3.4 THE EMERGENCE OF COMMERCIAL AIRCRAFT AS A MAJOR COMPONENT OF THE GLOBAL ATMOSPHERIC MONITORING SYSTEM

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1. INTRODUCTION

The use of commercial aircraft as platforms of opportunity to provide real time wind and temperature data began in 1979 (Fleming et al., 1979). The growth of the practice had been slow but steady – reaching 7000 reports per day within the USA in1991 and over 22,000 reports per day in 1996 (Fleming,1996). Today there are organized national efforts to use the commercial aircraft as observing platforms in 15 countries and another 18 countries have similar programs in various stages of development. The impact of such data has been proven positive, and steady growth is assured. Water vapor information from the aircraft has been sorely missed, but this has recently been solved. This paper will indicate the three factors that have come together to accelerate the use of commercial aircraft – leading to the emergence of these aircraft as a major component of the global atmospheric monitoring system.

The reasons for the growth involve the convenience of the platforms, the remarkable accuracy achievable by existing and planned sensors on-board the commercial aircraft, and the increasing demand for more accurate data in quality and quantity for various applications.

The first factor, the convenience of the commercial aircraft, arises from the coverage of the atmosphere provided by the aircraft (performing their primary function of moving people and/ or packages) and from the existence of several methods of communicating environmental data from the aircraft in real time. The original system used in 1979 in the United States was the Aircraft Communication and Reporting System (ACARS). This line of sight VHF communication system now has contiguous coverage over most portions of North America, Europe, and Asia. Coverage is continuing to grow in Africa and South America. Two other communications systems are the INMARSAT satellite and the Iridium satellite systems. Both of these are evolving with greater flexibility and reduced costs.

The second factor is the sensor accuracy. This has taken a dramatic turn for the better as will be discussed in Section 2. The third factor is the increased demand for more accurate data. Three different socioeconomic applications driving this demand are summarized in section 3. Section 4 will discuss the likely funding sources that will help contribute to the growth of the commercial aircraft observing system component.

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2. SENSORS FOR AIRCRAFT

The development of diode lasers, the associated software to achieve extremely accurate measurements for certain gases, and an efficient aircraft air sampling system has led to a perfect scenario for the advancement of a variety of sensors for commercial aircraft. This Section will summarize that development with four examples: the 2nd generation water vapor sensing system (WVSS-II), a new more accurate mobile temperature sensor (MTS) for commercial aircraft, and the use of new quantum cascade (QC) lasers for atmospheric trace gases – using ozone and carbon dioxide as expected initial examples.

2.1 *The WVSS-II*

The WVSS-II uses a near-infrared diode laser to measure accurately the atmospheric water vapor mixing ratio. This was first proven on high altitude balloons and NASA research aircraft (cf. May, 1998). These first applications were "open path" systems with the laser beam extending through the open air beneath the balloon or aircraft. The measurement concept uses Beer's Law in the form:

$$I = I_o \exp(-\sigma n 1) \quad (1)$$

where I = the laser light intensity at detector
I_o = laser initial intensity
σnl = absorbance

with n = number density of absorbing species
l = optical path length
σ = molecular absorption cross section, a function of pressure and temperature near the laser light path

In the usual application of the above formula, I and I_o are measured, σ and l are known, and thus the number density (n) can be calculated from all the other available quantities. For increased detection sensitivity, thus higher precision and accuracy, second harmonic detection is utilized in which a small-amplitude wavelength modulation is added to the laser current (described in May, 1998 and in greater detail in May and Webster, 1993).

The WVSS-II, an aviation product for commercial and military aircraft, is a small, compact and efficient measurement system using a diode laser (provided by SpectraSensors) and the flush mounted University

Corporation for Atmospheric Research (UCAR) air sampler (US Patent No.6,809,648). It was the diode laser and the air sampler that together led to the successful WVSS-II product (see Fig.1).

The WVSS-II diode laser is identical to that used in the telecommunication industry. These lasers are "Telcordia (formerly Bellcor) certified (GR-468-CORE)", which is an industry standard similar to "FAA or CAA certification". The air sampler brings the air into the measurement cell located just inside the aircraft. A 24 cm path length is achieved with a mirror located at the end of a 12 cm path.

The **mixing ratios** of measured quantities like water vapor and atmospheric trace gases are **conserved properties** whether they are measured in static conditions, in fully dynamic conditions (the Mach number effect of the fast moving aircraft), or in conditions between these two extremes. The UCAR air sampler has been designed to take advantage of this fact and designed to optimize conditions in the measurement cell for diode and quantum cascade lasers.

Figure 1. The three main components of the WVSS-II: the air sampler (top), the diode laser assembly (lower left), and combined measurement cell and electronics box (lower right). The two connecting hoses from the air sampler to the electronic box are not shown.

Fig. 1 shows the UCAR air sampler from different perspectives. The air sampler is in the form of an ellipse (major axis is 9 cm long). The flush mounted air sampler saves on fuel costs since there is virtually no drag [compared to the 2.5 lbs of drag associated with the total air temperature (TAT) probe used in the first generation water vapor sensor (WVSS-I)]. Also since the UCAR air sampler does not have to be heated (not an icing issue as determined in the FAA certification) this saves energy – and far more important, eliminates the major failure mode of the TAT probe -- its heater.

The diode laser used for water vapor measurements on the WVSS-II operates at 1.37 μm. This wavelength is not **absorbed** by ice crystals or aerosols; however, a very large number of such ice crystals or aerosols could **scatter** the laser light and reduce the **sensitivity** of the diode laser at the cold dry regions of the upper troposphere.

The NCAR air sampler is aerodynamically designed to remove particles from the air flow. Heavier particles (ice crystals, liquid water droplets, and aerosols) are more dense than the gaseous water vapor, and are inertially separated by accelerating the flow over the aperture in the air sampler leading to the measurement cell and forcing the majority of such particles out of the rear of the external portion of the air sampler. The stainless steel nipple on the air sampler and the Telcordia standard laser give the WVSS-II a 20 year lifetime. Further details are provided in Fleming and May (2004).

The primary reason for the abandonment of the WVSS-I technology of measuring relative humidity (RH) via a thin film capacitor was the liability of the sensor in general, especially for commercial aircraft. The problems of thin film in radiosondes are well documented: difficult to calibrate at the very low and high end values of RH, the slow response time in cold temperature, and software corrections when sensor is wet. Unique to fast moving aircraft is the Mach number effect that amplifies RH random errors on the ground by factors of 3 and 17 respectively for turboprop and jet aircraft at typical flight altitudes. Calibration over time remains the major problem (MOSAIC results from 2400 flights and 140,000 hours of data indicated that recalibration was required every month). Our 4 year test results (Fleming, 2004) indicated that the sensor loses sensitivity in a nonlinear way over time (making subsequent accurate statistical correction impossible).

The WVSS-II is now the most accurate operational sensor for water vapor. Examples of the data accuracy are shown in Figs. 2 and 3. These results were comparisons made at Louisville, KY in June 2005 with radiosondes supplied by the U. of Wisconsin. Fig. 2 compares an aircraft ascent profile with the radiosonde of 0900 Z. The two curves on the right are temperature and the two curves on the left are dew point (converted from aircraft mixing ratio and radiosonde RH data). This comparison is extremely close in space and time as the radial plot in the upper left of the figure shows the path of each platform. The two profiles have time stamps separated by only 12 minutes. The two curves lie virtually on top of each other!

Fig. 3 is another comparison two days later on 23 June 2005. The balloon launch was at 0900 and three different aircraft ascents occurred at 0852, 0855, and 0857. The aircraft data are consistent with the radiosonde and with each other! Only slight differences occur near 400 mb as the upper left radial plot indicates that the aircraft are traveling in three different directions.

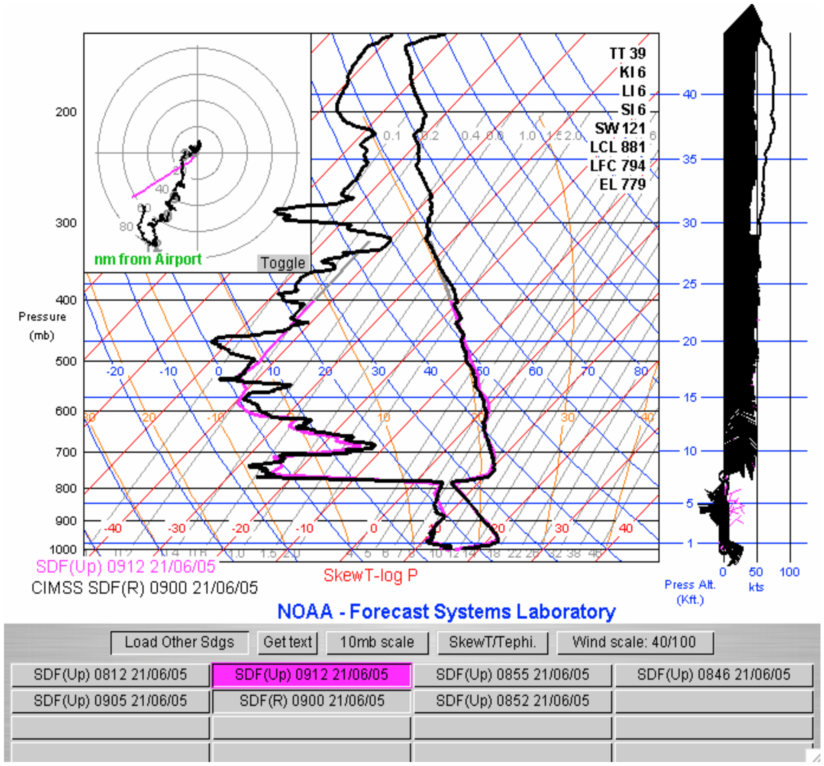

Figure 2. Radiosonde data (black) and WVSS-II aircraft (pink) on 21 June

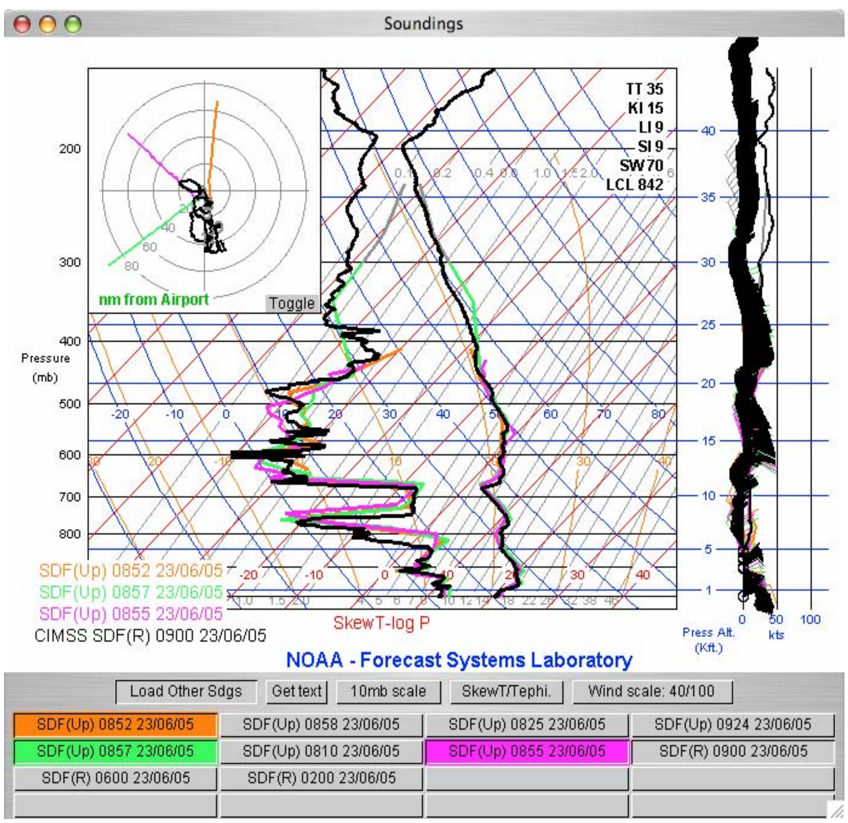

Figure 3. Radiosonde (black) and three aircraft ascents on 23 June 2005

2.2 *Improved TAT sensor for aircraft*

The current total air temperature (TAT) probe on commercial aircraft is the Goodrich Aerospace TAT probe that is on 95-98% of all jet aircraft. There are four deficiencies in these Goodrich probes that can be overcome. The greatest problem is a lack of accuracy, which under the best of conditions is ± 0.6 to 0.8 degrees C, but the temperatures are often found to have much larger random errors and biases (Randy Baker, personal communication, 2003). The Goodrich TAT probe's other three deficiencies are the probe heater (required by the FAA because it is susceptible to icing), which is a significant failure mode for the probe (causing maintenance costs and delays); the probes' drag (causing increased fuel costs); and the probes' radar cross section (unacceptable for some military aircraft).

The temperature accuracy is the important issue for aviation fuel savings and atmospheric science applications. While major bias issues can occur with bird strikes leaving residue within the probe, a more serious concern is smaller systematic biases between aircraft types. Bias differences between types of Boeing and Airbus aircraft were revealed at the AMDAR meeting in Beijing in 2004 (Jeff Stickland, personal communication).

SpectraSensors, Inc. (SSI) has begun work on two improved mobile temperature sensors (MTS) – one with a laser and one without. Only the latter product is discussed here. All four deficiencies of the Goodrich TAT probe are removed with either product. The non-laser MTS improves the accuracy by a factor of two, is flush mounted (no heater) , has little drag, and is more stealthy. A modification to the UCAR air sampler (shown previously in Fig. 1) is a solid metal measurement cell (aluminum or composite material to match the skin of the mobile platform) attached beneath the aircraft skin.

This measurement cell (see Fig. 4) contains two PRT temperature sensors which serve as the measurement system (and as the backup system for the laser version of the MTS). The extruded measurement cell is mounted to the skin and to the required doubler/filler plate necessary for the aircraft (or mobile platform) to maintain its original structural integrity. The measurement area contains a surface mounted temperature sensor (on the **side** of the hollowed out area) to measure "sensor ambient temperature" and a sensor (**extending into the middle** of the area to measure "sensor dynamic (total) temperature". Note that both the **sensor** ambient temperature and **sensor** dynamic temperature will be warmer than the natural ambient and dynamic counterparts due to the surface skin friction. The skin friction will be the **only** cause for the temperature difference as the measurement cell has been isolated from temperature inside the aircraft and from possible heat conduction from the aircraft skin by several methods.

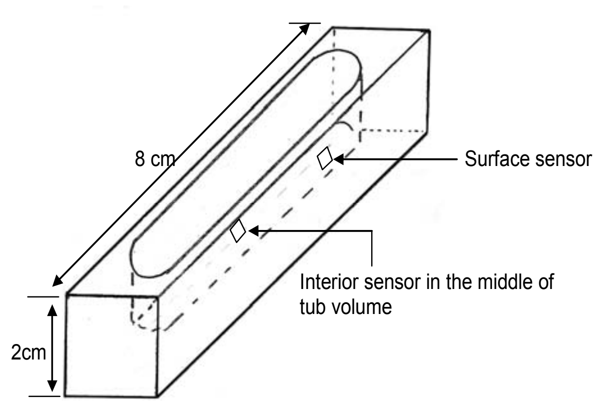

Figure 4. The bottom piece of the Fleming Air Sampler with the measurement area hollowed out like a tub. The air passes down on the left, flows to the right, and exits upward on the right – passing two temperature sensors (see text).

The skin friction is modeled as a function of Mach number (M) – a polynomial in M statistically determined by thousands of data points in the lab, by comparison with the other aircraft temperature sensors, and with laser temperatures (when available).

One will find that the statistics of the data analysis of Mach number (M) and the effects of frictional heating will **not** be a purely Gaussian process, and that a considerable number of outliers will occur with a positive bias in the tail of the probability distribution. Various statistical procedures have been used in the treatment of outliers – rejecting the more extreme outliers and accommodating other outliers in a robust manner.

The key to this approach (which could have been implemented 50 years ago had the computer power and software been available – thus avoiding the extended TAT probe) is (1) choosing a proper location for the flush mounted sensor on the fuselage (2) using accurate sensors (which are available) (3) placing the flow region of the air sampler the right distance from the fuselage (which reduces the effects of friction), (4) isolating the friction effect, and (5) implementing the proper statistical modeling of the friction effect as discussed above.

The non laser MTS (including the modified UCAR [Fleming] air sampler, the temperature design, and software) has a patent pending .The laser version of the MTS of Randy May (patent pending) is expected to be three to four times as accurate as the Goodrich TAT probe**. Various tests are in progress.**

2.3 *The ozone sensor*

Diode lasers typically have frequencies ranging from that of blue light to the near infrared. QC lasers (invented in 1994) have demonstrated emission wavelengths from 4 to 24 μm (Capasso, et al., 2002). The potential of QC lasers for many applications is well recognized, but their explosive use has been temporarily limited by their cost and by the lack of availability of lasers capable of operation at **both** room temperature and in a continuous-wave (cw) mode. [Note that there are currently lasers generating up to 1 W in pulsed mode and lasers generating similar power levels operating cw at liquid-nitrogen temperatures.] The QC lasers operate in the fingerprint region of many molecules of interest—though there may be choices of how best to measure a particular trace gas.

We begin by defining the minimum absorbance measurable by our proprietary 2f detection methods, consider the precision required for the application, and then determine the required path length (obtainable with a single path on a multi-path Herriott cell). Minimum detectable absorption (MDA) levels for a 2f spectrometer depend on a variety of factors including individual laser tuning characteristics, optical system design, and electronic circuit design and implementation details. For a field instrument which must tolerate vibrations, pressure and temperature fluctuations, and is constrained in cost, a typical MDA is in the 1×10^{-4} range (i.e., changes in I/Io of 1 part in 10,000 can be detected). With this MDA if is possible to calculate the optical path length required for a given gas mixing ratio (or number density, n) using the absorption cross section (see Eq. 1) for the transition of interest.

Ozone has a strong absorption band near 9.5 µm which is commonly used for atmospheric monitoring**.** This is in the “sweet spot” for QC lasers and a 9.2 µm QC laser was fabricated in 2001 that operated CW in a near single mode at room temperatures. So although room temperature, CW QC lasers with a distributed feedback (DFB) structure are not yet available at reasonable cost at the wavelength needed for ozone monitoring, such devices are very likely to be available within the next year or two based on market demand for the devices in many industrial monitoring applications (Blaser, et al., 2006). UV-based ozone monitors are also possible and in wide use today, but have several disadvantages for continuous operation on a commercial aircraft platform which won’t be discussed here (lamp lifetime being one of the most serious problems).

Using spectral line parameter from the Hitran 2004 database (Rothman, et al., 2005), simulations of the 9.5 µm ozone spectrum were carried out to determine the optical path length needed to produce a line center absorption value of 1×10^{-4} for an ozone volume mixing ratio of 10 ppbv (typical lower tropospheric value in a “clean” atmosphere). Although the line center absorption level on a particular transition will vary with pressure and temperature (because the cross section varies) the optical path length required for ozone is approximately 6 m. This optical path length can be achieved using a Herriott cell with a base path length of 20 cm and 30 passes using 1” diameter mirrors. Alternatively, a shorter base path and larger diameter mirrors can be used to realize the same optical path. There are well known design tradeoffs for a Herriott cell that generally dictate the optimum configuration for a particular application, and such a “trade study” would be completed to arrive at a final design for an aircraft ozone sensor using a QC laser operating near 9.5 µm.

2.4 *The carbon dioxide sensor*

As with ozone, it is straightforward to determine the required optical absorption path length for measuring CO_2 in the atmosphere using the known cross sections. However, unlike ozone, CO_2 is relatively well mixed in the atmosphere with a volume mixing ratio near 370 ppmv from ground level into the stratosphere. Small seasonal and latitudinal variations in CO_2 are well documented, and scientifically useful measurements require a higher level of precision than for ozone measurements.

CO_2 has a fundamental absorption band near 2.7 µm, and room temperature DFB lasers are commercially available now which operate in this wavelength region. Because the absorption cross sections for CO_2 are large near 2.7, and because the spectrum is simple (CO_2 is a linear molecule), it is possible to choose an isolated spectral line for monitoring that is free of interference from water vapor (which also has a fundamental absorption band near 2.7 µm). Furthermore, an optical path length of 24 cm (the same as used with the WVSS-II system) is adequate for measurements. Therefore, a CO_2 measurement system could be essentially identical to the WVSS-II system with appropriate changes to the optics and the detector (fused silica would be replaced with sapphire optics, and the WVSS-II InGaAs detector would be replaced with InAs and a modified preamp design).

Another possibility using a DFB laser near 2.7 µm is simultaneous measurement of both H_2O and CO_2 with a single system. With the appropriate choice of wavelength scan, it may be possible to identify a region with spectral lines of both molecules present and measure them at the same time. This is also common with diode laser spectrometers and the trick is to find lines which are sufficiently separated in wavelength to avoid a complicated analysis, and which have cross sections that allow their intensities to be within the detection range of the spectrometer. Since water vapor concentration can vary by four orders of magnitude over the altitude range of a commercial aircraft, the ideal H_2O line at cruise altitude may be completely saturated (i.e. 100% absorbing) at ground level. This would provide good H_2O measurement capability at cruise level but prevent measurements at ground level. So although it is possible, in principle, to design a single- laser system to measure both CO_2 and H_2O, a more detailed study is needed to determine feasibility over the range of H_2O concentrations in the atmosphere, and optimum choice of laser wavelength**.**

3. INCREASED DEMAND FOR MORE ACCURATE DATA

The demand for more accuracy in data can be created for a variety of reasons. Here we summarize three examples of requirements driven by relevant socioeconomic issues applicable to our time. The background for all these areas is the continued population growth and further industrial growth of many previously less developed countries. The world population growth rate has decreased (1.1% per year versus the 1.7% rate over the past 30 years), but we will still have 8.3 billion people on the planet in 2030 versus the 6 billion we have now. Many countries are developing stronger economies; e.g., the recent acceleration of the economies of China and India has added two billion consumers for new products not normally purchased by the average citizen in those countries.

3.1 *Aviation weather and mesoscale atmospheric science*

The requirements for aviation weather support have always been mesoscale in nature, but that upper air support has never been achieved. Conversely, the overall demands of future atmospheric research and applications dictate a migration to mesoscale upper air observations (which has not yet occurred), but that synergistic support can now come from the aviation community itself – all the elements are in place.

Fig. 5 indicates the kind of mesoscale upper air coverage possible using the airports used by the major and regional air carriers (show in red). Using just 2400 aircraft (less than half of the 5000+ aircraft that fly over the USA airspace everyday) the number of ascent/descent profiles that one can achieve would be over 100 times as many **independent** profiles of winds, temperature, and water vapor as provided by the radiosonde sites (shown in blue). Unnecessary duplication of ascent/descent profiles (close in space and time) would be removed.

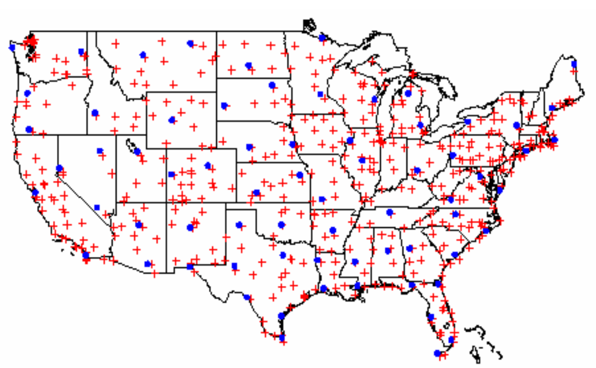

Figure 5. Radiosonde sites indicated in blue dots and airports used by major and regional air carriers indicated with red plus signs

3.2 *Global warming and intensity*

There remain debates over the timing and intensity of global warming due to anthropogenic causes. Two areas where climate model simulations do not agree with current upper air observations involve temperature and water vapor. The upper atmosphere should warm prior to the surface according to theory and model results.

The degree of this expected warming is not seen in the data. The water vapor loading due to a doubling of carbon dioxide should increase substantially according to the climate models (10 to 20%). Despite the increase in CO_2 since the industrial revolution there is only debatable weak evidence that water vapor has increased from radiosonde data and similarly weak evidence from satellites that it has decreased. This should be a clear signal according to the strength of the model result, but accurate water vapor information has been lacking.

The temperatures from radiosondes and satellites have accuracy deficiencies in the upper atmosphere. Temperatures from commercial aircraft can be more accurate and serve as a reference. They must be monitored for quality in their current form, but they can be significantly improved as described in the sensor improvement section above. The water vapor data set is in far worse shape – both from radiosondes and satellites. This can be dramatically improved with the WVSS-II added to commercial aircraft.

The data gathered from just 10,000 of the 30,000 aircraft that fly everyday could provide a marvelous data addition (well over one million **independent** data points per day) to the climate record. Moreover, as indicated by many authors, the addition of accurate *in situ* data merged with satellite data (having relatively large absolute errors, accurate gradient information, and spatially correlated errors) produces an analyzed field which is greater than the sum of the parts. This phenomenon occurs when proper four dimensional data assimilation is used. Such a global data set would go a long way toward removing the two uncertainties we have identified in the global warming issue.

3.3 *Air quality (regionally and globally)*

The impact of more people and of more industrial gases and chemicals (byproducts from our advancing technological cultures) certainly will raise the level of concern about the quality of the air we breathe and its impact on human health. We are optimistic that society can readily cope with this issue. However, coping will require a far greater monitoring of the four dimensional chemically laden atmosphere than we now perform. Several developed countries are beginning to address the prediction of air quality as weather prediction was address in its infancy.

The chemical species data available for this prediction problem are primarily surface data with a very small amount of usable satellite data and profile information. The convenience of the commercial aircraft platforms and the new sensors (for many of the chemical species of interest, but not all) that can be mounted on them together suggests that the aircraft can play a major role in raising the quantity and quality of data for this important social concern.

4. FUNDING CONSIDERATIONS

This section will compare the costs of equipping aircraft with the WVSS-II with the recurring costs of the radiosonde program. Extrapolation of the costs for aircraft with other sensors can only be approximated at this time. Finally, an indication of where the funding for the aviation component of the global monitoring program is projected.

4.1 *Cost comparison*

The active number of flight days per year per commercial aircraft (from major and regional air carriers) will conservatively average about 340. This accounts for down time for various periodic checks required (e.g., the C-check occurs every 2.5 years and is about two weeks in duration). The major carrier aircraft average about 4 ascents and 4 descents per day; for the regional carriers this average will be about 6 each. Thus, for a mixture of major and regional aircraft one could expect an **average aircraft** to provide a theoretical 10 profiles per day or 3,400 profiles (winds, temperature, and water vapor) per year. While some redundant data is beneficial for quality control purposes, the assumption is made that considerable data from major hub regions will not be required and the overall number of profiles actually produced will be 10% less or approximately 3000 per year per aircraft. [The enroute data will be discussed later.]

In order to simplify the discussion, only the **radiosonde recurring costs** (balloon, helium, and the radiosondes themselves) and the **aircraft recurring costs** are considered. The radiosonde communication costs for the data, the ground hardware required, establishment of the site itself, the people costs of salary and benefits, etc., are all ignored. By the same token, the communications costs of the aircraft data and the initial installation cost of the WVSS-II is ignored. **Assume these costs (nonrecurring except for the communication costs) for the two systems are equal, though the radiosonde system costs would be considerably higher.**

The WVSS-II will be leased (a recurring annual lease fee) rather than considered as a one time purchase – this is more expensive for the user, but makes his life easier (no concern for maintenance or calibration which is included in the lease price -- much like buying a new automobile and paying for a service agreement in advance).

The radiosonde recurring costs are expected to average $300 per launch (GPS sondes). So for a site that launches two balloons per day the yearly cost is

($300 X 2 X 365) = $219,000/yr for a total of 730 profiles

The balloons usually go higher than the aircraft, but the aircraft also provide enroute data. An extremely conservative estimate is that an average aircraft could provide 100 **independent** data points per flight day or 34,000 non-redundant data points per year. These enroute data can be providing mesoscale information in both space and time for the upper atmosphere – a goal for atmospheric science. Assume the higher balloon data and the additional aircraft enroute data are equal.

SpectraSensors, Inc. (SSI) will also sell the WVSS-II product, but for this comparison we will consider their lease program where the user pays $4,500 per year per aircraft as a single cost and all maintenance is covered, 24 by 7 on call service is provided, and the WVSS-II is replaced every 2.5 years (the expected maintenance interval) with an equivalent to new unit that has been accurately calibrated. Under this lease program, the user can call and request a replacement unit at any time the user feels it is necessary. This price is for a typical national program and could be slightly higher or lower depending on the volume.

Thus, the WVSS-II single aircraft cost is ($4,500 / $219,000 = 0.0205) or approximately 2% of the cost of the radiosonde site and provides (3000 / 730) = 4.109) or approximately 4 times as many useful profiles.

This suggests that the benefit/cost ratio for the aircraft is about 200 times better than the radiosonde site. The accuracy of the winds and temperatures of the two systems are comparable and the water vapor information from the aircraft is more accurate – particularly in the upper troposphere where the radiosonde data is notoriously bad (many participants involved in the GVAP project, personal communication).

The cost of the improved MTS will be less than the existing TAT probe. The costs of the initial systems for sensing various chemical species will be essentially the same as for the WVSS-II components except for the laser used. These laser costs are currently higher by a factor of 10 or more than the WVSS-II laser used. The QC laser costs continue to come down and these costs will be closely monitored by SSI.

4.2 *Funding sources*

The demand for more data and more data accuracy to serve the socioeconomic examples listed in Section 3 will provide the stimulus for resources to fund the commercial aircraft monitoring program expansion. The aviation industry continues to face difficult problems with fuel costs and most are struggling financially. They would benefit from the more accurate temperature and water vapor data in many ways but must continue to rely upon the National Weather Services and Civil Aviation Administrations of the world to finance the new water vapor sensors. The air carriers would agree to carry the WVSS-II free of charge because of the benefits to the industry.

The MTS for aircraft would save the carriers money and this use may not require outside funding. However, the need for additional and more accurate temperature data in the upper troposphere for reducing climate model uncertainty justifies an accelerated funding effort from outside sources.

The heated debate over the timing and intensity of global warming has not yet reached the boiling point. The costs of mitigation efforts have not reached a point of any serious impact on the average citizen. However, when the proposed mitigation efforts (many at odds with the growing world energy shortage, see Weisz, 2004)) reach a point a point of being implemented with harsh effects on people's pocketbooks and/or lifestyles, then many organizations that will demand that the uncertainties associated with that global warming intensity and timing be profoundly reduced. One may see "green" organizations, energy alliances, and consumer advocate groups all trying to spend money to reduce the uncertainties by any means possible. One could imagine government economic agencies (not previously involved in such funding) becoming involved in observing system funding that could directly reduce the uncertainty.

There is another large potential source for funding observations to reduce climate change uncertainty. This is the insurance business. Mills (2006) has recently discussed the implications of future climate change to this industry, the world's largest [$3.2 trillion in yearly revenue would make it the third largest country if compared to national gross domestic products (GDPs)]. Global weather-related losses in recent years have trended upward much faster than population, inflation, or insurance penetration, and faster than non-weather-related events. The consequences of future climate change, increased population,, and all the uncertainty associated with climate change bodes ill for the insurance industry as a whole and for the insured – complicating the fundamental actuarial and pricing processes that underlie well-functioning insurance markets. The industry will surely rise to the occasion and help contribute to reducing the uncertainty – for the industry and for us all.

The issue of air quality is another concern that is only now getting the serious attention it deserves. Expanding the predicting of air quality like the early days of weather prediction may require the assistance of research organizations to help accelerate the observing system and science fundamentals. The Global Weather Experiment of 1979 [another name for the First Global Atmospheric Research Program GARP Global Experiment (FGGE)] was an example where many research agencies combined their funds to significantly advance a global observing system effort (Fleming, et al., 1979). One of the outfalls of that effort is the current global commercial aircraft observing program.

Accelerating the use of atmospheric trace gas sensors on commercial aircraft may be a part of a larger effort to improve data and modeling to bring the air quality prediction effort to a level of world class stature.

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