Requirements for the Implementation and Operation of an AMDAR Programme

World Meteorological Organization

Commission for Basic Systems

Expert Team on Aircraft-Based Observing Systems

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Contents

Introduction

This document provides guidance to WMO Members on the requirements for the establishment and operation of a national or regional AMDAR observing system in collaboration with one or more partner commercial airlines. It has been contributed to and reviewed by observing system experts of WMO Members, including members of the WMO Commission for Basic Systems (CBS) Expert Team on Aircraft-Based Observing Systems (ET-ABO).

1. What is AMDAR

Aircraft Meteorological Data Relay (AMDAR) is a World Meteorological Organization (WMO) meteorological observing system that facilitates the fully automated collection and transmission of weather observations from commercial aircraft. The AMDAR programme is an integrated component of the WMO Global Observing System (GOS) of the World Weather Watch (WWW) Programme[1]. The system is operated by WMO Member NMHS in collaboration and cooperation with partner airlines and has grown rapidly and continuously over the past two decades.

While the AMDAR programme is currently served by a worldwide fleet of over 3000 aircraft contributing more than 400,000 high quality upper air observations per day, there are still many areas of the world with little or no AMDAR coverage and WMO is urging Members to work towards improving upper air coverage of the GOS by developing new and expanding existing national and regional AMDAR programmes.

This document briefly outlines and describes the requirements and basic steps required to develop and implement a national AMDAR programme.

1.1 The AMDAR Observing System

The figure below provides a general depiction of the AMDAR system in which onboard sensors, computers and communications systems collect, process, format and transmit the data to ground stations via satellite and VHF radio links. The transmission of this data is most often performed by the aircraft's ACARS (Aircraft Communications Addressing and Reporting System) system. Once on the ground, the data is then relayed to the global network of national meteorological services and other authorised users.

[1] WMO World Weather Watch Progamme: http://www.wmo.int/pages/prog/www/index_en.html

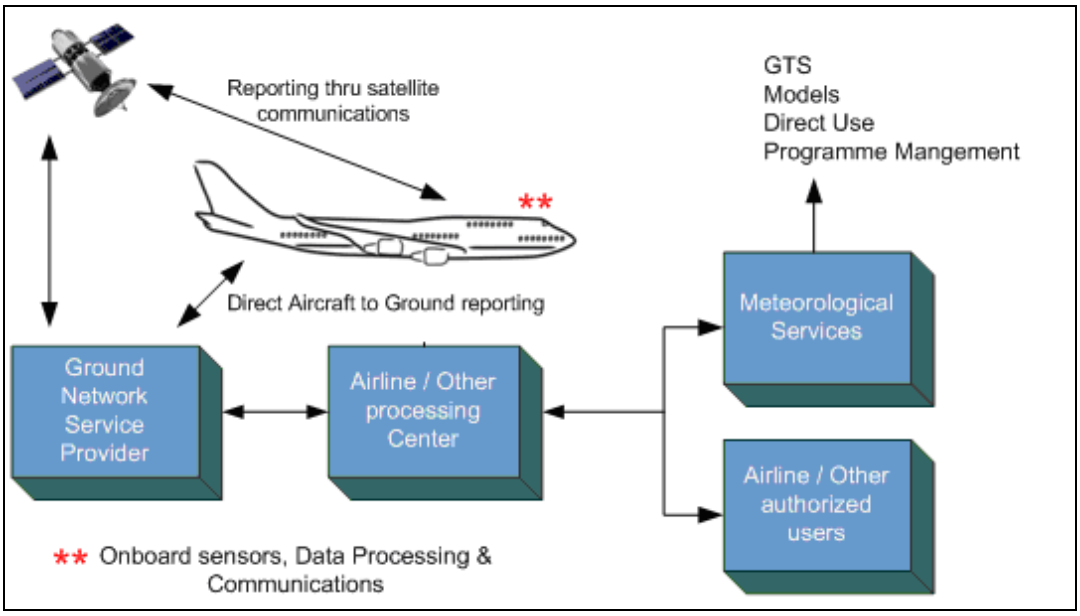

Figure 1: The AMDAR observing system.

The primary data set reported from the AMDAR programme includes position in time and three dimensional space, wind speed and direction, and ambient temperature. Additional parameters are optionally reported including, a turbulence metric and humidity, the latter requiring the deployment of a water vapour measurement sensor.

The temporal and spatial resolution of the AMDAR observations is related to the phase of flight as shown in figure 2.

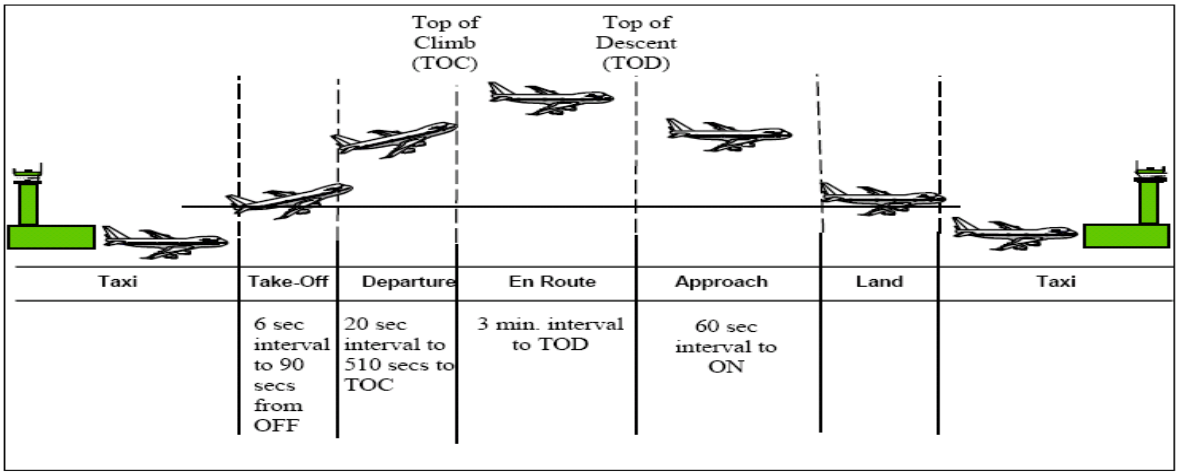

Figure 2: Reporting of AMDAR Observations during the different phases of flight (based on a particular configuration of the AEEC ARINC 620 Meteorological Report time-based specification).

1.2 Benefits and Impact of AMDAR

AMDAR data have been demonstrated to have similar quality to that of radiosonde data and can be used in much the same manner. The impact of AMDAR data on Numerical Weather Prediction (NWP) computer models in particular has been quantitatively determined to be significantly positive (generally reducing global NWP error by around 10-20%) and second only to that of high-volume satellite data when compared with other observing system impacts. Additionally, in some areas of the world, AMDAR soundings provide the only information available on the detailed vertical structure of the atmosphere. They provide high resolution information that help define certain critical atmospheric phenomena that are not well resolved by satellite data.

For more detailed information on the benefits and impact of AMDAR data see:

http://www.wmo.int/pages/prog/www/GOS/ABO/data/ABO_Benefits.html

In particular: WIGOS Technical Report 2014-1, *The Benefits of AMDAR to Meteorology and Aviation*[2].

For more detailed information on the AMDAR observing system and its operation see the WMO AMDAR website - http://www.wmo.int/amdar/

[2] Available from the WMO website: http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/publications/Benefit_of_AMDAR_Data_to_Meteorology_and_Aviation.pdf

2. AMDAR Programme Development

When considering the development and implementation of a national AMDAR programme with one or more partner airlines, it is necessary for the NMHS to address each of the following basic aspects:

1. Assessment of requirements for upper air data;
2. Assessment of national airlines capabilities and coverage;
3. Obtaining airline contacts and commencing negotiations with the airline(s);
4. Building a business case for airline participation;
5. AMDAR programme cost considerations;
6. Contracts and agreements between NMHS and Airlines;
7. Design and implementation of the AMDAR system; and
8. Data display and use.

Each of these aspects is described below but can be considered to provide an overview only of the various considerations for each topic.

Where possible, Internet links or references to additional material or guidance are provided.

2.1 Assessment of requirements for upper air data

Before commencing the development of an AMDAR programme the requirements of upper air data users and applications areas, including national, regional and global, should be taken into consideration. These requirements should be assessed against the capabilities of the current national composite upper air observing system and the ability of an AMDAR programme to fill gaps and/or to provide an efficiency dividend, for example through a reduction in operational costs based on a possible reorganization of the upper air observing system in conjunction with the AMDAR programme development. Other upper air observing systems that might come under consideration in such an analysis are radiosondes, radar wind profilers, polar orbiting and geostationary satellites and other ground-based remote-sensing systems.

The national aspects of such an analysis can be undertaken only by each NMHS individually in consideration of both the current configuration of the composite upper air observing system and its likely future evolution.

An obvious consideration is that the AMDAR programme coverage is fully dependent on when and where the participating airlines fly to and from, and that their programmes and flight schedules can vary from day to day, week to week, month to month and seasonally depending on customer demand and other airline-dependent factors.

Given the international operations (i.e. regional and long-haul international flights) of many national airline operators, it is also important to take into consideration that the AMDAR programme, by its nature, offers the opportunity to collaborate with regional and international NMHS partners to share and optimise the efficiency and coverage that can be provided. It is highly recommended that Members work within their respective Regional Associations and other international forums to investigate and take advantage of opportunities to collaborate on a regionally coordinated approach to national AMDAR programme development, including the possibility to share costs associated with infrastructure (e.g. ground-based data processing systems), resources and data production (e.g. an NMHS might pay the costs for data generated within its country by another AMDAR programme).

The WMO Rolling Review of Requirements[3] process and its associated tools may be of use in the process of determining the requirements of data users for upper air data, in particular the Observing Systems Capability Analysis and Review Tool[4], Observation Requirements[5] database.

2.2 Assessment of national airlines capabilities and coverage

Following on from the assessment of requirements for upper air data and gaps in the composite observing system should be an assessment and consideration of the capabilities of the existing national airlines and their potential to provide an AMDAR programme that might contribute to meeting those requirements.

Potential operators of a national or regional AMDAR programme should start with a preliminary assessment of the national airlines' aircraft fleets and analysis of the operational routes serviced by the airlines.

The overall aim of the survey and analysis of the national airlines should be to determine what coverage might be obtained by equipping one or more fleets of aircraft and which combination of airlines and aircraft fleets most efficiently provides the optimal coverage that best meets established requirements for upper air data.

Generally detailed information on the airline's fleets and the flight routes that they operate can be found on the airline's Internet website. If not, then it will be necessary to first undertake the process to establish contacts within the airline (see section 3) and obtain this information from those contacts.

The following aspects and questions regarding the airline especially require consideration:

1. Which types of aircraft does the airline operate and over which routes does each aircraft type tend to fly?
2. Of these types, which fly domestic routes and which fly internationally?
3. What is the age of the aircraft? The more modern the aircraft, the more likely they will be able to accommodate an AMDAR software application. Note however that it will eventually be necessary to determine exactly which avionics the aircraft have and whether or not they will support an AMDAR software application.
4. Of prime importance is whether the airline and aircraft have ACARS (communications) capability, which enables the near-real-time automated reporting functionality required for AMDAR programme operation.
5. Which airports does each airline and aircraft fleet service routinely?
6. Based on the airline flight schedules, how many vertical profiles per day at each airport are likely to be obtained through equipping the different aircraft types?
7. Is the airline well established, stable and likely to continue operation well into the future?
8. Does the airline have a strong maintenance division within the airline? While this is not crucial and, in fact, there are many airlines that outsource their maintenance operations, it is certainly beneficial to be able to liaise with technical people and engineers within the airline that understand the engineering aspect of aircraft maintenance and monitoring via avionics systems.

[3] See: http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html
[4] See: http://www.wmo-sat.info/oscar/
[5] See: http://www.wmo-sat.info/oscar/observingrequirements

Once the initial analysis of national airlines above has been undertaken, it is then necessary to make a more firm determination on whether or not the airlines and aircraft have the required technical capabilities. This can be done by asking the airline to complete a questionnaire, the Airlines AMDAR Compatible Systems Survey that is available from the WMO AMDAR/Resources website[6].

The survey should be completed either before or after the airline has agreed to participate in the AMDAR programme and will be necessary to identify the onboard avionics type and capabilities, which will determine the suitability and requirements for AMDAR onboard software (see section 5.3 below).

Once the survey has been completed it can be returned to the WMO Secretariat, who can assist in providing further advice regarding AMDAR software development. The relevant contacts are:

- Dean Lockett, Scientific Officer Aircraft and Remotely-sensed Observations, dlockett@wmo.int; and,
- Stewart Taylor, Chairman CIMO Task Team for Aircraft-Based Observations, stewart.taylor@metoffice.gov.uk

For a global summary of airlines operating AMDAR suitable aircraft, highlighting those that have been targeted by WMO to contribute to extending global AMDAR coverage, it is also recommended to consult the WMO report, *AMDAR Coverage & Targeting for Future Airline Recruitment, February 2013*[7].

2.3 Obtaining airline contacts and commencing negotiations

Once it has been confirmed that one or more national airlines operates aircraft that might contribute to the WMO AMDAR programme and the upper air data requirements, the NMHS should seek to establish some key contacts within the airline so as to be able to begin negotiations and present a business case to the airline for participation in the programme.

The following are the recommended key contacts within the airline, one of more of which will be necessary to be involved in at least the preliminary negotiations for AMDAR programme development.

Airline Contact	Role in the Airline	Role in AMDAR Programme Development and or Operation	Comment
Airline CEO or other senior executive officer	Executive manager and high level decision maker	• May understand the impact of weather on airline operations. • May be a recipient of the business case for programme participation. • May provide initial, high-level decision on airline involvement in the programme.	• Unlikely to be involved in detailed negotiations. • Unlikely to be involved in ongoing aspects of the programme.
Senior Pilot	Senior representative of pilots to airline executive	• Will understand the impact of weather on	• May be involved in the initial negotiations

[6] See: http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/resources/index_en.html

[7] Available from: http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/resources/AMDAR_Coverage_Recruitment_Study.html

	and is influential in airline decision making, particularly in relation to those aspects of flight operations and safety	• May provide influence on high-level decision on airline involvement in the programme • May be a recipient of the business case for programme participation. • May provide a link to flight operations aspects of the programme.	• Unlikely to be involved in ongoing aspects of the programme.
Flight Operations Manager	Manager of all aspects of aircraft flight operations and is often the contact that liaises with NMHSs for weather services.	• Will understand the impact of weather on airline operations and efficiency, including fuel usage. • May provide a link to aircraft maintenance and engineering areas of the airline.	• May be involved in the initial negotiations and also the ongoing aspects of the programme. • Often is the first airline contact made by the AMDAR programme manager due to the weather services link.
Avionics and Maintenance Engineering	Responsible for airline aircraft and avionics maintenance.	• Will be involved in determining avionics capabilities. • Will be responsible for AMDAR software integration.	• Can be a useful first-up contact but usually defers to other airline managers regarding participation in the programme and its benefit to the airline.

Once a suitable group of airline contacts has been established, the NMHS should start negotiations with the airline management in order to convince them of the benefits of participation in the programme and then to reach agreement on the operation of the programme, including AMDAR fleet size and configuration, AMDAR software development and integration, implementation and ongoing costs and other factors associated with the design of the AMDAR system (see section 2.4).

2.4 Building a business case for airline participation

Of critical importance in the process of convincing the airline to participate in the AMDAR programme is the development of a business case by the NMHS which should clearly establish the business relationship between the provision of the AMDAR data, resulting in an improvement to weather forecasting skill and services to aviation by the NMHS, which will lead to improved and more efficient flight operations by the airline, reduction in airline costs (e.g. fuel use) and increased airline customer satisfaction.

For more detailed information on the benefits and impact of AMDAR data, which should be used in developing the business case see:

http://www.wmo.int/pages/prog/www/GOS/ABO/data/ABO_Benefits.html

In particular, the WIGOS Technical Report 2014-1, *The Benefits of AMDAR to Meteorology and Aviation*[8], provides a detailed suite of information on AMDAR data benefits and impact that should be integrated into or referenced as part of the business case made to the airline.

Other important considerations for inclusion and explanation in the business case made to the airline are the following:

- It should be emphasised that the AMDAR software module, once installed and operational, will have no impact on the operation of the aircraft. The AMDAR software is tested and certified to ensure seamless and safe integration into the (non-sensitive part of the) avionics, such as ACMS or its equivalent.
- The AMDAR observations, collected and pre-processed by the special AMDAR software, are interleaved in the routine aircraft data flow over the standard aircraft-to-ground ACARS system.
- The airline may argue that the AMDAR data provided to the NMHS improves weather services generally, which benefits all airlines, including the competitors of the participating airline(s). While this is true, it should be emphasised that there are at least two benefits participating airlines have over non-participating airlines:
    1. The performance of onboard sensor(s) providing data to the AMDAR software, which are integral to the operation and performance of the aircraft, can be monitored as a result of the provision of AMDAR data to the NMHS. The NMHS can therefore provide a complimentary service to the airline to inform them if and when a sensor is errant or out of calibration; and
    2. The airline can promote its participation in the programme, demonstrating its commitment to improved airline operational performance, greater customer satisfaction and reducing its impact on the environment.

[8] Available at: http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/publications/Benefit_of_AMDAR_Data_to_Meteorology_and_Aviation.pdf

3. AMDAR programme cost considerations

The costs for the development and operation of an AMDAR programme are highly dependent on the relationship between the NMHS and the airline and the extent to which the airline perceives or quantifies the benefits based on the business case for AMDAR programme participation (see section 2.4).

Generally, AMDAR programmes have been and are established between NMHS and their partner airlines under the understanding and agreement that the mutual benefits (see section 1.2) dictate that the NMHS should pay no more that the incremental costs only of establishing and operating the programme in cooperation with the airline.

A costing model for comparing the estimated costs associated with operating an AMDAR programme with those of a radiosonde programme was developed and some summary results are available in Annex 5 of WIGOS Technical Report 2014-1, *The Benefits of AMDAR Data to Meteorology and Aviation* (see footnote 8).

In summary, the programme costs are largely dependent on the following factors:

- the communications solutions adopted in cooperation with the airline;
- the contractual arrangements between the particular airline and its data service provider (DSP);
- the volume of AMDAR data generated by the fleet;
- the extent to which the airline perceives and quantifies the benefits of participating in the programme; and,
- the extent to which the airline is willing to contribute (financially) to the programme.

3.1 Developmental and infrastructure costs

It is also recommended to budget for additional and ongoing maintenance cost for the required ground-based infrastructure and software.

3.1.1 AMDAR onboard software

In some cases, AMDAR software is already available for the aircraft and avionics configuration required, and developmental or adaptive costs may be relatively small (of the order of $10K USD or less). In other cases, it may be necessary for software to be developed, which may incur one-off costs (per aircraft and avionics type) of the order of up to $100K USD. The more optional functionality that is requested (e.g. uplink command and configurability), the higher the software development cost will be.

3.1.2 Software integration and roll out

Once developed, the airline is required to integrate the software roll out and implementation process into its standard operational procedures, which will likely incur a cost to the NMHS. Generally, it would be expected that such a cost might be of the order of $0.5K USD per aircraft.

3.1.3 Communications infrastructure

Costs to the NMHS associated with establishing communications will be dependent on the communications design solution (see section 5) to be established.

Irrespective of whether the AMDAR data is to be relayed from the airline or the Data Service Provided (DSP – e.g. ARINC[9] or SITA[10]) to the NMHS, it may be necessary to establish a network server to which the data can be pushed or pulled to – this may involve capital costs of the order of $5K to $10K USD including operating system costs.

If a network address is required to be established with the DSP a relatively small license establishment fee may be required along with ongoing service charges, which will likely depend on the volume of AMDAR data generated by the programme (see ongoing costs below).

3.1.4 Data processing development

The major developmental cost to the NMHS will be associated with the development of the in-house data processing and management system, which should have the following elements:

- Software module to process the decoding of the data and store in a database – the latter may require the purchase of an off-the-shelf database application;
- Software module to quality control the incoming data and re-encode into required formats for internal use and for transmission on the GTS (see section 5);
- Optimisation system development costs (see section 5); and
- Data monitoring system (see section 5).

For each of these developments, the costs will be dependent on many factors including: existing infrastructure and software applications, the requirements to engage external contractors for development and the level of sophistication required or desired in the data processing and monitoring system. Such costs, excluding the cost of the development of an AMDAR Data Optimisation System, might range from as little as $20K USD to as high as $100K USD or more.

WMO strongly encourages collaboration with other WMO Members and Experts to reduce such costs.

3.1.5 Data optimisation system

The costs associated with the development of an AMDAR Data Optimisation System to control AMDAR data output automatically through uplink command control, if such a development is required, will depend heavily on the specification of functional requirements and the solution chosen. Several Members have specified and developed solutions already and it is possible that collaboration between members could greatly simplify and reduce the developmental costs associated with such requirements. Additionally, the two major service providers, ARINC and SITA may be able to offer a solution for which a smaller implementation cost would be incurred but with a monthly service fee required.

Members are advised to contact WMO to discuss this system design aspect.

3.2 Ongoing operational costs

3.2.1 Data Communications Costs

The principal operational cost of any AMDAR system is in the ongoing communications costs associated with AMDAR data transmission, both the air-ground and the ground-

[9] ARINC, Aeronautical Radio, Incorporation (now a subsidiary of Rockwell Collins): http://www.arinc.com/
[10] SITA, Société Internationale de Télécommunications Aéronautiques: http://www.sita.aero/

based components. This cost will again be dependent on several factors, including the communications solution negotiated with the airline and/or the DSP.

Some operators of AMDAR Programmes have been able to establish communications solutions that deliver AMDAR data to the NMHS for less than $0.10 USD per observation.

3.2.2 Aircraft system utilisation costs

Although not common and not encouraged, some NMHS have agreed to pay the airline a small annual or monthly fee for the costs associated with maintaining and running the AMDAR data software onboard the aircraft. This cost would be expected to be small and no more than an annual cost of the order of $0.5K per aircraft.

4. Contracts and agreements between NMHS and Airlines

It is very important that an agreement, contract or memorandum of understanding (MoU) is established between the NMHS and each participating airline for the operation of the national or regional AMDAR programme. Such a document should outline the terms and conditions agreed upon to cover at least the following aspects of the programme operation:

- The time period for operation of the agreement and the programme, including an arrangement for contract or agreement termination.
- The number of aircraft to be equipped with AMDAR software for reporting AMDAR data at an agreed frequency of reporting (e.g. refer to an included specification of requirements or proposal).
- Costs payable to the airline by the NMHS.
- Requirements of the airline to ensure data supply and quality.
- Requirements of the NMHS to report to the airline any issues or faults associated with AMDAR software performance and data quality.
- The terms and conditions, including liabilities and the rights of the NMHS and 3rd parties (e.g. NMHS clients) covering use of the AMDAR data, which may desirably include ownership (i.e. jointly with the airline) of the associated meteorological data upon reception. It is critical that this aspect of the agreement at least allows AMDAR data to be distributed on the GTS and used by WMO Members according to WMO resolution 40[11].
- 3rd party liabilities associated with operation of the programme and AMDAR data use:
    - The NMHS should seek to ensure that the agreement precludes the NMHS from being liable for any damages (including 3rd party claims) associated with any aspect of the aircraft operation (this must be the airline's responsibility); and,
    - The agreement should preclude the airline being liable for damages (including 3rd party claims) associated with any aspect of data use by the NMHS and its data users and clients (this should be the NMHS's responsibility).
- Ownership and Intellectual Property (IP) rights. The agreement might stipulate that:
    - If appropriate and, depending on which party contributed resources to its development, the NMHS has ownership of the AMDAR onboard software.
    - WMO and/or the NMHS have rights over the IP associated with the specification of the AMDAR onboard software.

Important Notes:

- The making of contracts and agreements can be a complex process and such documents must be consistent and in keeping with both national and international laws and legislation. For this reason, it is highly recommended that Members consult with either their own or hired legal counsel to assist in the agreement development process and ensure that any agreement or contract developed is both compliant with the law and does not unknowingly or otherwise disadvantage any parties to the agreement.
- In many cases, national laws prevent contracts from the waiving of 3rd party liabilities. In such cases, it is critical to undertake a risk assessment and ensure that each party

[11] WMO Resolution 40: http://www.wmo.int/pages/about/Resolution40_en.html

has developed and implemented appropriate mitigation strategies for any risks associated with the operation of the programme.

If requested, WMO may be able to assist in the process of developing an agreement or contract between a NMHS and an airline for operation of a new or developing AMDAR programme. For example, the European E-AMDAR programme has developed a contract template which can be made available to be used as a basis and starting point for the development of a new agreement.

5. Design and implementation of the AMDAR system

When commencing a new AMDAR programme, there are many considerations that must be made in regard to the design of the system that will be required to be developed and implemented to support the reception, processing and utilisation of the AMDAR data delivered by the participating airlines.

In designing and implementing the AMDAR system, the NMHS must consider all those components of the AMDAR system that are shown in Figure 1 above. Only summary information on the AMDAR system design will be covered in this document.

For a detailed description of the AMDAR system, see the AMDAR website:

http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/AMDAR_System.html

For regulations and guidelines related to the WMO AMDAR programme, see the WMO AMDAR Resources/Standards site:

http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/resources/index_en.html

The following are the major system components that must be addressed, developed and implemented:

1. Regional and international design considerations;
2. Configuration and optimisation;
3. AMDAR onboard software development and implementation;
4. Air-to-ground communications;
5. Ground-based communications infrastructure for AMDAR message reception and processing;
6. Delivery to data users; and
7. Data quality management and monitoring.

5.1 Regional and international design considerations

There are two regional international aspects of an AMDAR programme design that might be taken into consideration before designing and implementing an AMDAR programme and system. These are:

1. International AMDAR data sharing and optimisation opportunities; and
2. International Cooperation on AMDAR system infrastructure;

Many national airlines operate internationally and, therefore, may be capable of producing AMDAR data both within and outside national boundaries, including both en-route data and vertical profiles at airports. This has implications for two aspects of the AMDAR programme. Firstly, if a national airline is not yet ready to participate in the AMDAR programme, it might be possible for AMDAR data to be provided over or within the country by another operational national AMDAR programme. Through a bilateral arrangement or agreement, the recipient NMHS pays the incremental costs to the operational AMDAR programme for providing the data. Secondly, when it comes to the make-up of the AMDAR fleet to be made operational, it is worth considering equipping a combination of domestic, regional and international aircraft fleets, which, when combined with suitable configuration or optimisation (see 5.2) would allow a more comprehensive national and regional coverage. This would have several advantages including an even greater impact on national, regional and global NWP and the opportunity for collaboration and data cost sharing with other NMHSs.

The second regional international consideration may lead to significant opportunities for reducing the costs associated with AMDAR system infrastructure. Because of the international aspect of airline operations and communications and the fact that the AMDAR programme relies on using standardised aviation and meteorological communications protocols (i.e. AEEC ACARS and WMO BUFR), it is possible that AMDAR data can be received and processed by dedicated regional data processing hubs. This offers the opportunity for international and regional collaboration and efficiency dividends in relation to the development of AMDAR programme infrastructure.

Examples of regional cooperation in AMDAR are:

- The E-AMDAR programme (14 airline partners, supported by 31 member states) which provides supplementary global data outside the EUCOS domain through bilateral agreements and as a contribution to the WMO World Weather Watch Programme;
- The US MDCRS programme (7 airline partners), which provides data outside the USA domestic airspace over central and south America; and,
- AMDAR data cost-sharing between Australia and New Zealand.

This activity is strongly encouraged by WMO and can be facilitated through cooperation within WMO Regional Associations[12] and communication between the national WMO AMDAR Focal Points[13].

Under the WMO Aircraft-Based Observations Programme (ABOP), Regional Implementation Plans for AMDAR have been or are being developed as a component of the Regional WIGOS Implementation Plans[14].

5.2 Configuration and optimisation

Even before AMDAR software is developed, it is necessary to consider the likely size of the national AMDAR fleet and how data production will be configured and controlled. AMDAR Onboard Software contains software configuration parameters and functions for optimising reporting, such as geographical area and time limiting and vertical profile targeting by airport. When limited to this onboard functionality, AMDAR systems and programmes could produce redundant data levels of up to 50% to 70%, depending on the meteorological requirements for vertical profile data, the size of the AMDAR fleet and the density of AMDAR aircraft at particular airport locations and the time of day.

Given the sometimes significant communications costs associated with the AMDAR system, AMDAR Onboard Software has been specified and developed to respond to "uplink commands", which are able to be transmitted and processed by the onboard ACARS system. Some AMDAR Programmes have then made use of this AMDAR software functionality by developing and implementing ground-based AMDAR Data Optimisation Systems. These systems automatically receive and process downlink trigger messages from AMDAR aircraft and compile and send uplink commands in order to reconfigure the reporting configuration of the AMDAR Onboard Software in near real-time based on assessment against data reporting and coverage requirements. Such AMDAR Data Optimisation Systems have demonstrated the capability to reduce the communications costs associated with the AMDAR system by 50% or more, while not adversely impacting on requirements.

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[12] http://www.wmo.int/pages/governance/ra/index_en.html

[13] A list of WMO Focal Points on aircraft-based observations is available at: http://www.wmo.int/pages/prog/www/CBS/Lists_WorkGroups/CBS/cross-cutting/amdar-fp

[14] See WIGOS Documents: http://www.wmo.int/pages/prog/www/wigos/documents.html

AMDAR Data Optimisation Systems have been implemented in the E-AMDAR and Australian AMDAR Programmes and ARINC is able to provide this as a service to their AMDAR client NMHSs. SITA is also developing such an application as a potential service to existing and future AMDAR programmes.

For national AMDAR Programmes with fleet sizes of the order of 50 or more aircraft, it is recommended that AMDAR Data Optimisation Systems be implemented as a component of the system.

In addition to reducing costs and data redundancy levels, AMDAR Data Optimisation Systems also offer the capability of altering and adjusting data observational outputs based on short-term requirements associated with targeting for synoptic weather system monitoring and prediction.

The AMDAR onboard software (AOS) also is configurable so as to control where and when AMDAR data is produced and the default configuration of the software should be discussed with the software developer and specified before the software is developed and released. This may include control over where data is produced geographically and at which airports vertical profiles are generated.

5.3 AMDAR onboard software development and implementation

The role of the AMDAR Onboard Software (AOS) is to facilitate the functions and the required system interfaces of the onboard AMDAR system. The primary functions of the AMDAR Onboard Software are:

1. Interface to and accept input data from a variety of aircraft innate avionics equipment;
2. Perform a coarse quality check on the input data;
3. Perform calculations upon the input data to derive required meteorological variables;
4. At set intervals, process collected data into standard output messages for transmission to ground stations; and,
5. Accept and process inputs, allowing users to alter the AOS behaviour.

Given that the full functionality of AOS is quite processing and computationally complex and demanding, the AMDAR system relies on and is usually best employed in modern, larger commercial aircraft, which will tend to have the necessary avionics, data computers and communications systems.

The current AMDAR Observing System relies on the communications protocols defined for the Aircraft Communications and Reporting System (ACARS), which are specified within the standards of the Aeronautical Airlines Electronic Engineering Committee (AEEC).

WMO currently specifies and maintains two meteorological standards for AMDAR Onboard Software:

1. The AMDAR Onboard Software Functional Requirements Specification (AOSFRS), which supersedes the ACARS AMDAR ACMS (AAA) specification series (versions 1 to 3).
2. The "ARINC 620" AMDAR Onboard Software versions 1 through 5 defined within the AEEC 620-7 Data Link Ground System Standard and Interface Specification (DGSS/IS), which is maintained by the AEEC Data Link Systems Sub-committee. Within the specification, AMDAR reporting formats and functionality are defined through the definition of the Meteorological Report.

The AOSFRS and the ARINC 620 specifications both rely on the basic DGSS/IS ACARS protocols. The specifications are provided from this site within the AMDAR Resources Area[15].

The NMHS and the Airlines will need to reach agreement on the terms and conditions for any software development that is required to be undertaken and whether there will be a requirement for the involvement of a 3rd-party applications developer.

The AOS will generally be required to undergo testing and certification with the avionics manufacturer to ensure that it complies with requirements and does not interfere with or adversely affect existing and standard applications.

5.3.1 Flight testing

Once software has been developed, it should be tested operationally to ensure its correct functionality and performance, including message format, response to uplink command, correct software configuration and the quality of the AMDAR data produced. Arrangements to conduct flight testing on one or more aircraft over a suitable period of time (e.g. 1-2 weeks) should be made with the airline and the AOS developer in advance and, if necessary, include a process to correct any software defects or bugs. Such testing can be initiated from the ground during aircraft maintenance but it is recommended to examine the AMDAR data received from a series of operational flights and to analyse the results very carefully before the full AOS roll out occurs and before AMDAR data is transmitted on the GTS.

The flight testing process and data analysis should include a number of checks including (as a minimum):

- Comparing temperature, wind and other meteorological data with co-located radiosonde or NWP data; and,
- Validating spatial and temporal coordinates.

Experts from the Aircraft-Based Observations Programme can assist and provide technical advice in relation to AOS specification, development and testing.

5.3.2 Software roll out

Once the AOS and the data quality have been tested and approved and the AMDAR data processing system is implemented and operational (see 5.6), the airline can be directed to install the software across the entire proposed AMDAR fleet, which will usually occur during standard aircraft maintenance checks and processes.

5.4 Air to ground communications

The communications system that supports communications for the global aviation industry is called Aircraft Communications and Reporting System (ACARS). The aeronautical communications infrastructure that supports air-to-ground communications of ACARS is normally provided by one of the two large aviation Data Service Provider (DSP) companies (ARINC and SITA)[16]. Independent communications companies are operating similar aviation services in Japan, China, Thailand and Brazil that link to the ground-based component of the global services provided by ARINC and SITA. Both companies provide 2-way communications based on VHF, HF and satellite systems. Airlines will usually have a contract with one or more of these companies to provide global communications services for their own commercial operational purposes.

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[15] http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/resources/index_en.htm

[16] Although a new operational system has recently been developed based on the low earth orbiting satellite system IRIDIUM and may also be an optional consideration.

While onboard avionics applications requiring ground communications via ACARS can utilise both VHF and satellite communications systems, AMDAR software applications are generally configured to use only the VHF communications channel for data delivery. This can mean that en-route reports, compiled over locations where VHF coverage is not available, can be delayed by up to several hours and longer on long-haul international flights.

5.5 Ground-based reception

Most airlines insist that AMDAR data must be sent directly from the aircraft to their own ground based data reception systems and then transferred to the NMHS. In this case, a method for transferring the data from the airline to the NMHS will have to be agreed upon and implemented. In some cases, the airline will agree to the data being addressed directly to the NMHS from the DSP, in which case it would be necessary to establish a network address and connection with the air-ground DSP. In both cases, the data is usually received by the NMHS in the same format as which it is relayed from the aircraft to the ground as a Type B ACARS message.

5.5.1 Ground-based processing

It is the responsibility of the NMHS to ensure that the necessary ground-based processing system for AMDAR data is developed, implemented and operational by the time the airline(s) commence producing data.

The data acquisition and processing system is normally located in the NMHS and is required to:

1. receive the data (most usually delivered as a Type B ACARS message, for which the format can be obtained from the relevant software specification – AOSFRS or ARINC 620);
2. decode the data;
3. conduct rudimentary data quality checks (range, rates of change, observations consistency etc – see AMDAR Reference Manual[17], Section 4);
4. reformat the data into acceptable messages/bulletins for operational use within the NMHS and for exchange on the WMO GTS.

5.6 Transmission of AMDAR data on the GTS

The general requirements for transmission of data on the GTS are described in the WMO Manual on Codes, WMO-No. 306[18].

AMDAR data is currently transmitted in both text (FM42, see Manual on Codes, Volume I.1 Alphanumeric Codes[19]) and binary (FM94, see Manual on Codes, Volume I.2 Binary Codes[20]) formats. However, by 1 November 2014, the migration from alphanumeric to the use of binary codes only must be completed by all WMO Members.

Specific information and procedures for pre-processing of AMDAR data for transmission on the GTS is available in the AMDAR Reference Manual, Appendix IV.

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[17] WMO-No. 958, 2003, Aircraft Meteorological Data Relay (AMDAR) Reference Manual: http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/publications/AMDAR_Reference_Manual_2003.pdf

[18] http://www.wmo.int/pages/prog/www/WMOCodes.html

[19] http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI1/VolumeI.1.html

[20] http://www.wmo.int/pages/prog/www/WMOCodes/WMO306_vI2/VolumeI.2.html

5.7 Data and quality management

As a component system of WIGOS and the WMO GOS, it is critical that Members manage their AMDAR programmes in accordance with the wider principles of the WMO Quality Management Framework (QMF) and the more specific requirements for quality management associated with WIGOS observing systems.

In the case of AMDAR, the critical aspects of quality management are:

- data quality control undertaken at two main points in the system:
    - some limited data quality control undertaken by the AMDAR onboard software (see section 5.3 above);
    - data quality control undertaken by the ground-based data processing system prior to NMHS data use and to transmission of the AMDAR data on the GTS; and,
- data quality evaluation (monitoring).

5.7.1 Data quality control

One of the major tasks of the AMDAR ground processing infrastructure is the real-time monitoring and quality control of the incoming AMDAR data (i.e. the data as it is received by the NMHS).

AMDAR data Chapters 5 and 6 of the AMDAR Reference Manual (see footnote 17) outline the requirements for AMDAR Data Management and Quality Control respectively, while appendices I and IV provide detailed information on AMDAR Sensor Data Processing and AMDAR Data Management.

The design of the AMDAR system must incorporate the required processes to:

1. identify an errant AMDAR data stream;
2. remove the errant data from the distribution of data on the GTS (i.e. blacklisting an aircraft); and,
3. ensure that the problem is rectified through a feedback process to the airline and by maintaining a check on the data quality before resumption of transmission on the GTS.

Generally, it is during the process of monitoring AMDAR data quality (see 5.7.2) and after GTS transmission, that the majority of AMDAR data quality issues are identified and, as a result, corrective actions as indicated above are taken.

An essential function of the data processing system is the ability to withhold data distribution and exchange of data selectable on an individual aircraft basis when data quality is known to be unacceptable. Ideally, the system should continue to monitor the poor performing aircraft until such time as the data are once again acceptable, whereupon the data can again be distributed.

5.7.2 AMDAR data quality monitoring

While there are important but a limited number of quality control checks that can be applied to AMDAR data in its pre-processing prior to GTS transmission, another critical aspect of the AMDAR Quality Management System is the routine monitoring of data both at the national level by AMDAR data managers and also by international data monitoring centres, through

the World Weather Watch, Data Processing and Forecasting System, Observational Data Quality Monitoring procedures[21].

The Lead Centre for aircraft-based data monitoring is the World Meteorological Centre, Washington, with the data monitoring processes carried out by the USA National Weather Service's National Centers for Environmental Prediction (Central Operations).

At the current time, aircraft and AMDAR data monitoring is limited to the compilation and notification of monthly Numerical Weather Prediction (NWP) comparison reports that are available online from the NCEP Central Operations, Quality Assessment Project[22].

Other international NWP centers also provide aircraft-based observations data monitoring services and information to the international AMDAR community. More information and data monitoring results and statistics are available from this site under Aircraft-based Observations/Data[23].

[21] http://www.wmo.int/pages/prog/www/DPS/Monitoring-home/mon-index.htm
[22] See: http://www.nco.ncep.noaa.gov/pmb/qap/
[23] http://www.wmo.int/pages/prog/www/GOS/ABO/ABO_Data.html

6. Data display and use

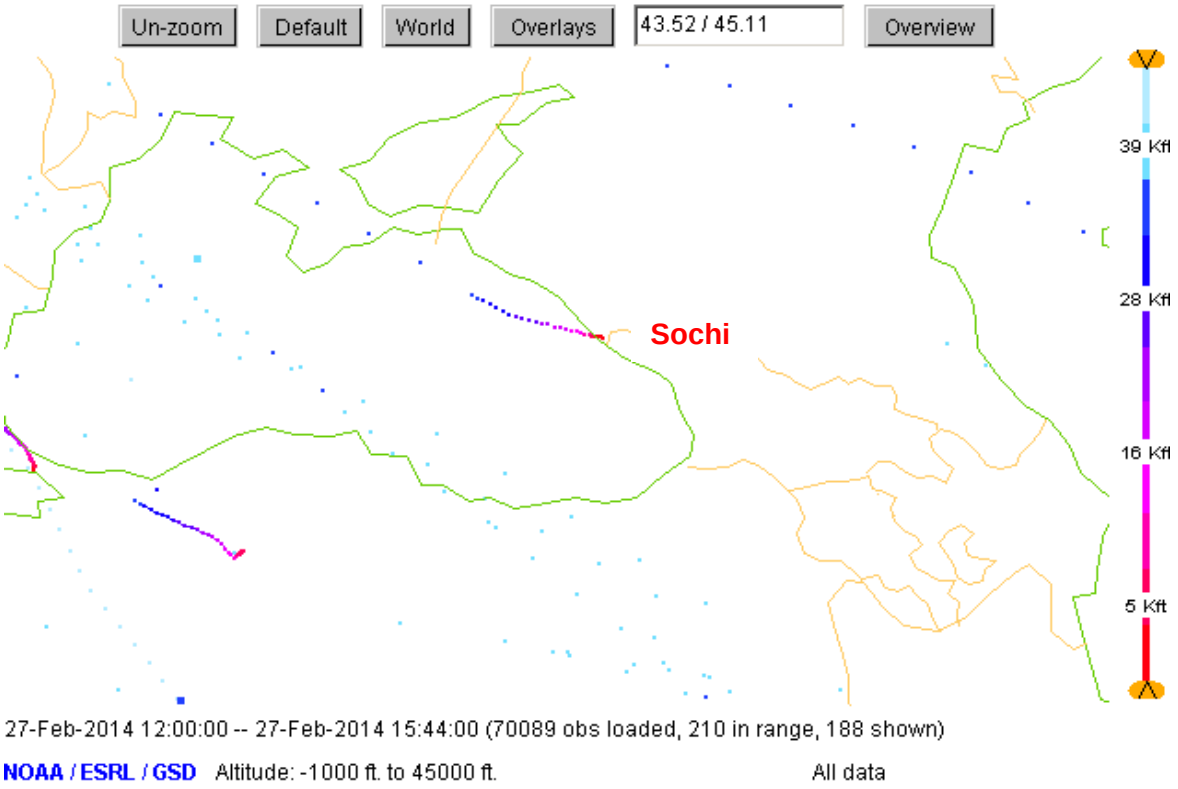
Making AMDAR data available and, ideally, fully integrated into the NMHS operational systems that facilitate data visualisation and data use by all relevant data users and application areas within the NMHS must be a primary consideration and aim for the NMHS and AMDAR programme developers.

The specific requirements of the NMHS for data visualisation and data use should be considered at the AMDAR programme design stage. Consideration should be given as to what is necessary within the ground-based processing (section 5.5) and within the data management (section 5.7) systems so as to most efficiently and optimally make use of and interface to existing databases and data user systems and applications.

AMDAR data (in particular AMDAR profiles, produced during ascent and descent) can be displayed in the same way as specified for radiosonde data. Many NMHSs have extended their meteorological display systems (meteorological workstations) with a module to display AMDAR data, and even to overlay AMDAR data with other observational data.

A few stand-alone systems are available either as internet accessible systems or as commercially available data display systems.

An internet accessible display system is available at the NOAA/ESRL/GSD Aircraft Data Web[24], operationally in use at several NMHSs (see figures 3A and 3B). Commercially available is the MeteoExpert System, produced by the Institute of Radar Meteorology (IRAM)[25], Russian Federation. The MeteoExpert System is able to display data from several different observation systems, including AMDAR (see figure 4).



[24] NOAA Earth Systems Research Laboratory, Global Systems Division (password protected): http://amdar.noaa.gov/java

[25] http://www.iram.ru/iram/index_en.php

Figure 3A: Flight from NW to Sochi Airport (27 February 2014, Courtesy NOAA/ESRL/GSD)

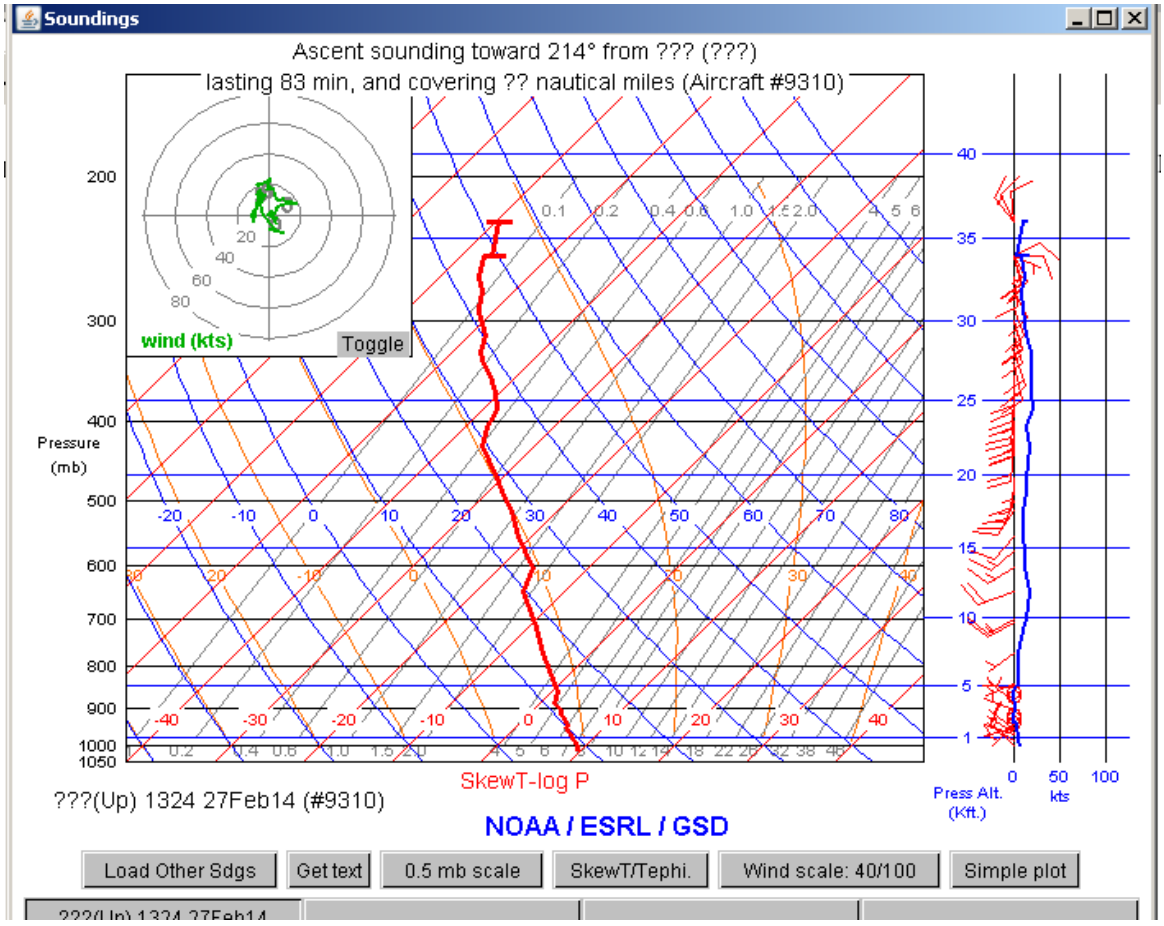


Figure 3B: Profile Ascent from Sochi Airport (27 February 2014, Courtesy NOAA/ESRL/GSD)

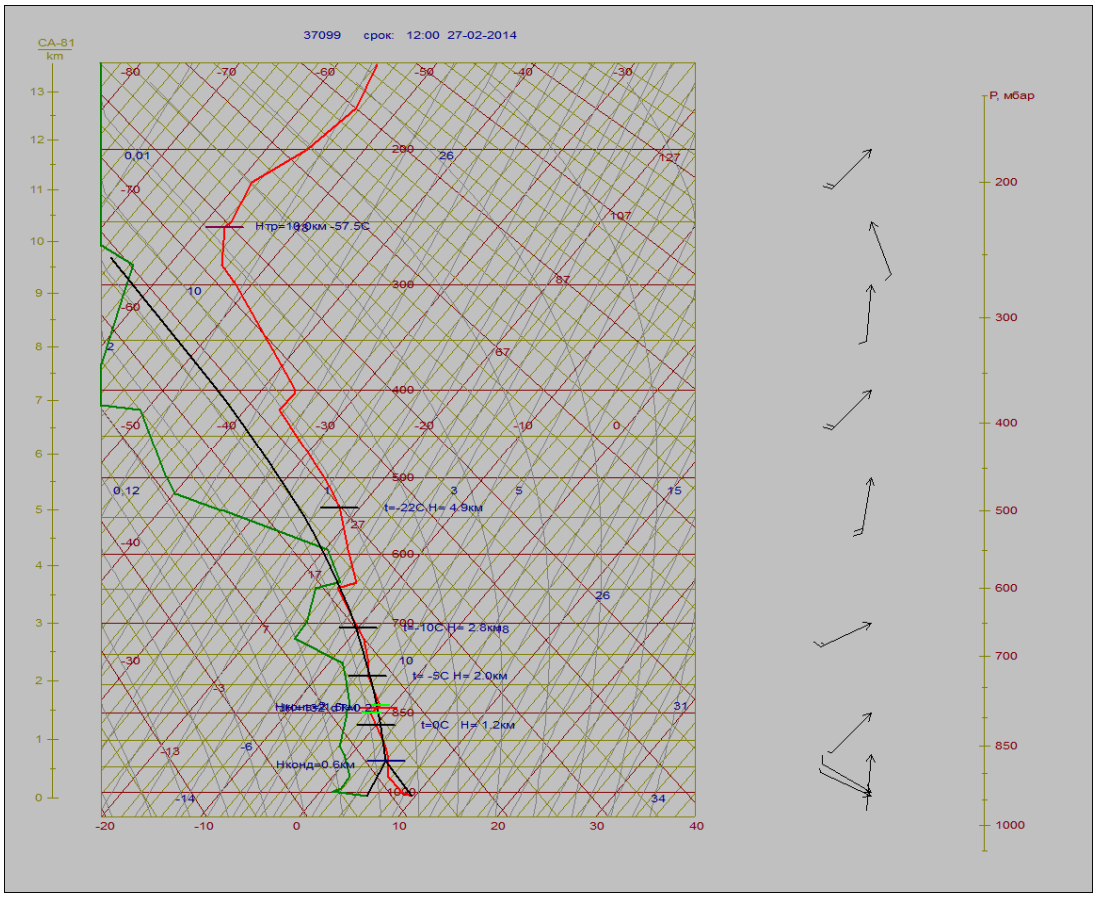


Figure 4: AMDAR profile (Temperature, Wind) from Sochi Airport (MeteoExpert System, 27 February 2014) (Courtesy IRAM)

7. Further information and support

More information and support for the development and operation of an AMDAR programme can be obtained from the WMO AMDAR website[26] and from contact with the WMO Secretariat and experts associated with the Aircraft-Based Observations Programme[27].

The WMO AMDAR Observing System Newsletter[28] contains material on the development and operations of Aircraft-Based Observing Systems, including AMDAR.

7.1 References, Manuals, Standards and Guidelines

References, manuals, standards and other guidance material related to the AMDAR observing system and AMDAR programme operation and development can be found at the WMO AMDAR/Resources website at:

http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/resources/index_en.html

[26] http://www.wmo.int/pages/prog/www/GOS/ABO/AMDAR/
[27] http://www.wmo.int/pages/prog/www/GOS/ABO/ABOWorkTeams.html
[28] https://sites.google.com/a/wmo.int/amdar-news-and-events/newsletters

Annex I - List of acronyms

AAA	ACARS AMDAR ACMS (AMDAR onboard software)
ABO	Aircraft-Based Observations
ABOP	Aircraft-Based Observations Programme (WMO)
ACARS	Aircraft Communications Addressing and Reporting System
ACMS	Aircraft Condition Monitoring System
AEEC	Aeronautical Airlines Electronic Engineering Committee
AMDAR	Aircraft Meteorological Data Relay
AOS	AMDAR Onboard Software
AOSFRS	AMDAR Onboard Software Functional Requirements Specification
ARINC	Aeronautical Radio, Incorporation
BUFR	Binary Universal Format for the Representation of meteorological data
CEO	Chief Executive Officer
CIMO	Commission for Instruments and Methods of Observation (WMO)
DGSS/IS	Data link Ground System Standard/Interface Specification
DSP	Data Service Provider
EUCOS	EUMETNET Composite Observing System
GOS	Global Observing System (WMO)
GTS	Global Telecommunication System (WMO)
HF	High Frequency
IRAM	Institute of Radar Meteorology
MDCRS	Meteorological Data Collection and Reporting System (US AMDAR)
NCEP	National Centers for Environmental Prediction (NOAA)
NHMS	National Meteorological and Hydrological Service
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
SITA	Société Internationale de Télécommunications Aéronautiques
USA	United States of America
USD	United States Dollar
VHF	Very High Frequency
WMO	World Meteorological Organization
WWW	World Weather Watch (WMO)