-character set indicates that the standard default values are used (e.g., 6 second intervals for samples in series #1). There could be preset software in the avionics box where "A4 x x" meant data samples every 3 seconds and "A5 x x" meant samples every 12 seconds as an example. The ground-based decoders would translate the header character set into a properly timed ascent profile.

The goal of standardization in ARINC 620 has been achieved-yet there is sufficient flexibility in its implementation to make it a workable solution for most abnormalities seen thus far. This somewhat opposite paradigm with standardization yet flexibility will undoubtedly be required in moving into the general aviation arena with regard to automatic meteorological reports.

3. ARINC 620 FORMATS AND CHANGES

It is not necessary to recall the full history of ARINC 620 specifications for ascent, descent, and revised enroute formats for the high resolution reporting of aircraft-based measurements of winds, temperature, and water vapor information. It is necessary to provide a copy of that specification (Attachment #1) and indicate how such a specification gets changed.

A copy of ARINC Specification 620 (Revised, November 15, 1994) is provided at Attachment #1. Page 70 (the first page of the attachment) presents the original version of the Meteorological Report, Version 1, page 70A (the second page of the attachment) begins the new Version 2 with Ascent Reports, Enroute Reports, Descent Reports, and subsequent Tables and Notes. Examples of key features and options will be provided shortly.

The procedure for making Version 2 an official part of ARINC 620 is briefly described as follows. After a few presentations on the value of meteorological data obtained from commercial aircraft (both directly to the air carriers and the airline industry itself, and to the greater atmospheric science community) were provided to the Airlines Electrical Engineering Committee (AEEC)'s Data Link (DLK) User's Forum, and after a general consensus that the high vertical resolution data would be good, the author drafted the formats with the assistance of ARINC's Mike Russo, secretary to the DLK User's Forum. Once drafted, corrected, and reviewed, the revised formats are formally accepted by the AEEC General Session, which convenes in the fall of each year.

3.1. Examples of key features

The most important part of Version 2 of ARINC 620 is the Ascent Report. This provides the greatest vertical resolution where it is most required-in the lowest part of the troposphere, the atmospheric boundary layer. In keeping with Principle #2 on lowering costs, the Ascent Report has a Series #1 and a Series #2 (see page 70A of Attachment #1 for details). In Series #1, the first report comes zero seconds after the "OFF" event (also referred to as take-off, wheels-up, or AIRBORNE), and subsequent reports are at intervals of 3 to 20 seconds (modifiable via uplink; default to 6 seconds) until the limit of 30 to 200 seconds (modifiable via uplink; default to 90 seconds) after "OFF" event. One will note that in Series #1 there is no time, latitude, or longitude information. This information is already in the header and these fields change very little over the first 90 seconds. Note that ground-based decoding algorithms can insert the time and interpolated latitude and longitude information as is performed in the USA. This saves communication costs and possible communication traffic congestion problems at busy airports.

The usual implementation of Series #1 by UPS was via the default conditions of data every 6 seconds until 90 seconds. Thus, after the initial "wheels up" report, there are 15 additional reports, for a total of 16 for Series #1 (a copy of the UPS sample format specification is presented as Attachment #2). For typical aircraft ascent rates this provides vertical resolution of about 100 meters-with the 3-second interval we obtain the coveted 50 meter resolution. Of course, some aircraft ascend faster or slower than "typical." There are at least three reasons for this time-dependent approach to gathering vertical data samples. It is easy to implement, the carrier knows exactly how much data he will have to pay for, and it doesn't matter to modern 4DDA methods how the data arrives in the vertical dimension-by equal time increments or equal pressure (height) increments.

Series #2 of the Ascent Report begins right after Series #1 and is appended to it and sent as a single report. Here, data samples are usually accumulated at 20-second intervals by UPS. Details can be read on page 70A of Attachment #1. One will note that there is no time information in the Series #2 report. This information has been predetermined (already chosen and made available to the ground-based decoder) or can be changed by information in the header for the decoder. This saves communication costs and possible communication traffic congestion problems at busy airports. The time information can easily be inserted by the ground-based decoders.

It should be noted that WVSS-I and WVSS-II actually sample data at a rate of 4 Hertz (4 samples per second), average the 4 samples to a one-second average value, and transmit this one-second data every second to the aircraft's Digital Flight Data Acquisition Unit (DFDAU). It is this data that is actually accumulated at the 6-second and 20-second intervals of Series #1 and Series #2.

The Enroute Report consists of six consecutive data measurement samples sent as a single message to lower costs. The interval of data measurement is from 1 to 60 minutes, the default interval is 3 minutes. This is the interval used by UPS-most other USA carriers have been supplying enroute data as a new complete message every 7.5 minutes. The new enroute format provides about 40-km horizontal resolution at typical aircraft speeds and is more efficient.

The Descent Report is not considered a vertical profile in the usual sense of an ascent report or a balloon ascent because the aircraft descend in different ways-often subject to surface winds, other traffic, weather conditions, etc. Aircraft in the USA approach a terminal at one of four gateways located around the terminal. Though not a "profile", modern 4DDA methods can effectively use this high horizontal resolution data-especially in local area models used in inclement weather conditions, where knowledge of when conditions might improve would be of enormous value. Details of the Descent Report can be found in Attachment #1.

3.2. Evolution of the four character water vapor information field

The sensor technology of the WVSS-I was a thin-film capacitor, which directly measured relative humidity (RH). This WVSS-I probe also had a closely connected temperature sensor (separate from the official Total Air Temperature (TAT) probe on the other side of the aircraft). As long as a valid temperature exists (it turns out we could have used either the new temperature measurement or the existing aircraft temperature measurement) one could downlink either relative humidity, dewpoint, or mixing ratio. Mixing ratio was the unit chosen and the first **four character** set for this information was:

$$nnnQ=n_1n_2n_3Q$$

where $n_1n_2n_3$ implies $n_1.n_2 \times 10^{-n3}$, e.g., $123=1.2 \times 10^{-3}$

and where Q was a quality control character. This format was used for the first six prototype WVSS-I units.

The original avionics vendor for UPS was AlliedSignal and they were responsible for developing the software for the WVSS-I. In the middle of this program, UPS switched avionics vendors and a major delay in activities occurred. This opportunity was used for some further program re-evaluation and it was determined that a second-generation effort (WVSS-II) in parallel with a diode laser would begin, and that the program could save maintenance funds for the WVSS-I quasi-operational phase (where 54 aircraft will fly) by simply using the existing aircraft temperature information and ignoring the delicate maintenance of the new temperature sensor (a new design).

The new avionics vendor for UPS (Teledyne) is now implementing ARINC 620 with a change in this four character water vapor information field as follows:

$$nnnQ=n_1n_2n_3Q$$

where $n_1n_2n_3$ implies $n_1.n_2 \times 10^{n3}$, for example,

040	=	0.4×10^0	=	0.4%
840	=	8.4×10^0	=	8.4%
331	=	3.3×10^1	=	33%
102	=	1.0×10^2	=	100%

Thus, the quasi-operational WVSS-I program, which will operate for about 2 years, will have the percent RH as the downlink variable. A table of Q values (the quality control character) is seen on Page 5 of Attachment #2.

There are several issues with regard to measuring RH on commercial aircraft. The first is that measuring RH is a poor choice because of the high random root-mean-square (rms) errors under conditions of high Mach number and low temperature (conditions found at flight level for most jet aircraft). This is due to the dynamic heating in the measurement probe from the aircraft's speed

$$T_t = T_s (1 + 0.2 M^2)$$

where T_t = total temperature
T_s = static (ambient) temperature
M = Mach number (0.7 to 0.8 for most commercial jets at flight level).

and due to the saturation vapor pressure (e_s, part of the definition: RH = 100 e/e_s) being such a strong nonlinear function of temperature. This combination of effects observed in Fleming (1996), and in further detail in Fleming and Braune (2000), leads to random errors of 15-17% at flight level conditions. It should be mentioned that this current WVSS-I unit is still more accurate than the radiosonde data at these same flight levels-primarily due to the very slow response times of thin-film capacitors on the balloon at such cold temperatures. The 30 degrees of dynamic heating significantly increases the response time of the aircraft sensor.

Applications that only care about ascent and descent can ignore the above concern about measuring RH on aircraft since the aircraft speeds are slow enough that the Mach number effect is small. However, the use of thin-film capacitors to measure RH is also a strategy that requires careful attention to detail to achieve quality data. The first concern is finding a thin-film capacitor with a sufficiently fast response time to match the commercial aircraft application. We tested a number of devices that were too slow. The Vaisala sensor was the best in this regard. However, what was used for the WVSS-I was better than the Vaisala sensor used in radiosondes-which has a strong temperature dependence. A more rugged Vaisala sensing system used in factories was modified by a temperature compensation circuit (to remove further temperature dependencies). After a series of tests, this was the final sensor used in the WVSS-I.

A final issue with thin-film capacitors is their ability to maintain calibration over time. The recommendation for WVSS-I is to replace or recalibrate the sensor every six months. How well, how often, and how easy this recalibration is required and performed in the general aviation application is a serious concern.

The motivation for the WVSS-II was driven by three important factors: (i) desire of the air carriers to have only a single probe (measuring temperature and water vapor information independently), (ii) desire of users for more accuracy at all levels of the atmosphere, (iii) desire by all concerned for a longer maintenance interval. The WVSS-II is expected to have a maintenance (recalibration) interval of greater than 3 years.

The second generation WVSS-II has a diode laser as the water vapor sensor. Through Beer's Law and some sophisticated processing, this sensor can achieve accuracies to less than 5% at all levels of the atmosphere and achieve a very low volume mixing ratio sensitivity down to 2 ppmv (parts per million by volume). This is important in the stratosphere where determining values like 4 or 5 ppmv is important. Water vapor amounts in the upper troposphere and lower stratosphere are important issues in unraveling the uncertainties that remain in the global warming issue. The entire airline industry has a stake in this global warming question; the industry has been identified as a significant contributor to future warming scenarios by the Intergovernmental Panel on Climate Change. As a point of comparison, in the upper troposphere these mixing ratios vary from 10-100 ppmv for the same pressure and temperature conditions. "Dry" conditions seen in the upper troposphere by the WVSS-I have water vapor mass mixing ratios of between 10-20 $\times 10^{-6}$ g/g or 16-32 ppmv.

There is no Mach number effect in measuring the mixing ratio. The existing four- character code being implemented by Teledyne will be the code used for the WVSS-II. It can be shown for typical values of temperature and water vapor pressure encountered by commercial aircraft operations in the stratosphere that differences between 4 ppmv and 5 ppmv produce RH values at 2.3% and 2.9% respectively. Thus such differences can be depicted with this format. **Efforts to have ARINC 620 revised for this four-character code are underway.**

4. INTERACTION WITH AVIONICS MANUFACTURERS

The WVSS-I contract was won by the Lockheed Martin Corporation (LMC). Their subcontractors were AlliedSignal (now a part of Honeywell), Rosemont Aerospace (now a part of BF Goodrich Aerospace), and United Parcel Service (UPS). AlliedSignal was paid to develop the initial WVSS software, which accepts the WVSS-I signals into their DFDAU and output ACARS messages according to ARINC 620. This software has worked well for the first six prototype WVSS-I units and over 200,000 quality-controlled reports have been received.

The next phase of testing is the quasi-operational phase. In this two-year program, 54 B-757 aircraft will fly the WVSS-I (30 from UPS and 24 from American Airlines). There will be 9 spare systems on the ground for one-month turnaround at the approximately 6-month recalibration point. This will maintain all 54 aircraft flying without interruption. This phase will be performed with new Teledyne avionics, which is being replaced at UPS and upgraded at American Airlines. Our arrangement with Teledyne to implement the software to operate the WVSS-I has been unique. Rather than pay Teledyne an upfront software development fee, they will receive a one-time payment of 1000 dollars per aircraft installation of the WVSS (version I or version II). This represents a win-win situation as it solved our cash-flow problem and gave Teledyne incentive to make this software available for all of their new DFDAUs (other B-757 aircraft and other aircraft types). This helps ease the growth of the water vapor sensor throughout the air carrier fleet. The one-time payment per aircraft is also fairly small as airline business goes and is simply included with the installation fee. **There is an action for the NWS and the FAA** to finalize the MDCARS interaction with ARINC so that they have the exact header information available to decode the new ARINC 620 from Teledyne and UPS. American Airlines will operate the same way.

Delta Airlines will be the first carrier to accept the WVSS-II. Delta is also upgrading to this same new Teledyne DFDAU.

Eventually, our contract options for the certification of the WVSS-II will lead us to other major jet aircraft and the new regional jet aircraft used by the commuter carriers. Thus, we will eventually have to return to Honeywell/AlliedSignal to implement the WVSS-II software on their then applicable and equivalent DFDAUs. Our plan is to offer the same financial arrangement as for Teledyne-if there is enough incentive for them and us; i.e., if there are sufficient aircraft equipped with their DFDAU and available or anticipated to carry the WVSS-II. **The author has the action to follow this through to completion.**

There is another avionics manufacturer, SFIM, which primarily operates with Airbus aircraft. They too should be made the same offer concerning the WVSS-II software. There already exists a carrier (SAS) that has ordered Airbus aircraft and wants it equipped with the WVSS-II. **The author has the action to follow this through to completion.**

The expansion of automated environmental information from general aviation aircraft is primarily driven by the communication systems chosen for such aircraft. Since this application will include data **to the cockpit** as well as data from the aircraft, the former bandwidth requirement will outweigh the latter. Nevertheless, working out the "standards with flexibility" issues discussed above in the preceding section will require some avionics interface. Thus, these same principles described in this paper will apply.

5. OTHER END-TO-END COMPONENTS AND SUMMARY

In the end-to-end look at a successful communication system to obtain environmental information from commercial and general aviation aircraft, there are other key components about which more must be said. The first of these is the ground-based center for decoding the real-time data from ACARS or another communication system.

Unless the laws of the land change, the NWS currently has official responsibility for aviation weather forecasts. Ultimately, they should be in control of the 24-hour, 7-day per week decoding effort. Through the evaluation phase of the WVSS, we have used the Internet and the decoding capabilities of NOAA's Forecast Systems Laboratory. This will switch to the existing ARINC/NWS connection whereby current aircraft wind and temperature information is decoded at ARINC and send to the NWS in a prescribed form. The possible development of an entirely new communication system for general aviation aircraft will likely follow a similar evaluation path. Industry or academia could establish the initial decoding activity with the final resting place determined by the success of the effort and by the then-existing governing laws.

There exists another activity, which is a necessary part of the evaluation of environmental data from commercial and general aviation aircraft that is described below. This is a long-term quality control effort-to be contrasted to the short-term gross error checks that might be performed at the time of ground-based decoding of data from ACARS or any other future communication system. This effort has begun at the University Corporation for Atmospheric Research (UCAR). There are several practical advantages to this activity. Only a few are mentioned below.

Here at UCAR, we have developed a three-tier quality control effort to monitor the possible drift in calibration of the thin-film capacitor on individual WVSS-I aircraft. Such an activity would be required for the general aviation aircraft sensors. This provides important feedback to those running the operational prediction models and helps alleviate concerns expressed in Section 2.1.

The next step in the quality control process is the preparation of high quality condensed data sets for subsequent original research or forecast impact studies. While on-going real-time evaluation of new data (e.g., additional water vapor information) will occur at operational centers, the full formal evaluation of case studies whereby the impact of each of the composite observing systems can be performed in a careful manner (away from the hectic pace of an operational center) is a very valuable commodity. Such studies are crucial in the evaluation of new satellite sensor systems, new ground-based remote sensing systems, and even new commercial aircraft-based remote sensing systems-all of which are coming soon.

Finally, such quality-controlled data sets from the commercial and general aviation aircrafts are especially valuable when combined with the composite data in a specific "test-bed" region. It is hoped that such a region (perhaps in the traffic-intense east coast area) can be identified in the combined FAA and NASA aviation programs to test the full impact of their respective programs. Checking out the benefits of the improved programs and all their interfaces (pilots, dispatches, controllers, weather personnel, etc.) in such a test-bed can act as a springboard for new funded national improvements.

Another obvious issue that has been addressed in the commercial aircraft area but not yet in the general aviation arena is "transparency". The entire environmental data gathering effort must be transparent (involve no financial burden and have no adverse impact on operations) to the air carriers. We have found air carriers responding very positively to data acquisition, however, their main business is moving people and/or packages-not meteorological data gathering. Thus, installation and maintenance of sensors and related software has always been accomplished at government cost and at the air carrier's convenience. Moving into the general aviation area may require more or less transparency-on the other hand, the safety issue at the level of an individual may offer more creative options for quid pro quo arrangements. General aviation is made up of many diverse interests and pilots will want sensor details to be transparent. This puts more pressure on quality sensors that maintain accuracy and reliability for long periods of time.

The subject of funding options for implementing data collection from general aviation aircraft is part of a much broader business case analysis. This is beyond the scope of this report. However, one can unequivocally say that significantly improved weather support for safety, efficiency, and capacity within the NAS will only come from the unique data gathering capabilities of the aircraft themselves. There is no other observing system on the horizon to replace it. Thus, the airline industry must help itself. Equally important, however, is the fact that the aircraft measurement system is not self sufficient and needs the other components of the composite observing system established by the various national weather and satellite services of the world. These weather services also gain from the aircraft data in application areas far broader than aviation weather support. It is a win-win situation for both the aviation industry and the government.