EIGHTH WORKSHOP ON
METEOROLOGICAL OPERATIONAL SYSTEMS

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Session 4

AIRCRAFT DATA FOR NWP

1. Introduction

1.1 For many years, meteorological observations obtained automatically from regular passenger jet aircraft have proven to be an excellent means of supplementing upper air observations obtained by conventional means. Not only is the data quality comparable to that of data obtained from conventional systems, but the system is also very cost effective. Such systems are known generically as Aircraft Meteorological Data Relay (AMDAR).

2. Historical Background

2.1 Automated meteorological observations from passenger jet aircraft have been available in one form or another since the late 1970s when the first Aircraft to Satellite Data Relay (ASDAR) systems using specially installed processing hardware and satellite communications were used in support of FGGE. Subsequently, by the mid 1980s, new operational AMDAR systems taking advantage of existing onboard sensors, processing power and airlines communications infrastructure were developed requiring only the installation of specially developed software. Many of the world's airlines use the Aircraft Communications and Reporting System (ACARS) which uses VHF, satellite and more recently, HF components. By the mid 1990s, three distinct AMDAR producing regions had developed - Australasia, North America and Europe.

2.2 The WMO AMDAR Panel was formed in 1998 to assist Members develop national and regional AMDAR programs. The main goal of the Panel is to enhance the upper air component of the Composite Observing System of the World Weather Watch through cooperation among Members in the acquisition, exchange and quality control of meteorological observations from aircraft using automated reporting systems.

2. Current Network

2.1 AMDAR programs are operated currently by Australia, New Zealand, the United States, South Africa, Namibia, and by five European countries - the Netherlands, the United Kingdom, France, Sweden and Germany. The European program is supported by a group of fourteen EUMETNET countries . A total of 16 participating airlines are providing observations as shown in Table 1. Whilst the national or regional interest is the main driving force behind these programs, never-the-less many flights are made well beyond these areas to many other parts of the world including some data sparse regions. AMDAR aircraft produce over-flight data at cruise levels and vertical profiles of wind and temperature observations at many remote airports. Up to 120,000 observations per day are produced globally, most of which are distributed on the WMO Global Telecommunications System (GTS). A typical example of global coverage for 24 hours is given at Figure 1.

Table 1 - Participating Airlines

Oceania	United States	Europe	Southern Africa
Qantas	Untied	KLM	SAA
Ansett	American	BA	Air Namibia
Air New Zealand	North west	Air France	
	Delta	SAS	
	UPS	Lufthansa	
	Fed Ex		

The number of daily AMDAR observations used operationally by ECMWF has increased from around 9000 in 1994 to about 90,000 in 2001 as shown in Figure 2.

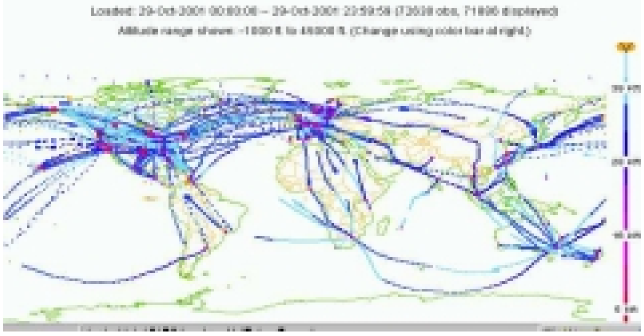


Fig. 1 24 hour AMDAR Coverage (Courtesy NOAA FSL)

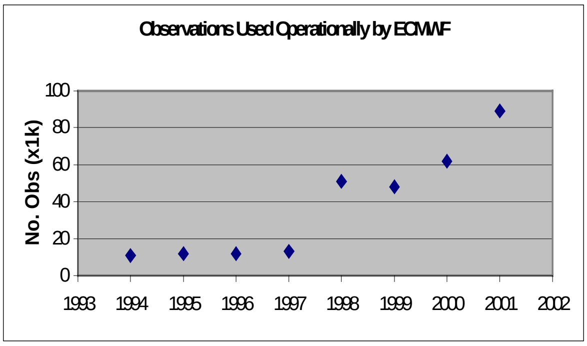


Fig.2 ECMWF Operational Use of AMDAR data

3. Network Expansion

3.1 Advances in network expansion have occurred in a piecemeal way over recent years, but the planning and development of new AMDAR programs are now being well-planned and co-ordinated by many countries and regions. It should be noted that it takes from between one to three or four years to develop a fully operational AMDAR system, so many of the systems under consideration and listed below, will not commence producing data for several years.

3.2 Development of new systems are grouped into three categories:

3.2.1 **Under Test** - Three countries are testing new systems:
1) Canada - will extend North American coverage to the Arctic;
2) Hong Kong China - will become the first operational system in Asia;
3) Saudi Arabia - will become the first operational system in the Middle East.

3.2.2 **Being Planned or Developed** - Twelve countries or regions are planning or developing new national or regional programs:
1) Europe: Spain, Finland, Iceland, Austria, Poland, Hungary;
2) Russian Federation
3) Africa: Morocco, the southern Africa region and Mauritius (under SADC);
4) Asia: Japan, China:
5) South America: Chile

3.2.3 **Interested** - Twelve countries or regions are interested in developing an AMDAR program:
1) Europe: Ukraine, Greece and Italy;
2) Africa: Kenya, and a group of 15 countries in Central and West Africa under ASECNA;
3) Middle East: Egypt and the United Arab Emirates;
4) Asia: Kazakstan, Singapore, Malaysia and Korea;
5) South America: Brazil.

4. Targeted Observations

4.1 AMDAR has a clear advantage over most other in-situ observing systems in that it has the capability of providing data at very low cost at remote locations. A number of National Meteorological Services (NMSs) have commenced their AMDAR programs by taking advantage of data provided by visiting AMDAR equipped aircraft from other countries that operate into local airports. This is usually achieved by arranging co-operative agreements with the NMS or agency responsible for AMDAR in the country whose airlines are providing the data, eg. the Bureau of Meteorology in Australia, the National Weather Service in the US and EUMETNET in Europe. In some cases data are provided free of charge, but it is normally expected that the country receiving the data reimburses the host country for the cost of providing it. It is now technically feasible to target observations at specific geographic areas and even individual airports almost any where in the world. These programs are being actively promoted by the AMDAR Panel in collaboration with the data providers and their participating airlines.

4.2 **Recipient Countries** - Eleven countries or regions are either currently receiving targeted observations or have indicated an intention to do so. Countries providing the data are given in parentheses in the following list:

Currently receiving targeted observations:

1) North America: Canada (E-AMDAR);
2) Africa: Southern Africa (Australia, E-AMDAR), Africa (E-AMDAR);
3) Eastern Europe: Most countries (E-AMDAR);
4) Middle East: Most countries (E-AMDAR);
5) Asia: Hong Kong (US and Australia);

Countries interested in establishing dedicated targeted programs:

1) African ASECNA group (E-AMDAR);
2) Middle East: Oman, Saudi Arabia, Egypt (E-AMDAR);
3) SE Asia and SW Pacific: RAV region (US, Australia and E-AMDAR);
4) Central and South America: Caribbean, Gulf of Mexico and Central America region, Brazil (US and E-AMDAR).

5. Communications Costs

5.1 Contracts are normally arranged between an NMS and its national airline(s) for a data delivery service and the airline charges for that service, of which, the cost of communications forms the major component. The cost per observation through VHF datalink varies significantly between airlines but the range is from less than 1 US cent to about 11 cents with the median value at 4 cents. An observation typically consists of time, latitude, longitude, altitude, phase of flight, temperature, wind speed and direction, and where available, turbulence and humidity. Aircraft are normally configured to transmit to a VHF ground station while within signal range, but there are many places, particularly the oceanic areas where this is not possible so satellite communications are used. Satellite communications charges are between 5 to 10 times those of VHF.

5.2 The cost effectiveness of AMDAR as a source of upper air data is demonstrated by comparing with the cost of conventional upper air sounding systems. An AMDAR profile consists of between 20 and 40 observations from the surface to cruising level at around 30,000 ft., depending on reporting configuration. Considering a mean value of 30 observations, then the typical cost of an AMDAR profile is US1.20. This compares to the cost of a GPS radiosonde sounding of more than $200 if staff time is considered. An annual program of 4 AMDAR soundings per day would cost $1,800. This is compared to an annual cost of one GPS radiosonde sounding per day of $73,000.

5.3 The limitations of an AMDAR sounding are to be noted:

- The maximum height of a sounding is the aircraft cruising level;
- The sampling rate is not as high as that of a radiosonde so some fine structure is missed;
- Except for a small number of systems under test in the US, no humidity observations are made;
- Many aircraft are not equipped with AMDAR;
- If satellite communications are considered to be too expensive, then the system is limited to the communications coverage provided by the VHF network providers for real-time data reception.

6. Cost Effective Targeted Observations

6.1 A most important aspect of AMDAR is revealed when the ability to target observations at remote locations is combined with the low cost of data. Targeting can be used to fill gaps in data sparse areas or in assisting with the detection of special meteorological events. AMDAR can also provide a source of very valuable upper air data for countries that cannot afford a complete conventional upper air program. WMO is encouraging the establishment of cooperative arrangements between such countries and those able to provide targeted data using their international aircraft fleets. As stated earlier, it is normally expected for the recipient country to reimburse the data provider for the marginal cost of data. However, it is clear that in some cases, this is not possible. It is noted that AMDAR data are not confined to national boundaries and that national programs are potentially of great benefit over large regions. Consideration should be given to the establishmentment of an operational fund to support targeted AMDAR data for countries that cannot afford to pay.

7. Network Optimisation

7.1 The rapid development of AMDAR programs in some regions has seen a steep growth in data availability to the point that aircraft are now producing too many observations in some areas and airports. This data redundancy is seen as wasting valuable resources and in need of a controlling mechanism.

7.2 Recent improvements in the functionality of AMDAR onboard software together with the availability of aircraft track and flight information, have provided valuable tools for the development of automated optimisation systems. Criteria are established for the required spatial and temporal density to meet operational requirements and are used by the optimisation system to control production of AMDAR observations. Controlling techniques include the onboard use of defined geographical areas, specific airports, and the use of the phase of flight, ie. ascent, cruise and descent. Inclusive and exclusive options are also available. Two methods are used to change these parameters. The first is through loading new software while the aircraft is on the ground. The second and much more flexible and convenient method is through radio uplink which provides a new capability of making changes in real time through an automated ground-based system.

7.3 By using a mixture of controlling methods, the E-AMDAR program has established a very powerful and cost effective optimisation system that has produced a saving of 40% for one airline and much improved coverage throughout most of Europe by applying those savings. Australia developed a very simple system using controls in onboard software and Canada has included high level optimisation in its new system.

7.4 Optimisation systems have now reached the point where it is technically feasible to run a single optimisation system for the whole world. Offers to run the system have been received from two companies.

8. Data Quality

8.1 A number of monitoring centres independently use the first guess field of global or regional NWP forecasting models to assess the quality of AMDAR observations. Australia has implemented two additional operational monitoring techniques. The first compares AMDAR observations with radiosonde soundings and the second makes an intercomparison between all available aircraft. Whichever technique is used, the results are very much the same except the intra-aircraft method removes any overall bias of the aircraft system.

8.2 Table 2 shows the results of two recent surveys. NCEP monitoring statistics for September of data from US, Australian and European aircraft were used to obtain a global estimate of the bias and RMS values for temperature and wind vector differences . Estimates of differences of wind speed and direction were obtained from the E-AMDAR Monitoring Report for the second quarter of 2001.

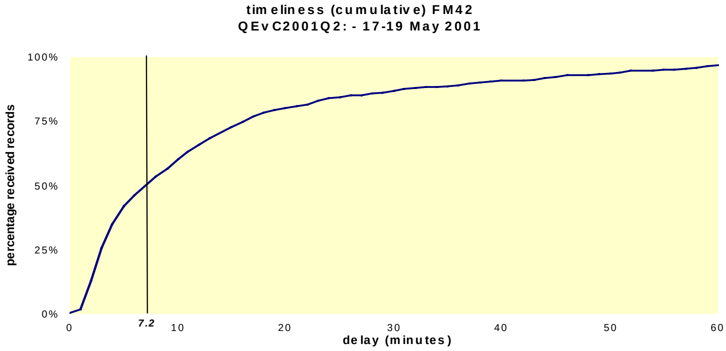
Table 2 - AMDAR Data Quality

Element	Bias	RMS
Temperature (deg.C.) (global)	0.1	1.1
Wind Vector (m/s) (global)	0.4	5.4
Wind Speed (m/s) (E-AMDAR)	0.1	0.4

Wind Direction (deg) (E-AMDAR)	8	10

9. Timeliness

9.1 AMDAR observations are stored onboard until a prescribed number to form a downlink message has been obtained. Normally, during the ascent and descent phases the period between messages is quite short but at cruise level various systems require between 4 and 10 observations to form a message. With a time interval of 7 minutes between observations, the oldest observation is 63 minutes old and the youngest only a matter of seconds before the message is sent. Aircraft to destination communications are normally very quick, only a minute or two, so the main cause for delay in delivering an observation is the onboard storage. The E-AMDAR Monitoring Report for the second quarter of 2001 shows at Figure 3 the median value to be 7.2 minutes. 99.3% of data is available within 60 minutes and 99.8% of data within 120 minutes.



▪ *Cumulative frequency distribution for all FM42 encoded EU-Amdar observations during the period 17-19 May 2001 as a function of the interval between observation and time of reception. (median value: 7,2 minute).*

10. Data Exchange

10.1 Most AMDAR observations are exchanged on the WMO GTS for operational use by NMSs in standard WMO code forms. All Australasian, African and most European data are encoded in WMO FM42-XI AMDAR text code and most US MDCRS and German data are encoded in WMO FM94 BUFR. The GTS data are enclosed in bulletins signifying the regions from where the observations are obtained. Some additional US data that is not available on the GTS is available through a secure NOAA FSL web site. The contact person is Bill Moninger at email: moninger@fsl.noaa.gov.

11. Quality Monitoring and Control

11.1 Quality control of AMDAR data consists of 4 main components:

- **Onboard software** where various checks can be made on sensor performance and gross error checks and trend testing on the derived observations;
- **Ground-based data acquisition system** located at the NMS or its agent where checks are made before data are distributed for operational use. Checks include incoming format errors, outlyer rejections, rates of change, lists of blacklisted and poor performing aircraft;
- **National or regional monitoring centres** providing detailed daily statistical reports of data referenced against NWP models, and performance enquiries to national focal points;
- **Global monitoring centres** providing monthly statistical and black list information to regional or national focal points.

11.2 The monitoring and control process being followed by most AMDAR centres requires a reliable link between the relevant monitoring and switching/distribution centres. These centres can be either regional or national depending on the local situation. The recommended model to follow is that whenever poor quality data are detected by a monitoring centre, information on the offending aircraft is passed within hours to the switching centre which then inhibits distribution of the data from that aircraft for operational purposes. This normally prevents data being used for local operations as well as being exchanged on the GTS and other international communication systems. The national or regional focal point then advises the relevant airline and requests that remedial action be taken. It is important to note that in the short term, data transmission from the aircraft need not be inhibited because it is useful to continue to monitor the data off line until such time that it once again becomes acceptable for operational use. However, depending on the likely length of time before the problem can be fixed, it may be prudent to inhibit aircraft transmissions to save wasting money on unwanted data. Once the airline advises that remedial action has been completed, data from the aircraft can be monitored off-line until such time as the focal point is satisfied it is acceptable for operational use. The switching centre is then advised accordingly. It is generally more convenient and easier to maintain control of this system if all the major elements are conducted within the NMS.

12. Onboard Software Standards

12.1 Two global software standards are currently in use although some airlines have developed software to their own standards to better suit their own operations. The two standards were developed independently to suit different operational requirements but are now being upgraded to meet one common specification reflecting the operational requirements of the global meteorological community. The work is being done by the AMDAR Panel in conjunction with the Airlines Electronic Engineering Committee to form a new ARINC 620 avionics standard.

12.2 The two standards are:

1. **ACARS Aircraft AMDAR (AAA)** which was developed from the original WMO ASDAR specification and has been upgraded several times to provide flexible functionality for observation triggers, targeting and optimisation. It also includes various forms of data compression. The AAA has formed the basis of the specification adopted by the AMDAR Panel. Resulting software is freely available for Teledyne ACMS avionics hardware. Various forms of this specification have been implemented by nine airlines.

2. **ARINC 620 Meteorological Report** which is the industry standard adopted by avionics companies. The specification has been implemented by most avionics manufacturers to suit a limited range of hardware and has been implemented in various forms by 6 airlines. It contains limited targeting and optimisation functionality and is currently undergoing a substantial upgrade along similar lines to the AAA.

13. New Observation Elements

13.1 In recent years there has been a growing demand for observations of humidity, turbulence and icing.

13.2 **Humidity/Water Vapour:** The importance of the detailed knowledge of atmospheric water vapour structure is well recognised. This has resulted in AMDAR managers placing a high priority on finding a suitable but inexpensive aircraft sensor. Many NMSs have decided to postpone replacing some radiosonde soundings with AMDAR data due to the lack of a suitable humidity measurement. Work continues in the US and the UK on the development of reliable sensors that meet the exposure requirements of the harsh aircraft environment. In the US, a series of operational trials on a Mark 1 sensor are nearing completion and a new Mark II system has been built. It is undergoing final checks before being certified for flight on B757 aircraft early in 2002. Certification on other aircraft types will continue over the next few years. The sensor will form part of a new combined temperature/water vapour probe with an estimated purchase and installation cost of the order of $20,000. Airlines will need to obtain spare sensors and modify installation and maintenance manuals but it seems unlikely that they will agree to meeting these costs. It will therefore become the responsibility of government through NMSs or other agencies to fund these sensors. The most cost-effective way to use the sensors is on lower flying regional aircraft with cruising altitudes less than 18,000ft. rather than the conventional national or international aircraft. The purchase and installation price together with the an ongoing maintenance cost of an estimated $1000 per year as well as the need for changes to airline procedures, make the task of implementing a broadly based AMDAR humidity sensor program a non-trivial matter. It is likely therefore that the implementation of operational humidity sensor programs will take a much longer time than perhaps had been anticipated originally.

13.3 **Turbulence:** Turbulence observations although seen as being mainly relevant to aviation is becoming a valuable verification tool for forecasters and forecasting products. Turbulence has been reported by a number of AMDAR systems since the mid 1980s in the form of the aircraft independent element to estimate Derived Equivalent Vertical Gust Velocity (DEVG). It has been used operationally for forecasting and as a verification tool in some countries since then. DEVG is included in the AAA software specification. More recently, the US has developed another aircraft independent turbulence measurement called Eddy Dissipation Rate (EDR). Operational trials are being conducted on 80 US aircraft with the view to developing a system that will be used to provide a range of aviation forecast and warning products as well as a verification tool and eventually as input to NWP. ICAO has included EDR in the automated air reporting program as part of the Aircraft Dependent Surveillance System (ADS). However, work needs to be completed to verify the proposed reporting scale to ensure that it is consistent with the affects experienced in the aircraft cabin. It is noted that no NMS has firm plans or has undertaken any work to evaluate the operational use of EDR. It is anticipated that once substantial trials have been undertaken and confidence in using EDR develops, then implementation on regular AMDAR fleets will become more extensive.

13.4 **Icing:** Although a number of icing sensors and detection techniques have been developed for aviation applications, mostly in the US., no single system has been selected for operational reporting of icing conditions. At least one operational system is under development in the US but it will be several years before a clear choice is made and systems become available for installation. The AMDAR Panel keeps a monitoring watch on activities in this field.

14. Future Directions

14.1 It is clear that many new operational AMDAR systems will be established by a wide range of countries over the next few years. Quite a number of these countries are located in data sparse areas of the world. Where gaps remain, affected countries will be encouraged to develop cooperative programs of targeted observations with countries hosting AMDAR systems. An international funding source should be established to help support programs where local support is not available.

14.2 Recent developments have shown the effectiveness of implementing sophisticated optimisation schemes to control redundant data. These same techniques can be used to target observations to improve global coverage and to provide additional observations whenever they are needed. There is a growing level of international cooperation, particularly at the regional level, that shows how sharing resources can help to reduce development and operational costs and increase the mutual benefits that AMDAR can provide.

14.3 The valuable developing collaboration between WMO and the aviation industry is expected to continue. The outcome over the next few years will be:

- the availability of a much broader range of AMDAR equipped aircraft meeting the same performance standards;
- more readily available and affordable AMDAR systems with flexible onboard software to meet operational needs of individual NMSs; and
- increased support for AMDAR to airlines from avionics providers.

14.3 There will be an increasing number of lower flying regional aircraft that will result in more profiles at smaller airports and an increase in the number of en-route observations in the 15,000 to 20,000 ft altitude range.

14.4 The introduction of humidity sensors is expected to commence in the next few years but implementation is likely to be slow. Likewise, the implementation of turbulence reporting using an aircraft independent element will become more extensive. The choice of a suitable system to measure and report icing conditions will also be made in the next few years with implementation to follow.