EUROCONTROL
Experimental Centre

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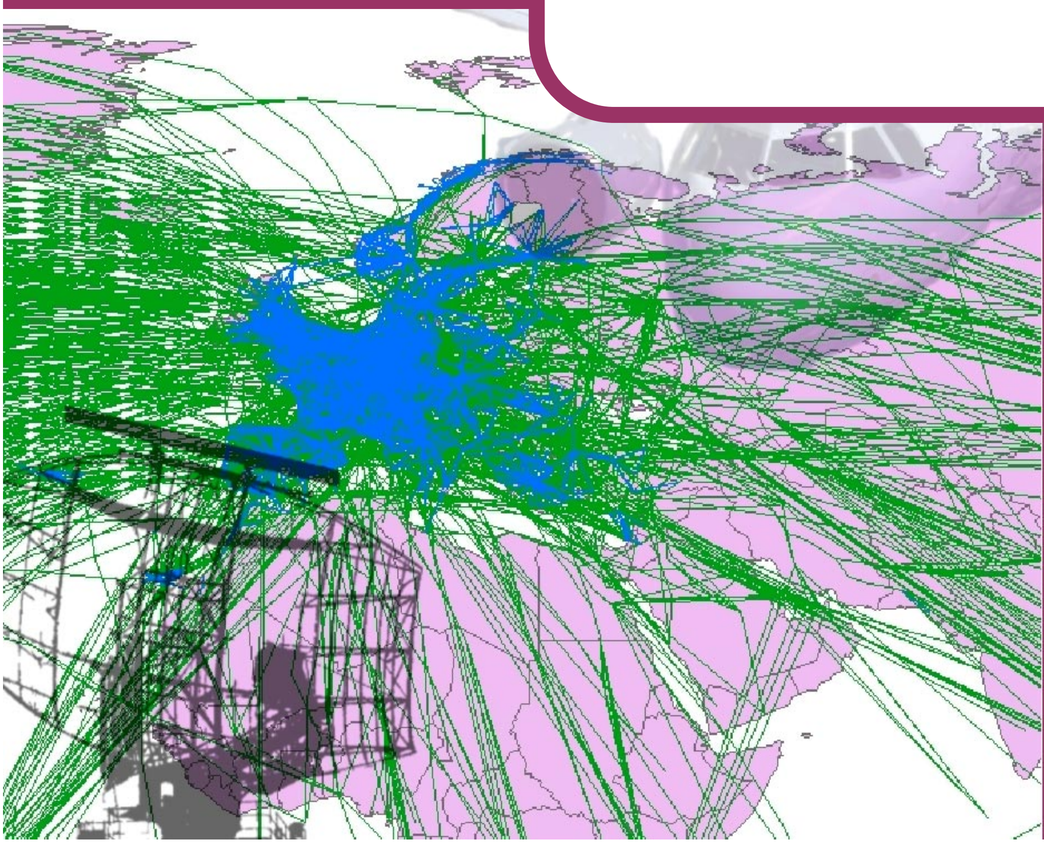
ENVIRONMENTAL KEY PERFORMANCE INDICATORS

2001 Study

EEC/ENV/2002/002



EUROCONTROL

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Environmental Studies Business Area
EUROCONTROL Experimental Centre

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Abstract:

This Environmental Key Performance Indicators (Env-KPI) 2001 study evaluated air traffic control route efficiency and total fuel burn. The data for the study used surveillance data derived from ARTAS system and flight plan data from the CFMU. The fuel burn was modelled using the Eurocontrol Experimental Centre's (EEC) Advanced Emission Model version 3 (AEM3).

EXECUTIVE SUMMARY

The Air Traffic Management (ATM) route structure is organised in around a set of navigation beacons and waypoints. Aircrafts are constrained to follow these routes rather than fly directly from one airport to another. In addition, air traffic conditions may force the aircraft to fly at altitudes that are not optimal for the route flown and the type of aircraft. These imposed restrictions incur an increase in fuel consumption, and therefore a supplementary production of gaseous emissions.

The purpose of the 2001 study was evolve Environmental Key Performance Indicators (Env-KPI) that will allow the environmental cost of the differences in route length and fuel consumption to be measured. The differences were measured between routes and profiles actually flown and direct routes between airports.

The study was carried out for the Eurocontrol Performance Review Unit (PRU) by the Environmental Studies Business Area at the Eurocontrol Experimental Centre (EEC).

The main parts of the study were:

- Research and collection of representative data of the real European air traffic: radar data from ATM suRveillance Tracker And Server system (ARTAS).
- Filtering of the collected radar data to obtain usable trajectories.
- Creation of direct trajectories corresponding to each real trajectory, which were used as the reference for further studies.
- Calculation of fuel consumption for each trajectory.

The study was based on data collected during the 3rd and 4th quarters of 2001 with the support of the Performance Review Commission (PRC), Eurocontrol member states who supplied surveillance data and the AMOC, SurVITE and AEM project teams at EEC.

Two Env-KPIs were studied:

- **Route Efficiency (Distance Analysis)**: A comparison of difference in route length between ‘actual’ and ’direct’ routes. This study was ‘anonymous’ in that the flight plan data were not used (aircraft type, callsign) because the radar data covered a much wider area than the recorded flight plan data. The direct route was calculated using the ArcGIS tool. The actual route was determined from the point-to-point radar updates provide every 30 seconds for each flight. Flights were selected for analysis using filters based on measured ground track and vertical profile characteristics.
- **Total Fuel Burn**: The ‘Total Fuel Burn’ indicator (also called Fuel Efficiency) combines the Route Efficiency with vertical profile and the aircraft performance. The indicator was based on the total fuel burn emissions indicator employed by Celikel [Ref 3]. It was measured by comparing the actual 4D route to the 4D direct route for a given aircraft type and route. The Fuel Burn was simulated using the EEC Aircraft Emissions Model version 3 (AEM3). The analysis was restricted to flight samples where the aircraft type, departure and destination airports were correctly correlated with the ARTAS radar data. The shortest distance between two airports is not necessarily equivalent to the optimum route for minimum fuel burn due to meteorological effects. Nevertheless, the direct ground route and optimum height profile may be used as static (arbitrary) reference.

The results indicate the average Route Efficiency in Europe to be in the order of 10 to 12% for flights less than 400km and 8% for flights greater than 500km. The KPI provides an independent view of actual routes followed. In Europe non-optimum routes are mainly due to airspace organisation.

The results of the Total Fuel Burn analysis indicate fuel inefficiency of 8% for our traffic samples representing European traffic between 200 and 800km route length.

The work reported here is relevant in the context of “airspace design”, "sustainable aviation" and in the concept of "environmental capacity of the ATM system" for the next twenty years, coupled with the mode towards valuing the environmental effects of Air Traffic.

For the 2002 study we plan to increase the proportion of surveillance data used over a wider geographical area by using surveillance data from the Enhanced Traffic Flow Management System (ETFMS) Correlated Position Reports (CPR).

In the 2002 study the 4D direct routes will be based on aircraft performance and optimum cruise level for a given aircraft type and direct route.

In the 2002 study we aim to improve the classification of results by taking into account ATM restrictions, diversions due to meteorological phenomena (thunder storms etc.), runway in use, Terminal Movement Area (TMA) manoeuvres and flight plan changes.

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1 Introduction

The Air Traffic Management (ATM) community has recently been faced with a new goal:

- Reducing the impact of ATM on the environment

The environmental impact of ATM has to be counterbalanced against the traditional goals of safety, capacity and cost effectiveness. Changes to the ATM environment must be assessed for their impact on emissions and noise. The IPCC in its report “Aviation and the Global Atmosphere” [Ref 1] suggests that improvements to the CNS/ATM system could reduce world-wide fuel burn and associated emissions by an estimated 6 to 12% for a given traffic demand.

The Environmental Key Performance Indicator (Env-KPI) project is an Eurocontrol Experimental Centre (EEC) environmental business area project, sponsored by the Performance Review Commission (PRC), with the aim of establishing and making an annual assessment of environmental KPIs. The results of the emission study 2001 were used for the “Flight Efficiency” chapter in the Performance Review Report 5 (PRR5) [Ref 2] published in July 2002.

KPIs used by airlines, e.g. Passenger Kilometres (PKT), are often based on commercial data such as the number of passengers transported per kilometre, take-off weights, load factors and aircraft weight. Since the commercial data used by airlines are not normally available to the ATM organisations, Env-KPIs must be designed to use information readily available to the ATM organisations such as flight plans or surveillance data.

The emission study 2001 complemented work carried out by Celikel in 2000 [Ref 3], who used Air Traffic Control Radar Tracker And Server (ARTAS) radar tracks with a geographical coverage limited to the Maastricht zone.

The emission study 2001 used ARTAS radar tracks and flight plan data gathered over a wide area of Central Europe including Austria, Belgium, France, Germany, Italy, Luxembourg, Netherlands, Switzerland and the U.K.

The initial part of the study involved categorising recorded radar data and correlating them with flight plan information. The second part of the study established reference routes for the recorded traffic. It was important to choose a reference that would remain stable for subsequent studies. For this reason the concept of direct route was used as a reference in the Env-KPIs studied in this report.

Finally, the fuel consumption for each flight was calculated for the real and direct traffic using the Advanced Emission Model 3 (AEM3).

Two key performance indicators were studied:

- **Route Efficiency (Distance Analysis):** A comparison of difference in route length between ‘actual’ and ’direct’ routes. This study was ‘anonymous’ in that the flight plan data were not used (aircraft type, callsign) because the radar data covered a much wider area than the recorded flight plan data.
- **Total Fuel Burn:** The Total Fuel Burn indicator (also called Fuel Efficiency) combines the Route efficiency with vertical profile and the aircraft performance. The indicator was based on the total fuel burn emissions indicator employed by Celikel [Ref 3]. It was measured by comparing the actual 4D Route to the 4D Direct Route for a given aircraft type and route.

The report describes the methodology used in the Environmental Key Performance Indicator 2001 study and presents results from the KPIs analyses.

The different analyses required different levels of information for each flight. The airport pair and fuel burn analyses required knowledge of the flight profile and aircraft details. The type of data required for each flight is shown in Table 1.

Table 1: Analysis Parameters

Study	Parameter			
	Ground Track	Departure and destination airports	Vertical profile	Aircraft type
Route Efficiency Analysis	X			
Total Fuel Burn Analysis	X	X	X	X

The data collection and analysis was composed of five steps, see Figure 1:

- Radar data collection and Merge Recordings
- Radar data filtering and Profile selection
- Flight Plan correlation.
- Creation of the corresponding direct routes
- Calculation of the fuel burn for each flight.

In the report the term radar data is used to mean ARTAS tracks. This is to avoid confusing radar track with the ground track followed by the aircraft. The radar tracks are also called "Actual routes".

The radar data representing the real European air traffic were derived from en-route surveillance track data from ARTAS (ATM suRveillance Tracker And Server) system. The ARTAS track data were provided by the EEC SurvITE project and UK.NATS.

The ARTAS radar tracks were correlated to the Flight Plans in the ATFM Modelling Capability (AMOC) Simulator.

The optimum profile for each Direct Route was calculated using the AMOC tool.

The Total Fuel Burn and emissions were modelled using the Advanced Emission Model 3 (AEM 3) tool.

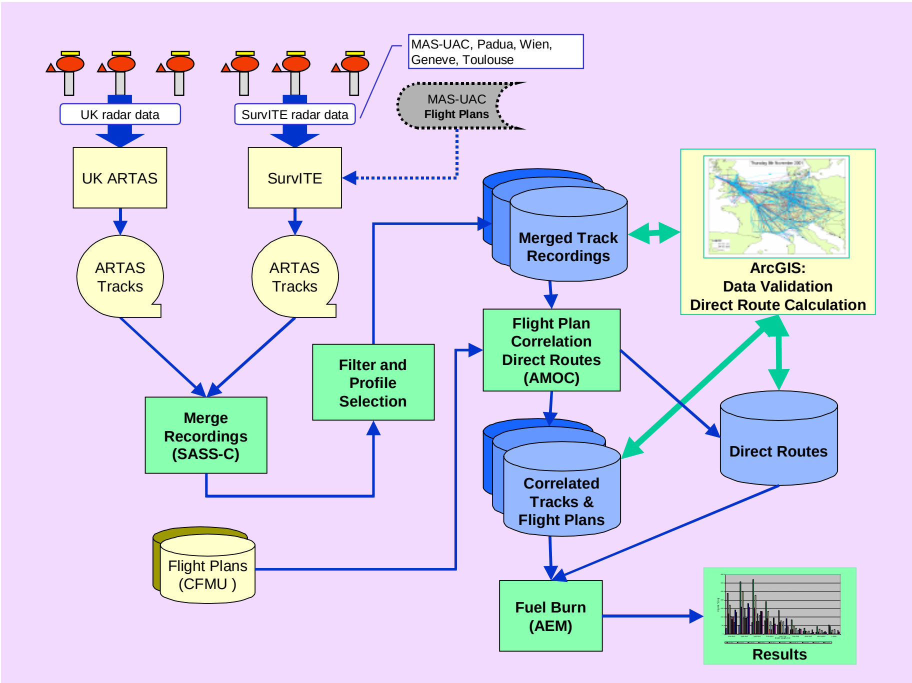

Figure 1: Emissions Study 2001 – Analysis and Data Collection Schematic

2.1 ARTAS Radar Data

2.1.1 Data Collection

The actual flight data for the study were derived from the radar data and flight plan data covering the central European area as indicated in Figure 2.

The traffic samples obtained from the recorded data were subject to a number of constraints as follows:

- Data sources
- Recording durations and times
- Radar coverage completeness (4D Route)
- Operational influences

This section summarises the constraints.

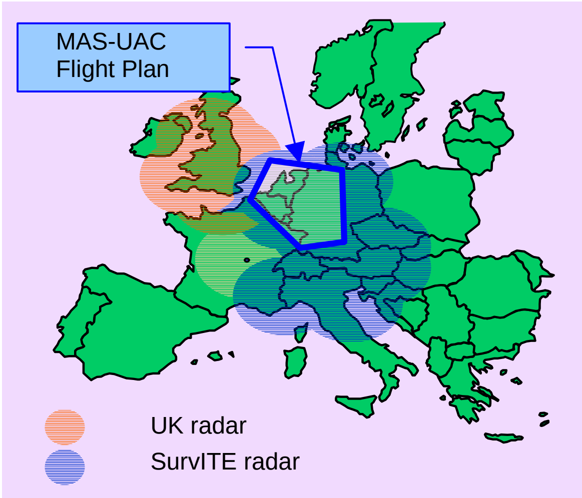

Figure 2: Radar Coverage Limits

2.1.2 Data sources

The radar data used for the study were ARTAS tracks provided by NATS-UK and the SurvITE project at EEC. The typical radar geographical coverage before preparation (as recorded) and after preparation (prepared) is illustrated in Figure 3. ARTAS was selected because the track messages are in a coherent co-ordinate system irrespective of recording point, thus allowing a wide area to be covered without incurring projection errors. The ARTAS servers at SurVITE and UK were configured to provide a track updates at 30 seconds intervals; a suitable interval to provide sufficient granularity when traffic are manoeuvring whilst keeping file size.

The SurvITE ARTAS tracks were generated from radar data provided by Austrocontrol Austria, STNA-4 Toulouse France, ENAV Padua ACC Italy, Maastricht UAC and Skyguide Geneva.

In some recordings coverage over Switzerland used raw radar data provided by Skyguide at Geneva and the Maastricht airspace was covered by processed track data provided by MAS-UAC.

The ARTAS team at STNA France was unable to provide data due to high workload. However, STNA provided plot data during a limited period, which was correlated using the SurvITE ARTAS system.

The ARTAS tracks from the SurVITE system were provided on internal EEC agreement. The radar data provided to SurvITE are covered by agreements for supply of radar data to EEC for studies. For the UK data a contract was made with NATS-UK to receive ARTAS track recordings.

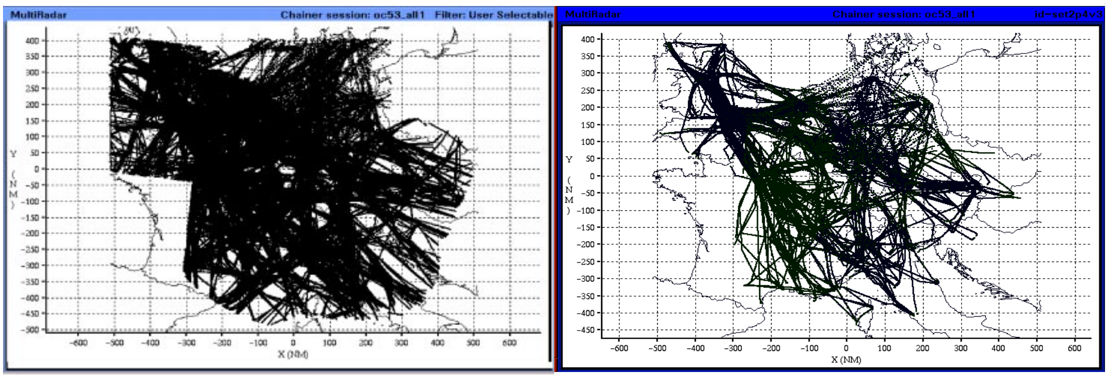

Figure 3: Radar Geographical coverage – left: 'as recorded', right: 'prepared'

2.1.3 Recording durations and times

Table 2 shows the radar data sources, dates and times of the recordings used in the study. The recording timetable had been fixed according to ARTAS system availability.

Table 2: Summary of Recording Start/End Times

Date	**Duration (UTC)**	**ARTAS EEC**	**MAS-UAC**	**Austria**	**Italy**	**France**	**Switzerland**	**ARTAS UK**
08/10/01	16h>>23h	X	X	X	X			
09/10/01	15h>>22h	X	X	X	X		X	
15/10/01	13h>>20h	X	X	X	X		X	X
23/10/01	15h>>20h	X	X	X	X		X	X
30/10/01	16h>>23h	X	X	X	X			X
02/11/01	16h>>23h	X	X	X	X		X	X
06/11/01	13h>>17h	X	X	X	X	X		X
07/11/01	18h>>23h	X	X	X	X	X		X
08/11/01	16h>>23h	X	X	X	X	X		X

2.1.4 Radar Data Preparation

The ARTAS tracks that were recorded at EEC and in the UK were merged and correlated together using the SASS-C tool.

The radar configurations were not always the same for each recording due to operational constraints and maintenance schedules. To accommodate the effect of these constraints it was necessary to adapt the data preparation for each recording to present a coherent picture at the input to the analysis system.

The version of SASS-C (5.3) used for the radar data preparation was geographically limited to an area of 1024NM x 1024NM. This area was sufficient to cover the recorded data – see the window illustration in Figure 3. However, it must be noted that the SASS-C restriction also influenced the geographical extent of the recorded radar data used in the study.

2.1.5 Filtering and Profile selection

A large proportion of the recorded radar data were of no interest for this study, the extent of which is indicated in Figure 3. The causes of this unwanted data were due to radar coverage and recording duration that limited the recorded data to a sub-set of the daily air traffic in the ECAC area. Since our objective for this study was to analyse complete flights, it was necessary to classify and filter the trajectories to reduce the risk of incorrect correlation with flight plans.

The radar trajectories were classified according to completeness of the vertical profile from the recorded radar data, and then they were selected on the basis of their vertical profile characteristics and correlation with departure and destination airports, see Figure 4.

Complete flights included the climb, cruise and descent phases of flight. The climb phase must have begun below Flight Level 75 and the descent phase finished below Flight Level 75.The classifications are explained below.

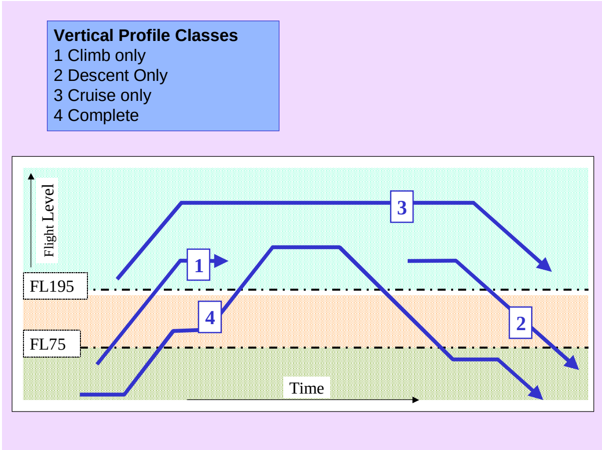

Figure 4: Trajectory Profile classification schematic

Trajectories that were of no interest were:

- Flights that did not start or end inside the geographical limits of the recorded radar data
- Flights without flight plans – based on the following trajectory characteristics:
    - Short (less than 15 minutes) or incomplete flights; the trajectories with incomplete profiles (Profile ID 0, 1, 2, 3) were excluded from the analysis because of uncertainty of departure/destination airports
    - Local flights with the same departure/destination airports - see example in Figure 5
    - VFR SSR codes

The choice of Flight Level 75 and 15 minutes duration were based on experience with radar data and the assumption that traffic cruising below FL75 would not have a flight plan and hence of no use for this study.

The classification was applied in SASS-C using filters based on the following criteria:

- filter on time
- filter on recorded zone
- filter on length of tracks
- filter on altitude

The filters also removed false targets and the occasional track that was incorrectly merged.

Table 3 lists the vertical profile classes that used in the study and illustrated in Figure 4. The radar trajectories that were classified in Profile-id 4 (complete) were selected for further analysis.

The filtered trajectories were validated visually using ArcGIS©, see 2.4.3 on page 13.

Table 3: Vertical Profiles classes

Profile ID	Profile Class	Remarks
0	Unusable	Small trajectory segments less than 15 minutes duration
1	Climb	Take-off and/or climb from FL75 or below to cruise
2	Descent	Descent from cruise to FL75 or below
3	Cruise	End of climb (starting >FL195) to start of descent (ending >FL195)
4	Complete	Climb (starting below FL75), descent (ending below FL75) and cruise

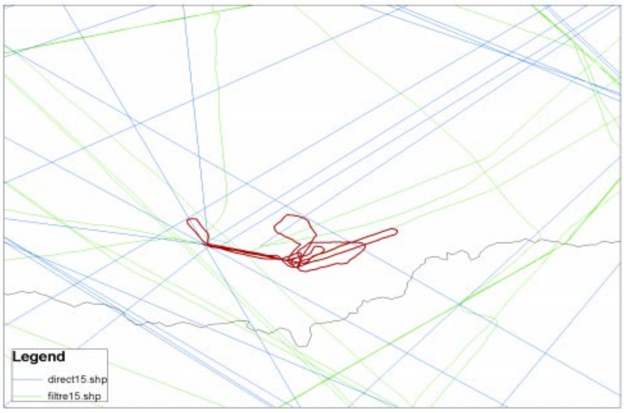

Figure 5: Example of same departure and arrival airports

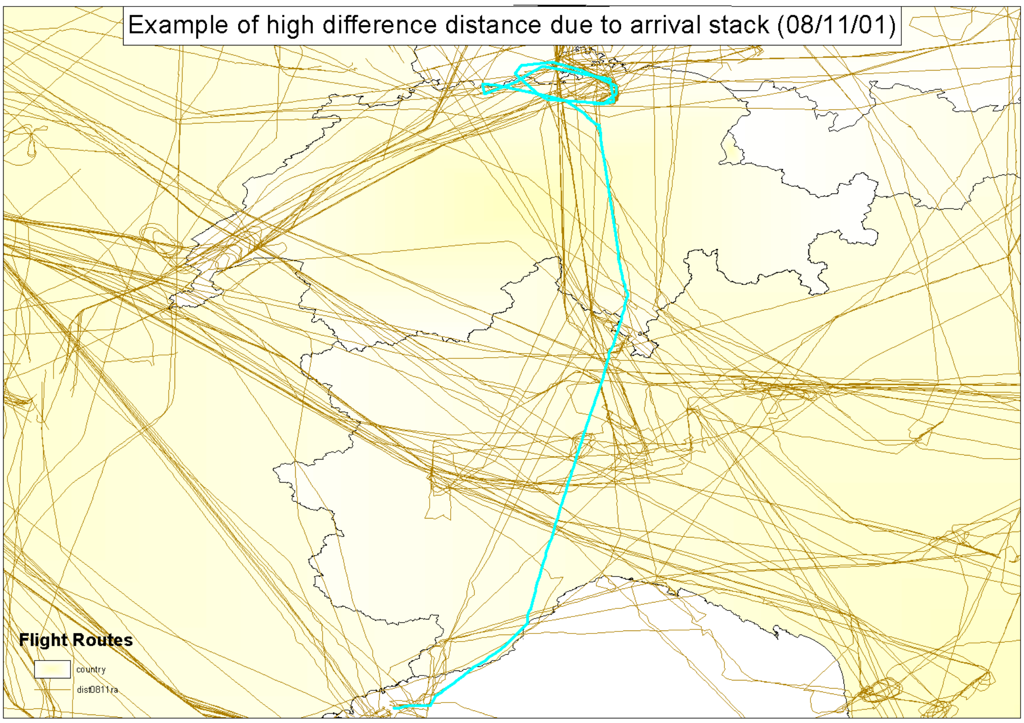

Figure 6: Distance extension due to an arrival stack

2.2 ATM environment data

The ATM environment notes in Table 4 were compiled from the CFMU Monthly summaries for October and November 2001 for the dates and times of the recordings used in the study.

Fog at an airport would normally incur extra trajectory length due to stacking and procedural manoeuvres if automatic landings were used.

Figure 6 shows an example where the actual trajectory length was increased by time in a stack. Otherwise, traffic diversion or flight cancellation will disturb the traffic sample. Widespread fog can result in a significant reduction in traffic. A consequence of this situation is an increase in direct routing for the remaining traffic.

Airports that were closed would incur diversion or cancellation of traffic.

Normally, days where extreme weather conditions had a significant impact on traffic flow would be removed from the analysis or subject to a special class. In this study, because the number of samples was restricted, the meteorological effects and airspace restrictions were not correlated with traffic phenomena.

Table 4: Operational notes for recording days

Day	Date	Events	Remarks for analysis usage.
Monday	08/10/01	Meteo-strong winds: Schiphol, Brussels, London Meteo Low visibility: Munchen, Milan/Linate (Fog) APT Closed:- Dusseldorf 1600-1900 (traffic diverted to Bremen) Milan/Linate (Accident)	No use for Airport pair analysis with Milan/Linate closed. Although traffic should normally diverted to Milan/Malpensa.
Tuesday	09/10/01	APT Closed: Milan/Linate (Accident)	No use for Airport pair analysis with Milan/Linate closed. Although traffic should normally diverted to Milan/Malpensa.
Monday	15/10/01	Meteo Low visibility: Zurich(fog) APT Closed: Bale/Mulhouse (ATC industrial action)	Generalised fog caused significant reduction in traffic, consequently there were more direct routes allocated.
Tuesday	23/10/01	Meteo Low visibility: Zurich, Venezia (fog)	
Tuesday	30/10/01	Meteo Low visibility: Milan, Bergamo (fog) APT Closed: LHR single runway OPS (18:33-19:06)	
Friday	02/11/01	Meteo Low visibility: Rome (Fog)	
Tuesday	06/11/01		
Wednesday	07/11/01	Meteo-strong winds: Schiphol Meteo Low visibility: (fog): Milan	No influence to traffic.
Thursday	08/11/01	Meteo-strong winds: Schiphol, Frankfurt, Munchen. Meteo Low visibility (fog): Milan, Torino Meteo Cumulonimbus: Paris	Redirect to avoid Cumulonimbus means this data set is not representative as no more traffic management or routes allocations.

2.3 Validation of the Traffic Samples

The recorded radar data did not include all flights in the ECAC area. As described in Radar Data section 2.1 above, the ARTAS radar data covered the Central part of Europe. Also, the recordings were approximately 8 hours duration so did not cover a whole days traffic. To ensure that the traffic samples obtained from the recorded radar data were representative of the air traffic in the ECAC area, the samples were validated against an independent reference.

The validation criterion was the proportion of flights per route distance for published flights within Europe.

This section describes the validation process and results.

Two sources of published traffic information were available:

- CFMU Monthly Summary Report
- Back Aviation Database

2.3.1 CFMU Monthly Summary Report and Traffic Statistics

This includes a description of any Special Events occurring during the recording days, with a description of the delays and durations of flights per State.

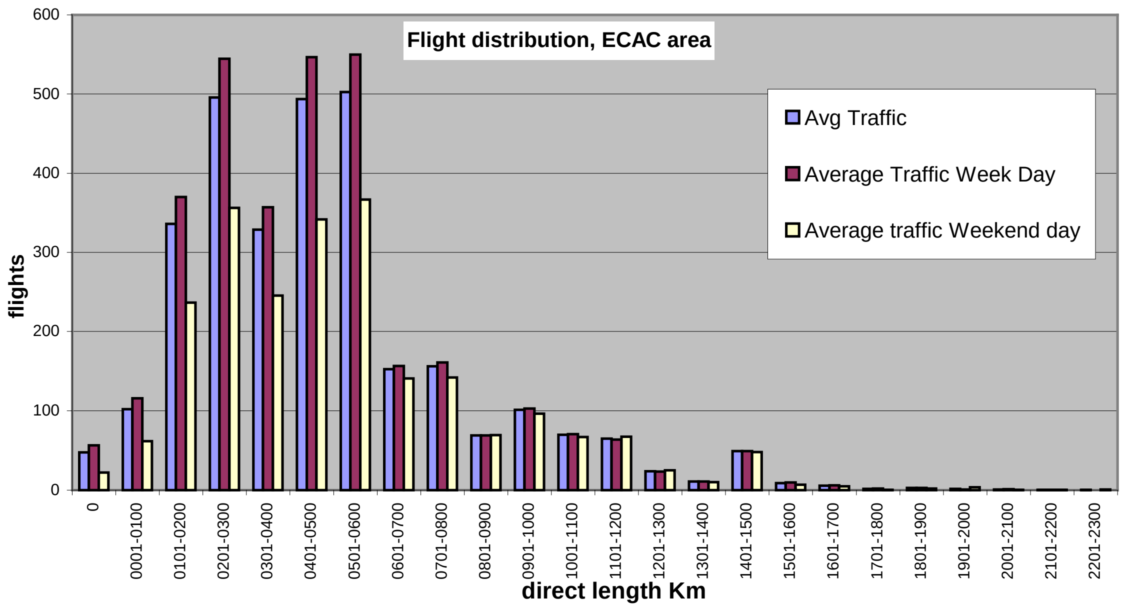

Figure 7: Distribution of Average traffic in function of direct flight length for ECAC Area (source CFMU)

Figure 7 shows the distribution per day of the average number of flights that start and end in the ECAC area for the period 16:00 to 22:00 UTC. The CFMU data clearly indicates that the majority of flights within the ECAC area are between 100 and 800km with peaks between 200 and 600km. The CFMU source was used to validate the distribution of the direct flight distance.

2.3.2 Back Aviation Database

The BACK Aviation Airline Schedule is a database of world-wide scheduled passenger and cargo flights. The database is compiled from information published by the Official Airline Guide (OAG). The database includes departure airport, destination airport, route and aircraft type and is updated on a monthly basis with the latest changes filed by the carriers.

In the emissions study 2001 this database was used to validate the traffic samples obtained from the recorded radar data. The database was queried for each of our recording days using the following selection criteria:

- Traffic departure and destination airports inside Europe
- Scheduled passenger and cargo flights – non restricted classification (no military or charter flights were included)

The recorded traffic samples were compared to the database using graphs of the number of flights per distance class. It was established that the recorded data corresponded well with the published traffic for the recording days.

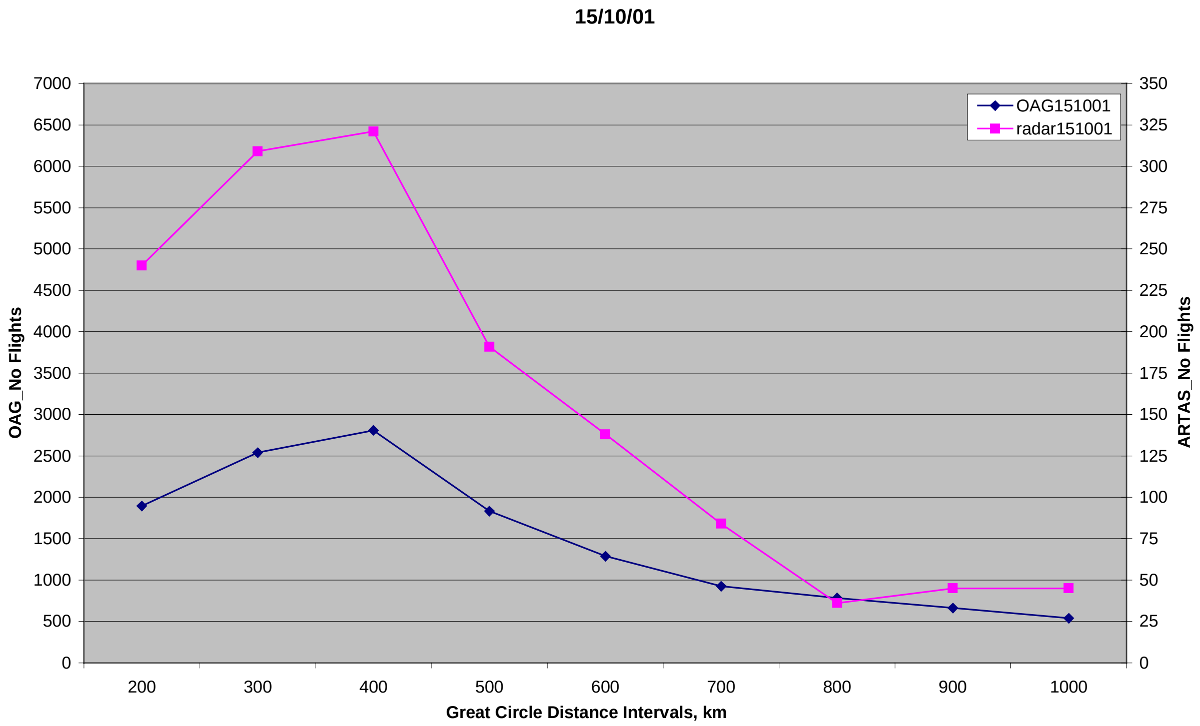

Figure 8: Number of flights from OAG and ARTAS Sources, 15/10/01

Figure 8 shows the distribution of flights per direct route distance for the 5th October 2001. A ratio of 10 was observed between analysed flights and against the declared flights from the OAG Database. This distribution of flights against distance is generally respected for flights with a great circle distance from 200 to 1100 km.

Consequently it can be assumed that the proportion of recorded flights is representative in proportion of length of the European traffic, for the 15th of October 2001. We say Europe here because the OAG data in the graph included some other states, e.g. Iceland.

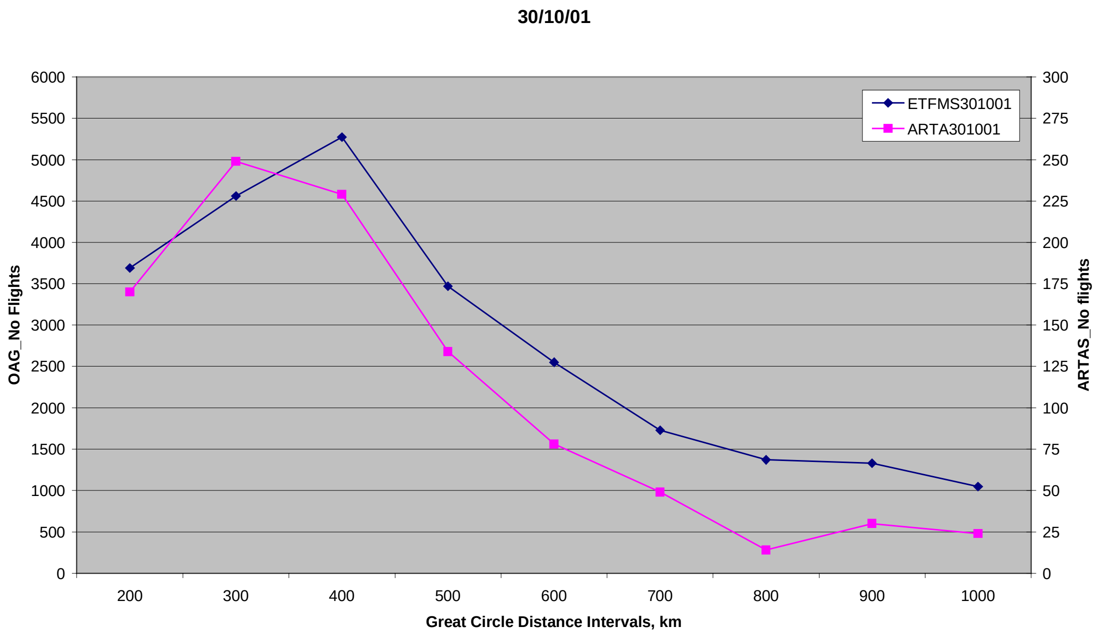

Figure 9: Number of flights from OAG and ARTAS Sources, 30/10/01

Figure 9 shows that the factor between OAG data and ARTAS data for 30th October 2001 is approximately 20. The distance interval proportions correlate sufficiently well. The lower proportion of selected radar traffic in this sample was due to the duration of the recording and the radar availabilities.

The following Table 5 summarizes the proportions of recorded data compared to the OAG data. On two of the recordings the proportion of short haul flights was more than expected due to the recording time and duration parameters.

Table 5: Traffic Sample Validation Results

Date	Duration (UTC)	Scale Factor ARTAS to OAG	Appreciation of ARTAS to OAG Distribution correlation	Remarks
08/10/01	16h>>23h	40	High	
09/10/01	15h>>22h	24	Good	
15/10/01	13h>>20h	10	High	
23/10/01	15h>>20h	50	Medium	Factor is <30 below 400km
30/10/01	16h>>23h	20	High	
02/11/01	16h>>23h	33	Medium	Increase proportion of short haul flights
06/11/01	13h>>17h	33	High	
07/11/01	18h>>23h	17	High	
08/11/01	16h>>23h	14	High	

The diagrams of the validation for the other recordings are presented in Appendix 1 - on page 37.

2.4 Correlating radar tracks to flight plan tracks

It was essential for the fuel burn analyse to know the arrival and departure airports for each trajectory. This could only be obtained by correlating the radar data to flight plan data. As the ARTAS radar data were recorded from non-operational ARTAS systems that did not have flight plan correlation functions. Therefore, an alternative method was sought to correlate the separate recordings of radar data and Flight plan data.

2.4.1 Flight Plan correlation using SurVITE

At the beginning of the study it was planned to use the SurvITE system to correlate the ARTAS radar data to the flight plan (ASTERIX Category 150) information obtained from MAS-UAC. This system would have allowed restricted correlation of flights that passed through the MAS-UAC airspace. The flight plan correlation system part of SurvITE allocated the same callsign to different flights, one of which was correct and the others incorrect. The problem was caused by the system correlating the radar ModeA code with the first entry in the flight plan list but not making further checks to confirm the correlation. After several trials this method was abandoned because the limited correlation yielded too little traffic for the analyses coupled to technical difficulties with the SurvITE Flight Plan correlation.

2.4.2 Flight Plan correlation using AMOC

The AMOC Simulation team at EEC rapidly developed an alternative time based correlation method using the start and end of radar chains and flight plan data provided by CFMU. The Flight Plan data covered all ECAC, which allowed a higher proportion of the recorded ARTAS data to be correlated.

The correlation was based on position and time correlation of the flight plan information, start/end of radar track and airports location. Runway in use information was not available.

The post-correlation, made by the AMOC team, used a geographical grid coupled with a flight level filter to examine the limits of each trajectory. Since radar cover did not always extend to ground level it was often found that the start/end of trajectories were some distance from the associated airport (in some cases up to 40NM) and the trajectory heading was not aligned with the runway, e.g. aircraft on downwind leg when radar cover lost.

The geographical correlations were further verified using the time of trajectory and flight plan information for candidate flight plans associated with the correlated departure and arrival airports.

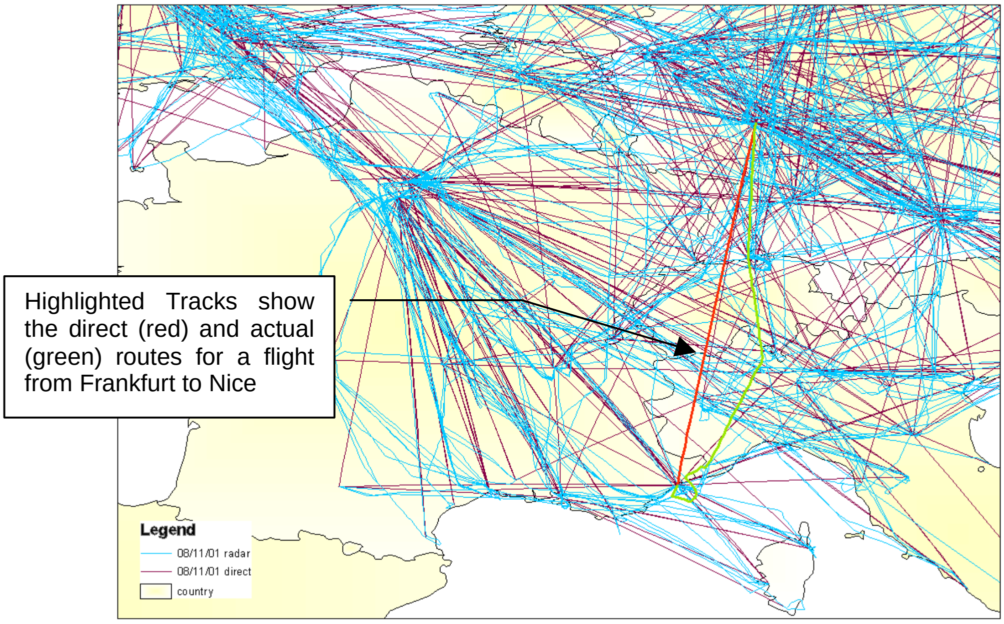

Figure 10: Actual routes and correlated direct routes

2.4.3 Validating the actual-direct route correlation

The validation of the correlation between the actual routes and direct routes were validated visually using ArcGIS8©. The direct and Actual Routes were displayed in different colours for each recording. The relatively low number of trajectories in each recording allowed incorrect correlations cases to be easily identified.

Figure 10 shows an example of the direct (purple) and actual routes (blue) for a recording. A successful correlation is highlighted which shows the actual (radar) and direct tracks. In this a flight from Frankfurt to Nice is shown where the actual (green) and direct (red) tracks correlate for start and end of trajectory. This type of picture was used to visually validate the correlation of tracks. Most incorrect correlations involved trajectories at the periphery of the study area. Cases of incorrect correlation, when direct and real trajectories started and terminated in different geographic zones were removed.

2.5 Trajectory Selection – Results of Classification and Validation

In each data set not many radar chains had both a complete profile (see 2.1.5 on page 6) and were correlated to filtered flight plan data. Table 6 shows the counts of total numbers of chains in each data set together with the number chains after all filters had been applied that had complete profiles and start and end correlated to airports.

The number of chains with 'profile 4' (complete profiles) is not proportional to the number of the chains in a recording. The relationship depends on which data sources were present and the duration of recording – see Table 2 on page 5.

Table 6: Counts of chains with complete profiles

Date	Total Chains	Complete
08/10/01	8065	399
09/10/01	9093	392
15/10/01	18026	1409
23/10/01	8351	338
30/10/01	10577	977
02/11/01	10326	314
06/11/01	15362	582
07/11/01	6077	607
08/11/01	10392	739

2.6 Direct Routes

The direct routes were used as the references for the EnvKPIs used in this study. The Route Efficiency and Total Fuel Burn indicators (Env-KPIs) are based on the principals of ‘direct route ground track’ and ‘4D direct route’.

2.6.1 Direct Route Ground Track

The direct route ground track is the great circle distance between start and end latitude and longitude of the flight in the simulation airspace. Normally start and end would correspond to the departure and destination airports. Two methods of calculating direct route ground track distances were used in this study:

- First-last data point: the great circle distance between the first and last radar plot of each trajectory. The first-last direct distance was used in the route efficiency analysis, it was calculated using Arc-GIS from the radar data.
- Airport-to-Airport distance: the great circle distance between departure and destination airport reference points. The airport-to-airport distance was computed by AMOC.

2.6.2 4D Direct Route

The 4D direct route is the combination of optimum vertical profile and direct route ground track and was used in the fuel burn analysis. The optimum vertical profile is the vertical profile that an aircraft would follow along the direct route without any ATM and meteorological restrictions. The vertical profile takes into account aircraft performance.

The Airport-to-Airport distance was complimented for each flight with an optimum vertical profile (Altitude-Time) calculated using the ATFM MOdelling Capacity Simulator (AMOC Simulator). AMOC is an integrated ATFM simulation platform developed by the Eurocontrol Experimental Centre (EEC) in Brétigny sur Orge. This tool is normally used to identify and evaluate ATM capacity problems, to translate them in terms of delays (using various slot allocation systems) and to test the various potential solutions. A new module was developed for this study that allowed the simulator to calculate the 4D direct routes corresponding to planned flight path.

The 4D direct routes are based on:

- flight plan to derive the aircraft type, departure and arrival airports, and departure time.
- Requested Flight Level (RFL) to identify the maximum altitude for each flight. If the RFL was considered too high for the calculated Airport-to-Airport Direct Distance and Aircraft type a lower maximum Flight Level was determined by AMOC based on the CFMU (TACT) aircraft performance characteristics.
- Aircraft performance, to determine the intermediate profile points during the climb and descent phases of flight.

The above parameters were derived from the CFMU Environment Data and Traffic.

The arrival times were recalculated as function of the 4D direct route.

An example of direct route represented in two dimensions is illustrated in Figure 10.

2.7 Fuel burn modelling

The Advanced Emission Model version 3 (AEM3) was used to model the fuel burn.

2.7.1 AEM3 Description and Method

AEM3 [Ref 7] is a stand-alone modelling system that uses flight profile information to calculate fuel burn and emissions.

The input information is the type of aircraft, the departure time, departure and arrival airports and characteristics of plots representing the flight trajectory. AEM3 calculates the fuel consumption for each phase of the flight.

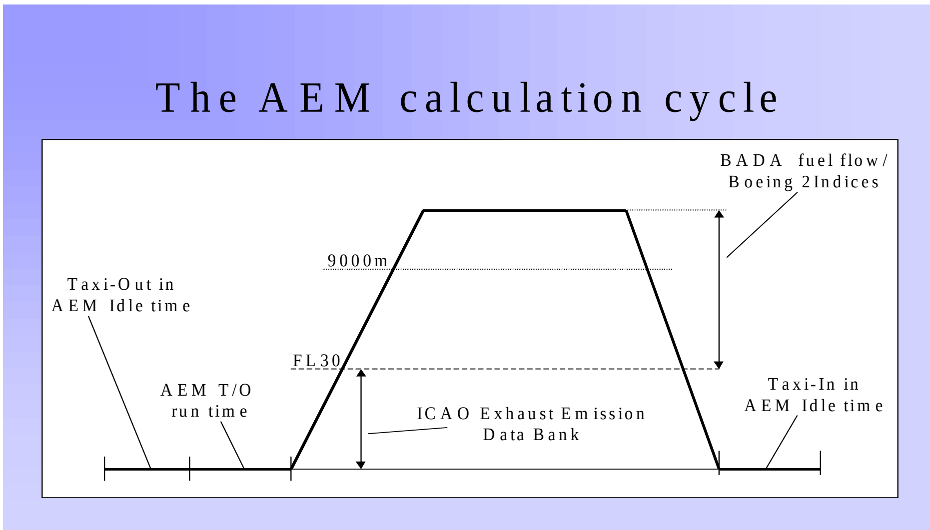

Figure 11: AEM3 flight profile for emission calculation

For flight phases above 3000 feet, AEM3 uses BADA aircraft performances to calculate fuel consumption and the Boeing 2 method to calculate the emissions, see Figure 11.

It must be noted that AEM3 has an option to exclude target position data below 3000 feet altitude and recalculate the Landing and Take-Off (LTO) phases of flight from standard data. The recalculation of the LTO data is based on the ICAO exhaust emission databank and AEM built-in taxi times, see Figure 12.

The LTO option permits calculation of standard LTO phases for a given aircraft when actual LTO position and profile data are not available. This option was very useful in this study since the radar tracks did not have complete coverage of the ground track and vertical profile, even though we had filtered the data for 'complete' profiles starting and ending below FL75. AEM was also used to recreate the LTO phases of the 4D direct routes from the same altitude (3000ft), in order to make a relevant comparison with the radar trajectories results. The results using this method were more consistent.

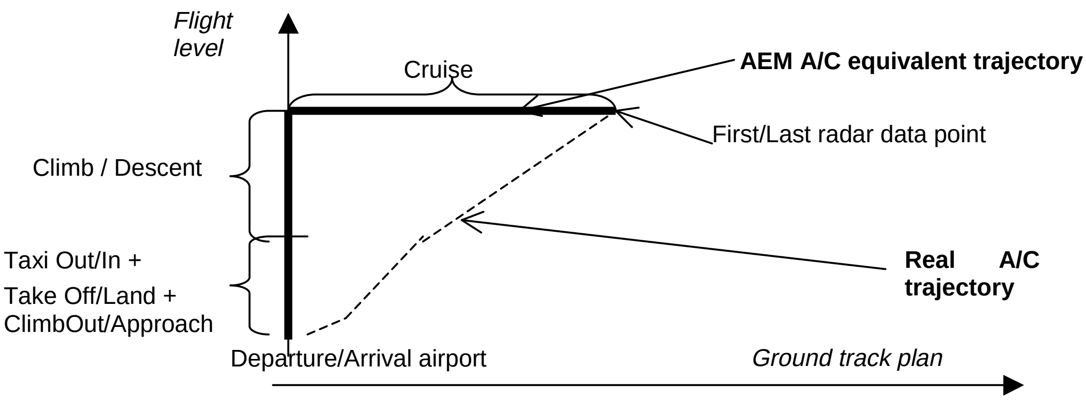

Figure 12: AEM3 method to create the Landing Take-Off phases

2.8 ArcGIS

The ArcGIS system is an integrated Geographic Information System (GIS) that represents geography and provides all the tools necessary for creating and working with the geographic data, produced by ESRI Company. ArcGIS is composed by ArcView, ArcEditor, and ArcInfo. In this study, we have only used the ArcView 8.1 application which provides comprehensive mapping and analysis tools along with simple editing and geoprocessing tools. ArcView 8.1 can be also customized using the industry standard Visual Basic for Applications (VBA). A specific module have been developed in VBA to import radar data, it converts the coordinates, and links the plots together to obtain a polyline, for the calculation of length and also a better visualisation.

This tool was used to classify and verify the actual and direct data, and also to calculate the indicator: Route efficiency, based on the length of the trajectory calculated by ArcView 8.1.

Another module was created to visualized directly the output of the emission model AEM3, this module allows the selection of a track from the map, and the visualization of its attributes: callsign, length, duration, coordinates of each plot.

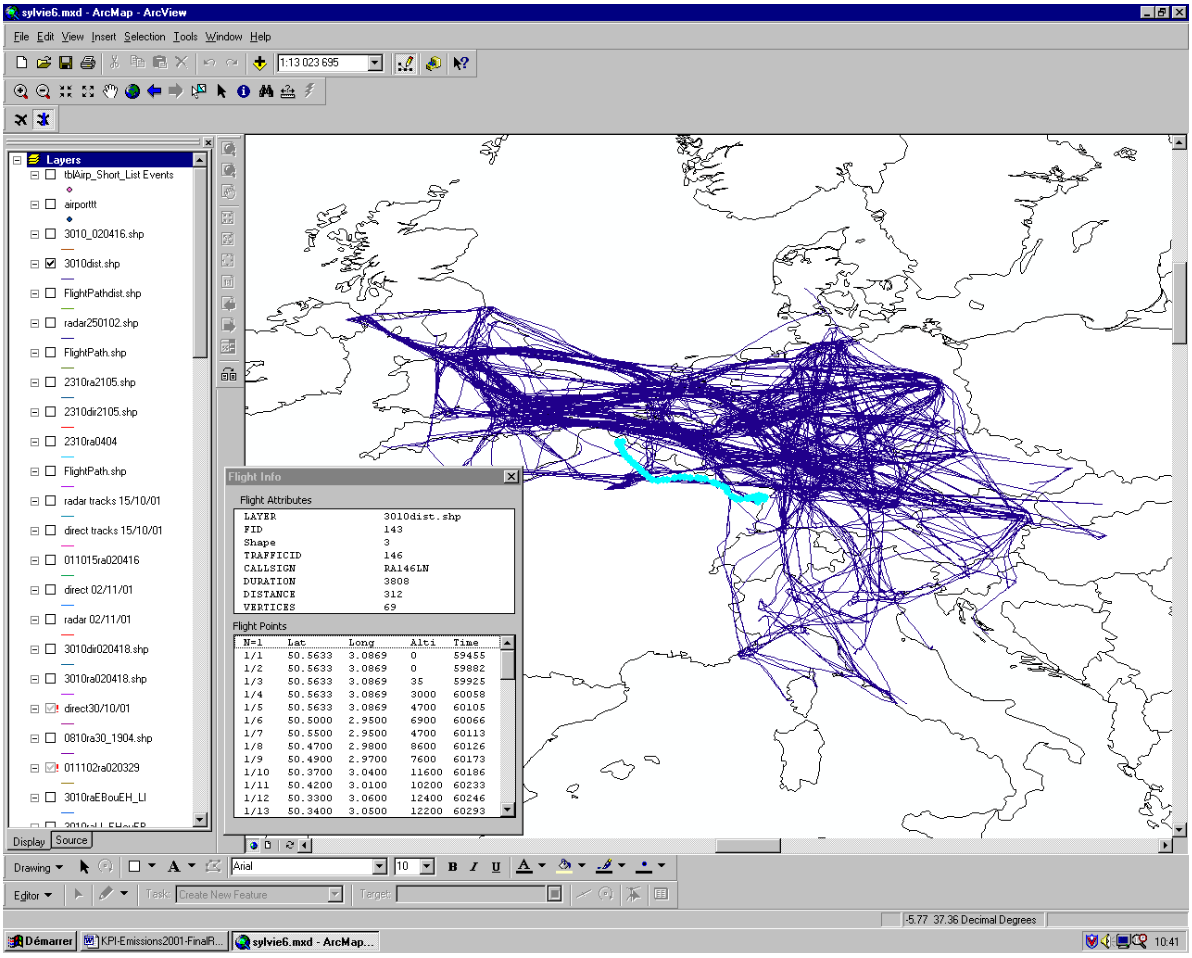

Figure 13: ArcView Interface, with a specific module to select aircraft tracks

The Route Efficiency analysis compared the 'actual' ground track of each flight to the so-called direct route ground track – the great circle distance between initial and final plots of each radar track. The radar data were filtered prior to analysis to select flights that had 'complete' profile trajectories starting and ending within European airspace, see 2.1.5 on page 6. Flight plan information was not required for this analysis.

Since the recordings were of different durations and we only considered complete flights, some spread of results was expected since the proportion of long duration flights in relation to the number of short duration flights was artificially reduced. Note, the distribution of direct distance length was validated for each recording, see 2.4.3 (page 13). However, the issue is complicated because the recordings did not cover same geographical areas.

This Route efficiency comparison was realized using the ArcGIS 8.1(ESRI) Geographical Information System. A complementary module was implemented in Visual Basic to calculate distances. It was based on Great Circle distance between the first and last radar plots of each trajectory and between each radar track update.

The Direct Route did not take into account compensation for SID/STAR manoeuvres in the Terminal Management Area (TMA), as the radar recordings do not always give coverage for those phases for all airports.

Table 7 and Figure 14 represent the repartition of the number of flights for each recording as a function of the direct route ground track length. Figure 15 is the average of Figure 14 – average of number of flights for five days function of the direct route ground track length.

Table 7: Count of tracks per recording as function of direct path length

		Dates								
		Tuesday 09/10/2001	**Monday 15/10/2001**	**Tuesday 23/10/2001**	**Tuesday 30/10/2001**	**Wednesday 07/11/2001**	**Friday 02/11/011**	**Monday 08/10/2001**	**Thursday 08/11/2001**	**Tuesday 06/11/2001**
intervals (km)	**200-300**	34	240	101	170	86	103	69	143	128
	300-400	52	309	90	249	153	93	98	180	157
	400-500	70	321	71	229	120	76	110	134	133
	500-600	79	191	35	134	73	25	52	96	60
	600-700	53	138	18	78	72	7	31	92	44
	700-800	25	84	15	49	36	4	21	31	29
	800-900	16	36	4	14	17	1	5	26	10
	900-1000	10	45	1	30	22	4	11	16	9
	>1000	53	45	3	24	28	1	2	21	12
	SUM	*392*	*1409*	*338*	*977*	*607*	*314*	*399*	*739*	*582*

Note: The number of flights per direct route ground track interval was greater for the 15th October 2001 than for the other days because of longer recording time – 13:00 to 20:00 UTC (7 hours) compared to the usual 6 hour recordings.

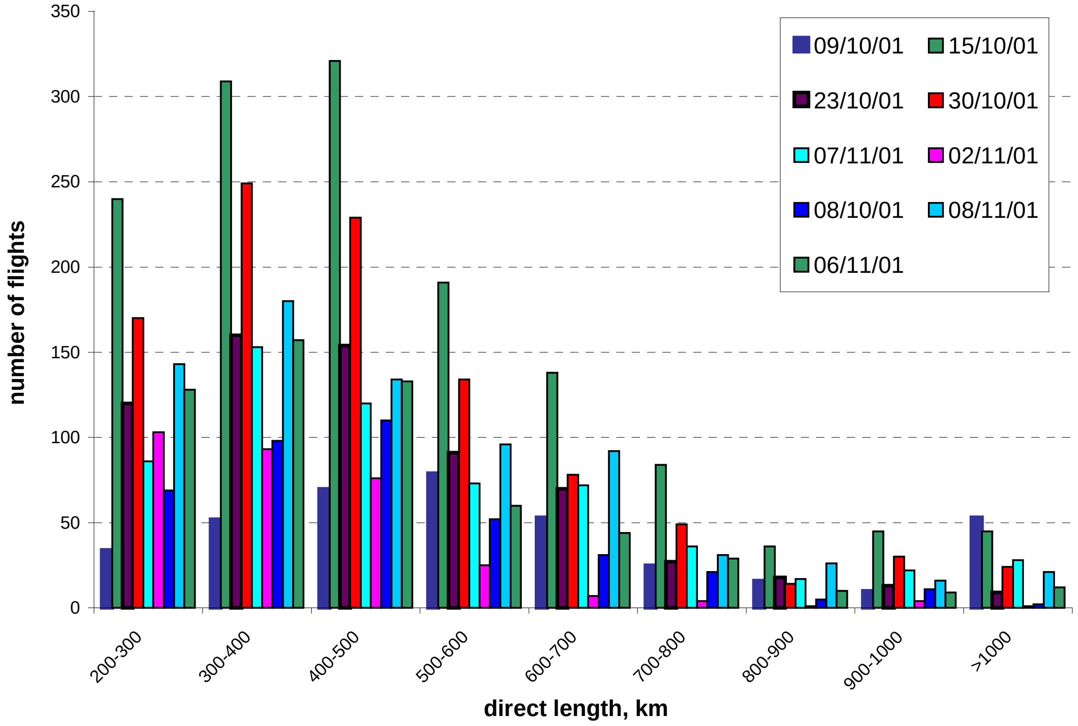

Figure 14: Number of flight per direct route interval

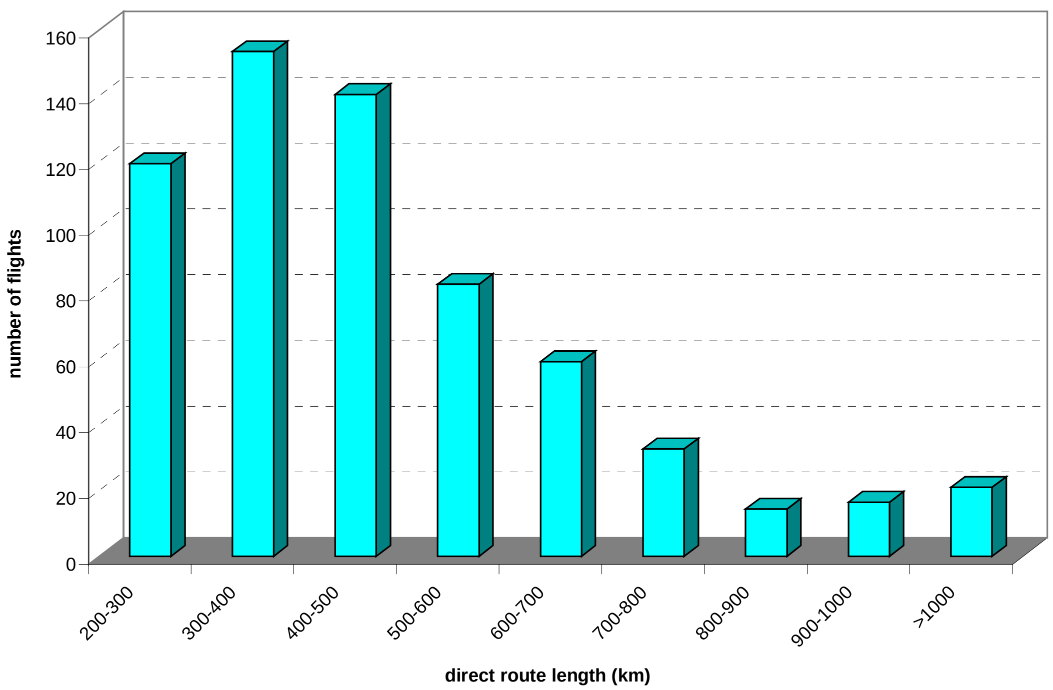

Figure 15: Average over 5 days - number of flight per direct route interval

Flights with a Direct Route length of less than 200 kilometres were not included in the analysis to avoid wide dispersion of results due to inconsistent and incomplete data. Such flights had Landing and Take-Off (LTO) and TMA manoeuvre segments that formed the major part of each flight. The LTO and TMA segments were also affected by inconsistent radar coverage due to the type of radar used in the recordings and the fact that not all radars were connected to our recording system. These were 'en-route' radars that are not designed to give full cover at airports. Locations that benefited from complete coverage to ground level included; Brussels Zaventem, London Heathrow, Amsterdam Schiphol, Frankfurt, Geneve.

Figure 16 shows the difference between real routes and direct routes for each flight. The difference was calculated using the formula:

$$\%(\text{real-direct}) = (\text{real route, km} - \text{direct route, km}) * 100 / \text{real route, km}.$$

For short route lengths, less than 500 kilometres, Figure 16 shows a large dispersion. This difference is in part due to the influence of airspace constraints and LTO manoeuvres, including extensive time in stacks. The results are also influenced by the fact that the real route that was calculated on a point-to-point basis, from one 'track update' to the next, and subject to occasional tracking errors – jumps in position.

For longer direct routes, more than 500 kilometres, the dispersion tends to decrease because the influence of the LTO cycles and airspace constraints become less significant. Conversely, the effect of winds-aloft becomes significant with increasing distance, the effect of this will be considered as part of the fuel burn analysis.

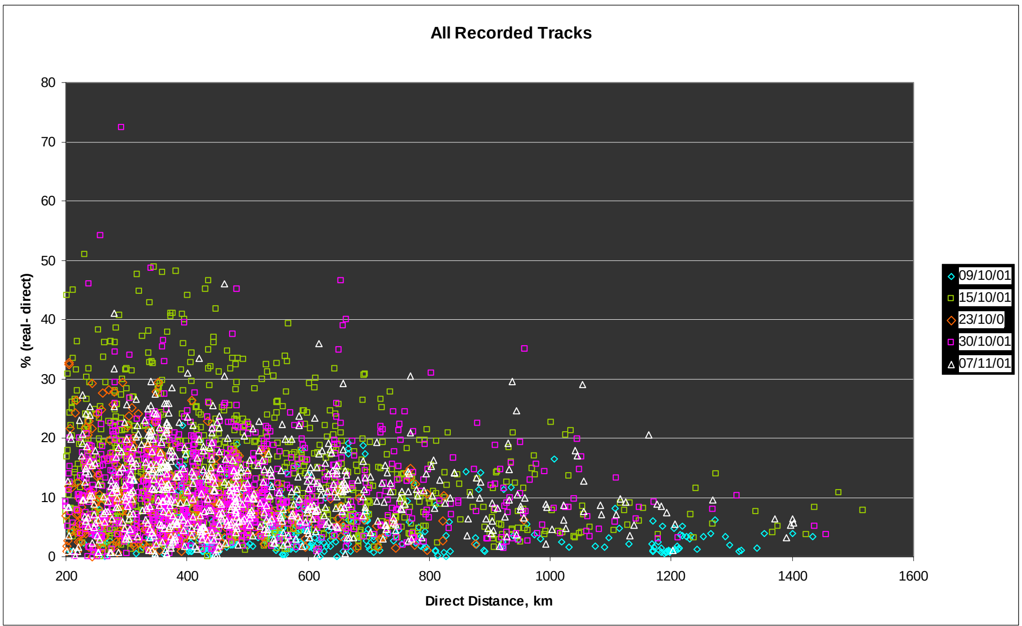

Figure 16: Mean difference (percentage), real-direct as function of Direct distance.

The influence of LTO and other constraints for flight with a great circle distance below 500 kilometres, can be seen in the bar charts in Figure 17 and Figure 18. The average extra distance decreases as a function of direct distance below 500 kilometres. Above 500km the influence of LTO and track errors remains constant. The difference in distance for longer flights is largely due to airspace constraints.

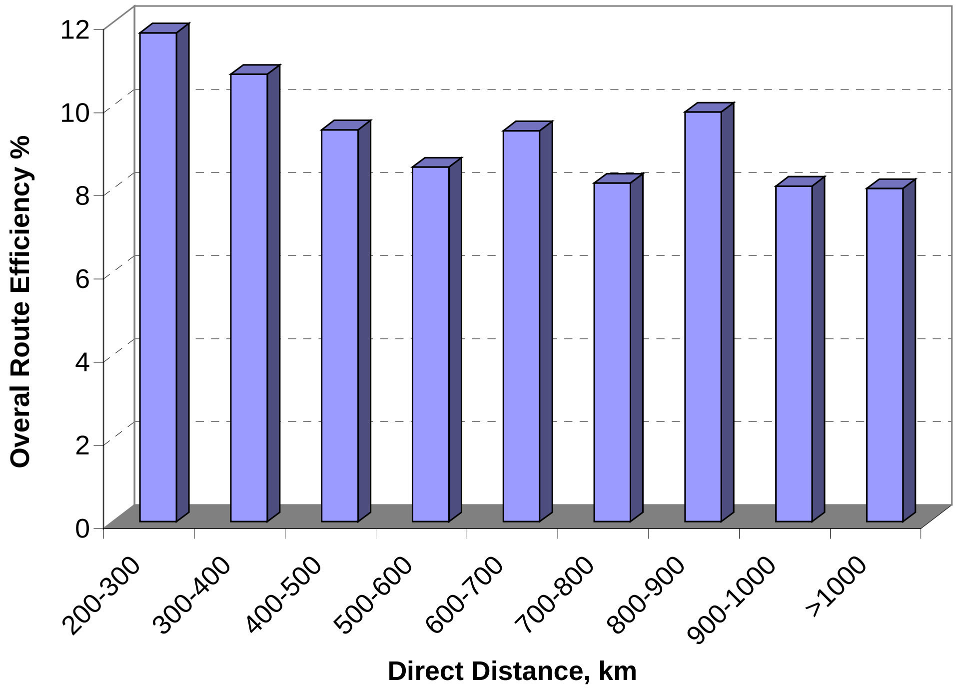

Figure 17: Average route efficiency as function of direct route length

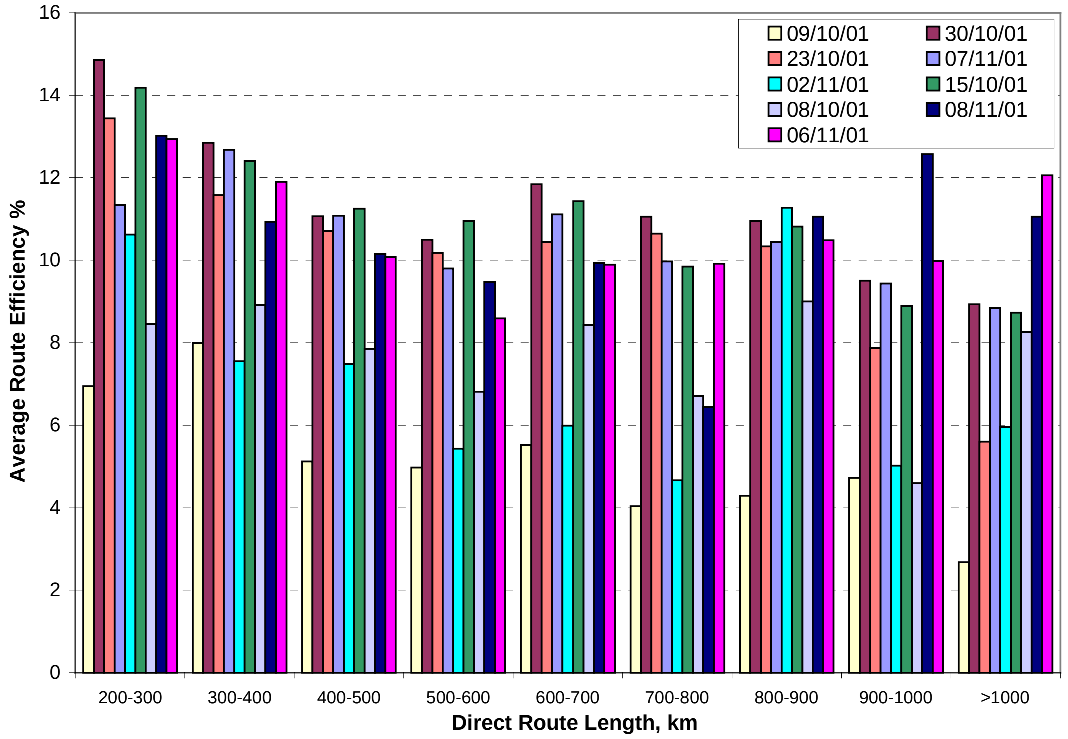

Figure 18: Overall route efficiency as function of direct route length

3.1 Route difference trend graphs

The scatter graphs in Figure 19 through Figure 21 show the measured difference between real and direct route for each flight.

The absolute differences increase as a function of direct distance.

The results are grouped by recording in three graphs as a function of distance flown:

- direct distance between 200 and 500 kilometres
- direct distance between 500 and 800 kilometres
- direct distance greater than 800 kilometres

As with the distribution of traffic graphs, the real-direct difference was calculated using direct route lengths of more than 200 kilometres to avoid the influence of short flights. In future campaigns short flights will be analysed when the correlation with departure and arrival airports is reliable.

Category of flights between 200 and 500 kilometres

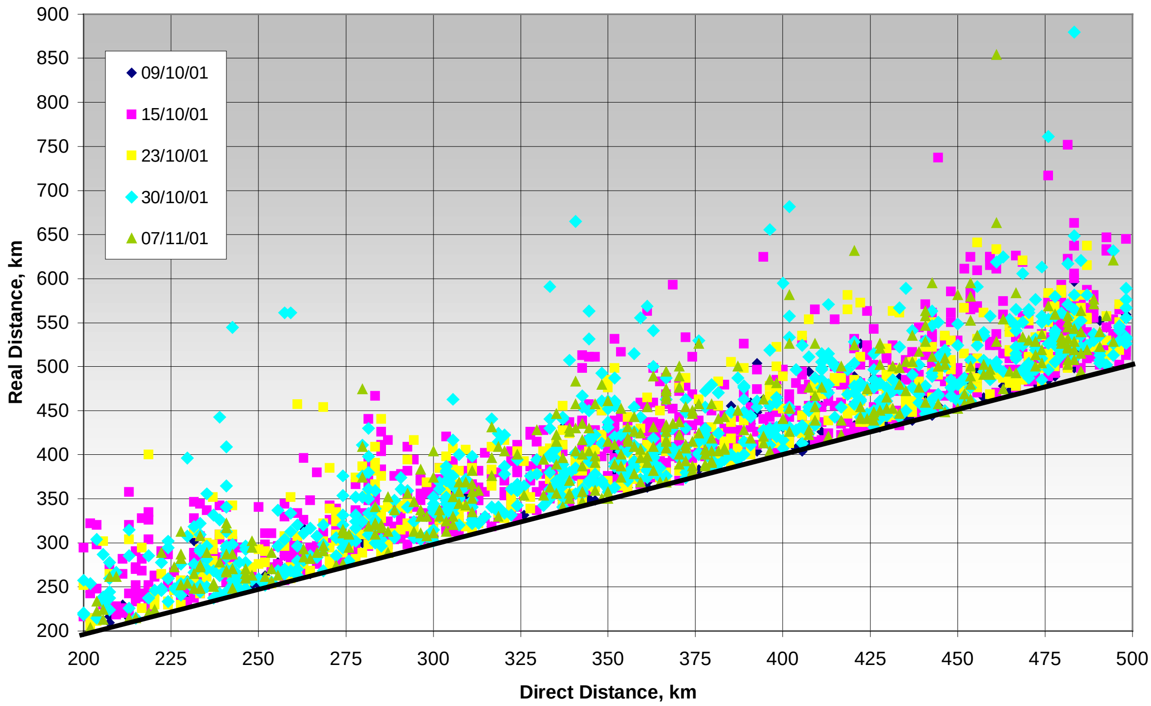

Figure 19: Direct distance in function of real distance - 200 to 500 km

Category of flights between 500 and 800 kilometres

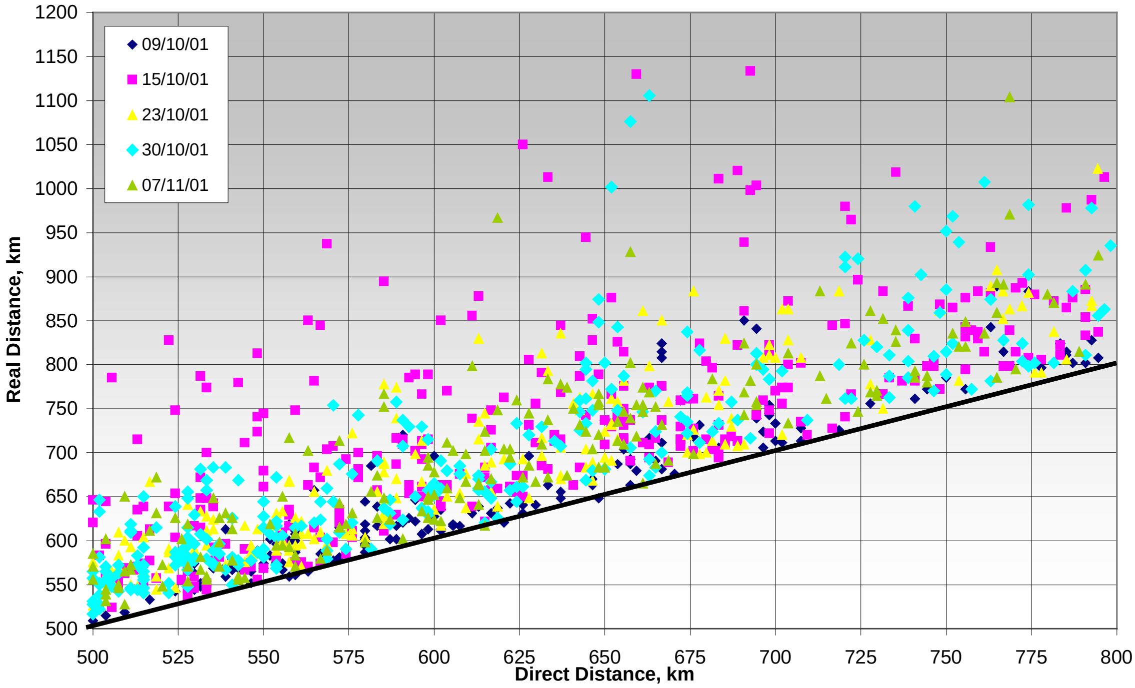

Figure 20: Direct distance in function of real distance - 500 to 800 km

Category of flights greater than 800 kilometres

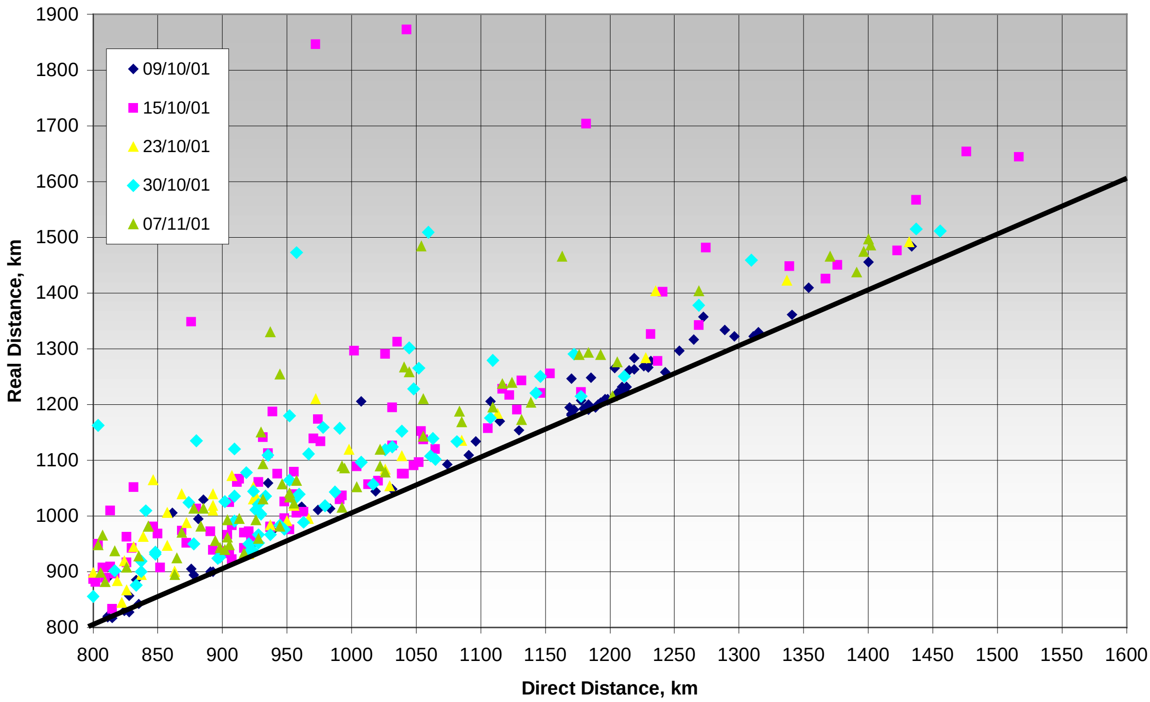

Figure 21: Direct distance in function of real distance - more than 800 km

3.2 Choice of direct route ground track

The direct route ground track is the independent variable in the route efficiency and total fuel burn indicators. In the 2001 study two methods of direct route ground track were used:

- First-last data point
- Airport-to-airport distance

Both routes were the great circle ground projected distances between the route start and end points.

In the case of the ‘first-last data point’ it was the radar data and in the case of the ‘airport-to-airport distance’ it was based on departure and destination airports. Although that this ‘perfect’ route is idealistic and would never actually be flown by fixed wing aircraft – at least by foreseeable future of air transport[1] – it served as a useful ‘fixed’ baseline.

The direct route did not take into account ATM airspace constraints. These constraints may vary on medium term, day-to-day, basis or short term, due to congestion, operational requirements or meteorological phenomena. A future study would incorporate these constraints by using either the filed flight plan and/or the corrected flight plan as a reference and by classification of data using the CFMU route information.

The errors in route length due to LTO phases at each airport were considered to be systematic errors in distance (i.e. time). Future analyses will allow these systematic errors to be expressed as a function of each airport for departures and arrivals.

In future studies, if runway-in-use is taken into account a greater degree of realism could be introduced at a cost of increased complexity. Because of the large geographic area involved, all airports in the study domain would need to be updated with runway in use for the duration of each recording. Each departure and arrival airport would be correlated with the runway in service at the time of arrival/departure. Runway in service knowledge is not automatically available to flight plan information. It can be relatively easily derived if there is good radar coverage around the airport and knowledge of the runways at each airport. However, specialist software would be required to analyse the radar data and maintain a database. Also, our experience with the 2001 data collection showed that radar data obtained from non-operational sources, even when radar coverage is good, were subject to day-to-day variations that result in correlation errors between the start of a trajectory and the departure airport and the end of the trajectory with the arrival airport. More reliable radar cover would be obtained if airport approach radars were included in the recorded radar information. However, this is often not the case and we had to rely on data from en-route radars located sufficiently close to airports to give the required coverage.

Further precision could be obtained by accounting for SID/STAR variations at each airport completed with flight plan information from the departure and approach functions at the departure and destination airports.

[1] Readers who remember the Startrek Television series will understand the hint !

The total fuel burn environment indicator used the 4D direct route as reference for each flight. As discussed in 2.6.2 (on page 14), the 'perfect' 4D route would never actually be flown – at least by foreseeable means of air transport – but served as repeatable 'fixed' baseline. The errors in route length due to Landing and Take-Off (LTO) phases at each airport were considered to be systematic errors in distance (time) and counted by the Advanced Emission Model version 3 (AEM3) as a constant for all airports. Future versions of AEM3 will allow separate LTO parameters for each airport.

Table 8: Output of AEM for each recording

Date		08/10/01	09/10/01	30/10/01	02/11/01	07/11/01	08/11/01
No Flights		339	234	759	289	587	498
Sum Duration (s)	*Radar*	1480029	1914760	3500462	1074184	2768360	2191222
	Direct	1169916	1513388	3246912	945049	2228612	1944892
	Difference	310114	401372	253550	129136	539747	246330
	Percentage	21	21	7	12	19	11
Sum Distance (km)	*Radar*	159901	208001	405865	118489	334160	259398
	Direct	135124	175695	342312	98911	278741	222597
	Difference	24777	32306	63552	19579	55419	36800
	Percentage	15	16	16	17	17	14
Sum Fuel Burn (kg)	*Radar*	512000	672686	1267352	365953	1096440	784348
	Direct	453291	587958	1204297	328719	959784	734498
	Difference	58709	84729	63055	37234	136656	49851
	Percentage	11	13	5	10	12	6

The results shown in table 8 were calculated by AEM3 using filtered traffic in selected recordings. Recordings were selected on the basis of consistent meteorological conditions. The trajectories were filtered visually using ArcGIS©.

Earlier results from the analysis for flights in the 200 to 800 kilometres range indicated the margin between average fuel burn for real routes to be in the order of 8 % more than the direct route fuel burn. The variation in results from day-to-day correlate with the route efficiency results allowing for the LTO cycles.

The option of calculating the LTO cycle is standard, see 2.7.1 on page 14. Since this option uses a fixed LTO cycle for all flights irrespective of airport, there are implicit errors incurred with respect to the real ground track and profile. The errors have systematic (constant) and random components. The systematic errors are a function of airport at the lowest level of resolution. Increasing the error resolution would allow classification of errors as a function of track and profile characteristics, such as SID, STAR, taxiing routes, operator and aircraft type. The random errors are flight-by-flight variations due to the influence of random effects such as weather and ATM constraints.

The Total Fuel Burn was calculated using AEM3 with a constant LTO factor for all airports. The results indicate fuel burn margin to be somewhat higher – in the order of 10 to 15% depending on route length. The variation in results from earlier calculation was due in part to the AEM3 tool and also more stringent selection of traffic samples. More precise results will be possible when the validation process of the AEM tool is finished.

It is important to note that AEM3 is undergoing continuous improvement. The data sets used here will be kept as baselines to evaluate future versions.

The flights used in the airport pair study were selected from the fuel burn analysis in order to study the influence of military zones on the real routes. The callsigns were used only to identify the flights departure and destination airports. The selected examples must not be taken as representative of all flights of an airline on the route.

The vertical limits of the military zones are not taken into account neither are the active status of the zones analysed. Although the basic military zones in the CFMU environment did not change during October and November. Only the active/non-active status may have changed from day-to-day.

The basic military zones are shown on Figure 22 in light blue.

The differences in route distance outside the TMAs were due to active military zones for the tracks in this example.

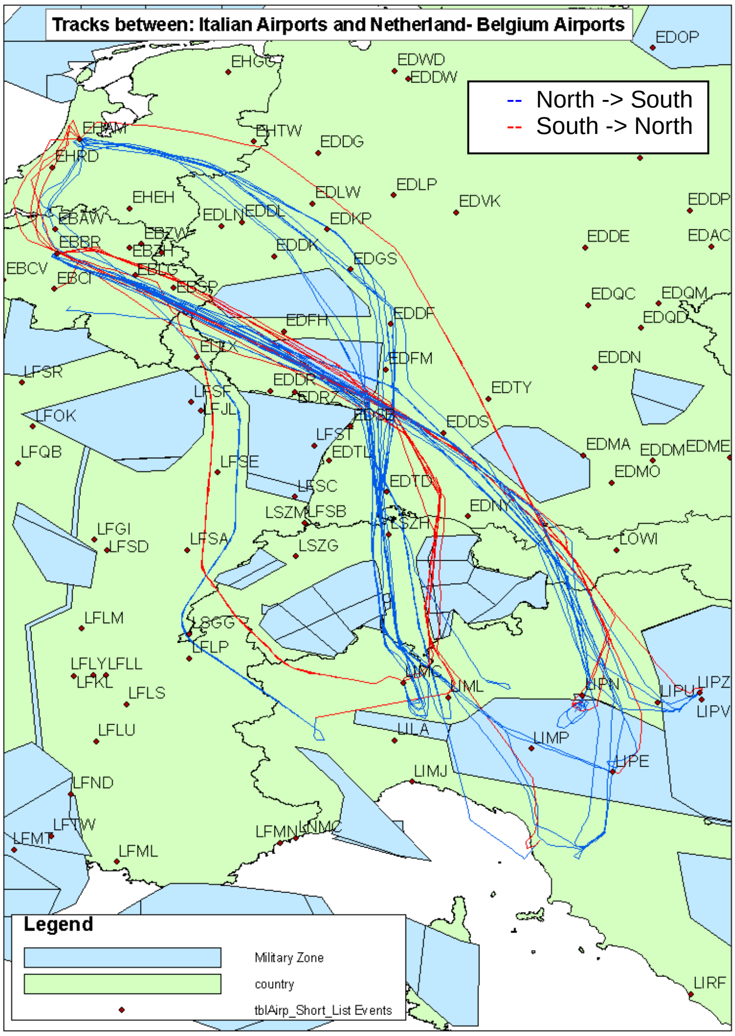

Figure 22: Selected tracks between Italian and Brussels/Amsterdam airports

The 'Environmental Key Performance Indicators 2001 study' focussed on two flight efficiency performance indicators: route efficiency and total fuel burn. The 'total fuel burn' indicator is part of the 'total fuel burn and emissions' indicator previously studied by Celikel in 2000.

The Env-KPI 2001 study was sponsored by the Eurocontrol Performance Review Unit (PRU). The results presented in this report were used to provide results for their annual report PRR-5.

Although the geographical coverage obtained from the ARTAS data was better than that available to the 2000 study, the a-posteriori correlation of those radar tracks data to flight plan data was uncertain, resulting in large proportion of unused data due to incorrect correlation with departure and arrival airports. The correlation was uncertain because the surveillance coverage was often incomplete for the landing and take-off phases of flight. Correct correlation could only be assured when the surveillance data covered the flight path on the extended runway centre line. In other cases an assumption had to be made about departure or destination airport and in such cases where several commercial airports were in close proximity the data were rejected.

6.1 Route efficiency analysis

The results of the 'route efficiency' analysis indicate that the average route inefficiency for the core area of Europe varies between 10-12% for very short flights (under 400km) and 8% for routes between 400 and 1000 kilometres.

The traffic samples used for the study were representative of the days studied in terms of route length distribution.

6.2 Total fuel burn

The 'total fuel burn' indicator (also called 'fuel efficiency') combined the route efficiency with vertical profile and the aircraft performances. The indicator is measured by comparing the real 4D route to the optimum 4D direct route for a given aircraft type and route. The optimum profile was based on CFMU (TACT) aircraft performance and requested flight level. The fuel burn was simulated using the EEC Aircraft Emissions Model version 3 (AEM3). The analysis was restricted to flight samples where the aircraft type, departure and destination airports were correctly correlated with the radar data.

The results of the total fuel burn analysis indicate an average fuel inefficiency of 8% for flights between 400 and 1000 kilometres within the ECAC area. With further refinement of the analysis procedures and classification of data we anticipate the total fuel burn inefficiency could to be in the order of 10 to 15% depending on route length. More precise results will be possible when more extensive correlated data area available and AEM tool is validated.

6.3 Future work

A more thorough data collection using the correlated position reports (radar tracks already correlated to flight plans) from the ETFMS should provide results from a wider area over longer duration that can be achieved using radar data. The processing overhead when using radar tracks from ARTAS is too expensive in terms of effort and delay if daily recordings are to be analysed.

A more detailed route efficiency analysis should be carried out to determine the error related to the landing and take-off phases and airspace constraints such as conditional route availability. The 2001 study did not allow for LTO cycles, as the direct route simulation facility was not set up for this. The data requirements for such a study must be reviewed to ensure sufficient resolution of manoeuvring traffic.

The reference '4D direct route' should be enhanced to allow the user to include optimised LTO and cruise phases as a function of aircraft type and route. It would also be useful to consider compensation for different SID/STAR options in the results, since the AMOC simulation software could calculate these. It will be useful to evaluate suitable simulators to determine which produces the most suitable reference routes and profiles for environmental work.

Meteorological information was not considered in the comparison of real and direct route. Fog and thunderstorms affected two days in the study causing cancelled or re-routed flights. Future studies should make use of timely meteorological data to classify trajectories in terms of runway in use, location of storms and winds aloft.

ATM airspace constraints could be considered in a future study by using the flight plan profile as the reference route.

For the 2002 study we plan to increase the proportion of surveillance data used over a wider geographical area by using surveillance data from the ETFMS (Enhanced Traffic Flow Management System) Correlated Position Reports (CPR). The ETFMS promises some advantages:

- A coherent picture of the actual traffic in the ECAC area,
- the ETFMS data are already correlated to Flight Plan data.

However, the time resolution of the CPR data, in the order of 1 to 8 minutes, may mean that the CPR data can be used only for average route efficiency and fuel burn metrics. This aspect will be reported in the 2002 study.

The time available did not allow a full 'optimum profile' to be generated for each flight. In the 2002 study the 4D direct routes will be based on optimum cruise level for a given aircraft type and direct route instead of requested flight level.

In the 2002 study we aim to improve the classification of results by taking into account ATM restrictions, diversions due to meteorological phenomena, unway in use, TMA manoeuvres and flight plan changes.

7 Acknowledgements

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- Eurocontrol MAS-UAC, Engineering division, Maastricht, Netherlands.
- UK-NATS, Engineering support, Gatwick south. England
- Skyguide Geneva, Switzerland
- ENAV Padova, Italy

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[Ref 1] Aviation and the Global Atmosphere, Intergovernmental Panel on Climate Change (IPCC) report, Cambridge University Press, 1999.

[Ref 2] Performance Review Report PRR5 Year 2001, Eurocontrol Performance Review Commission, July 2002.

[Ref 3] Environmental Key Performance Indicators for PRC: Ayce CELIKEL, EEC Note N°9, March 2001.

[Ref 4] Performance Review Report PRR4 Year 2000, Eurocontrol Performance Review Commission, April 2001.

[Ref 5] CFMU Environment of October and November 2001.

[Ref 6] Review of Research Relevant to Rail competition for Short Haul Air routes, M. Wardman, A. Bristow, J, Toner, G. Tweddle, EEC Environment Note EEC/ENV/2002/003, May 2002.

[Ref 7] AEM User Guide, version 3.2.

[Ref 8] ARTAS Tracker Software Requirements Specification. Document no 46-127-302-306, revision 4.2, July 1999.

[Ref 9] ARTAS Interface Requirements Specification, ARTAS Document 46-127-301-506, revision 2.0, April 1996.

[Ref 10] SASS-C Users Guide, version 5.3, September 2001.

9 Glossary

ACC	Air Traffic Control Centre
AEM	Advanced Emission Model
AMOC	Aircraft Modelling Capacity
ARTAS	ATC Radar Tracker And Server
ASTERIX	All purpose Data Exchange and Interchange Format
ATC	Air Traffic Control
ATC	Air Traffic Control
ATFM	Air Traffic Flow Management
ATM	Air Traffic Management
ATS	Air Traffic Service
BADA	Base of Aircraft Data
CFMU	Central Flow Unit Management
CNS	Communications, Navigation, Surveillance
CPR	Correlated Position Report
EATMP	European Air Traffic Management Plan
ECAC	European Civil Aviation Conference
EEC	Eurocontrol Experimental Centre
ENAV	Ente Nazionale Assistenza al Volo
ETFMS	Enhanced Tactical Flow Monitoring System
FAA	Federal Aviation Administration of the USA
FAP	Future ATM Profile
GIS	Geographical Information System
IPCC	Intergovernmental Panel on Climate Change
KPI	Key Performance Indicators
LTO	Landing Take-Off Cycle
MADAP	Maastricht Automatic Data Processing and Display System
MAS-UAC	Maastricht Upper Area Control Centre
NATS-UK	National Air Traffic Services, United Kingdom
OAG	Official Airline Guide
PKT	Passenger Kilometre, Number of passengers carried multiplied by the great distance flown (1 PKT=1 passenger carried over 1 km))
PRC	Performance Review Commission
PRU	Performance Review Unit
RKT	Revenue Passenger Kilometre, Number of seats multiplied by the distance flown in km for every individual flight.
RPK	Revenue Passenger Kilometre
SASS-C	Surveillance Analysis Support System for ATC Centres
SID	Standard Instrument Departure
STAR	STandard Arrival Route
STNA	Service Technique de Navigation Aérienne
SurvITE	EEC Surveillance Integrated TEstbed
TACT	Tactical Computer System
TMA	Terminal Management Area
TOL	Take-Off and Landing

Appendix 1 - Traffic Distribution Validation

The graphs in this section show the comparisons of the traffic that were selected for analysis against the reference traffic in the European area. The graphs show the distribution of ARTAS radar derived traffic against the great circle distance intervals in kilometres. The reference traffic data were derived from the OAG database and were corrected for the date and recording times of the radar data.

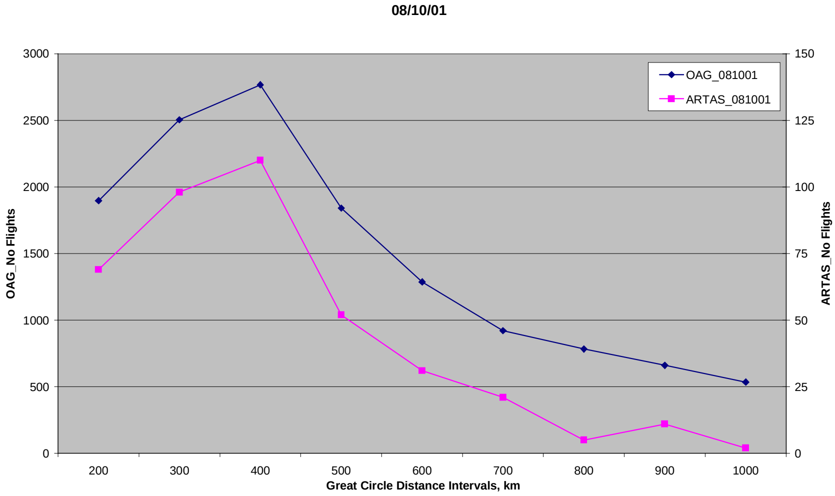


Figure 23: Traffic Distribution 08/10/01

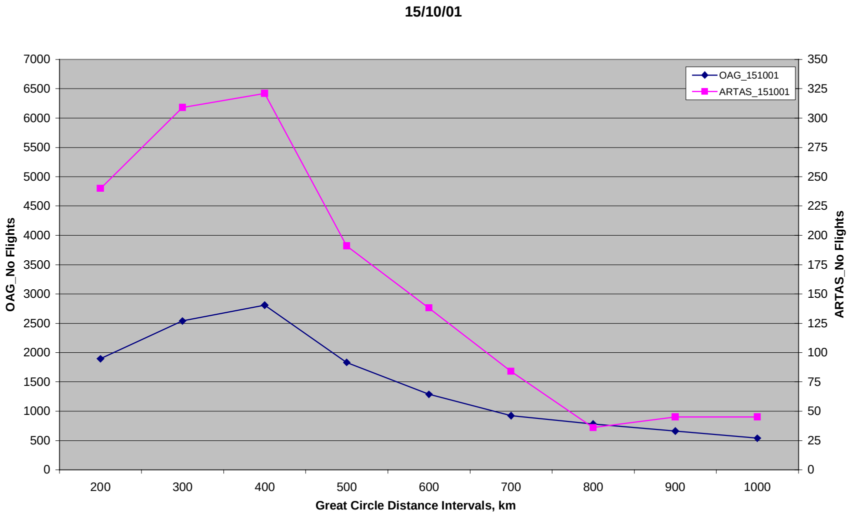


Figure 24: Traffic Distribution 15/10/01

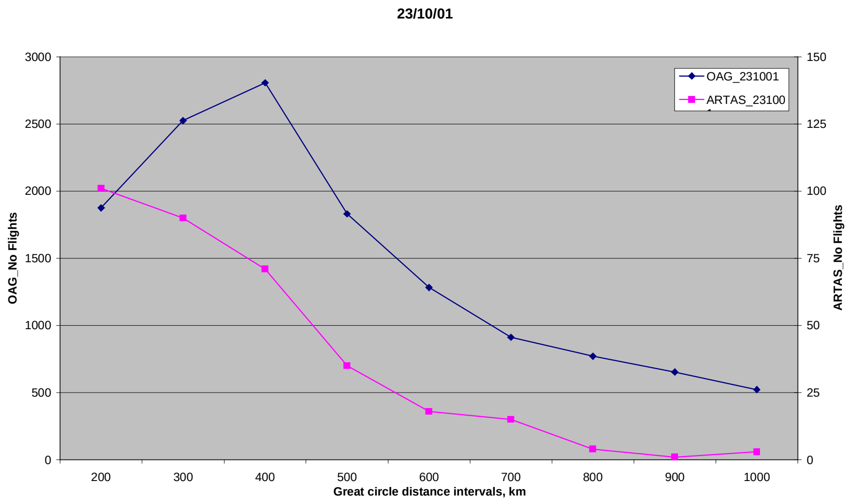


Figure 25: Traffic Distribution 23/10/01

Figure 26: Traffic Distribution 30/10/01

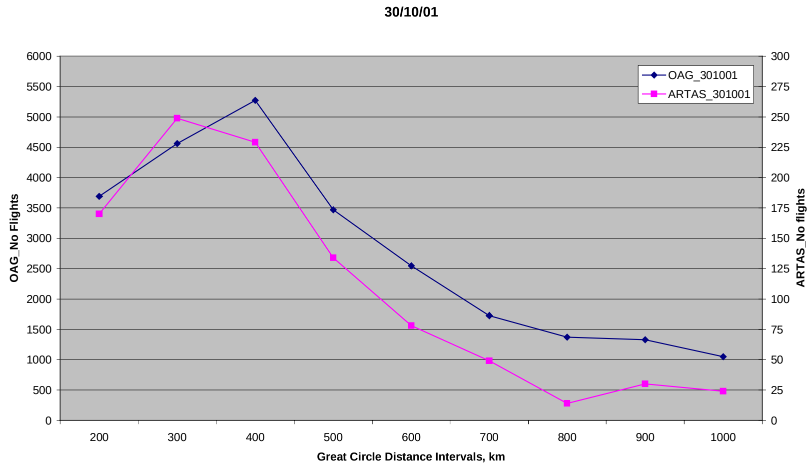


Figure 27: Traffic Distribution 02/11/01

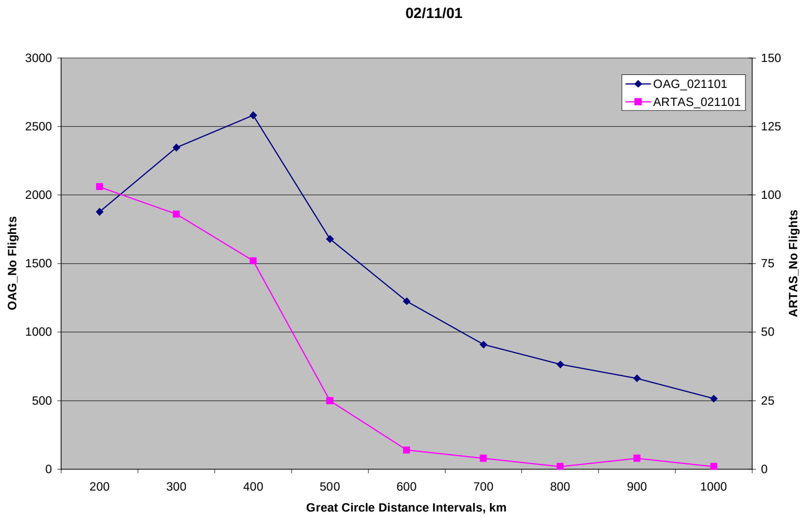


Figure 28: Traffic Distribution 06/11/01

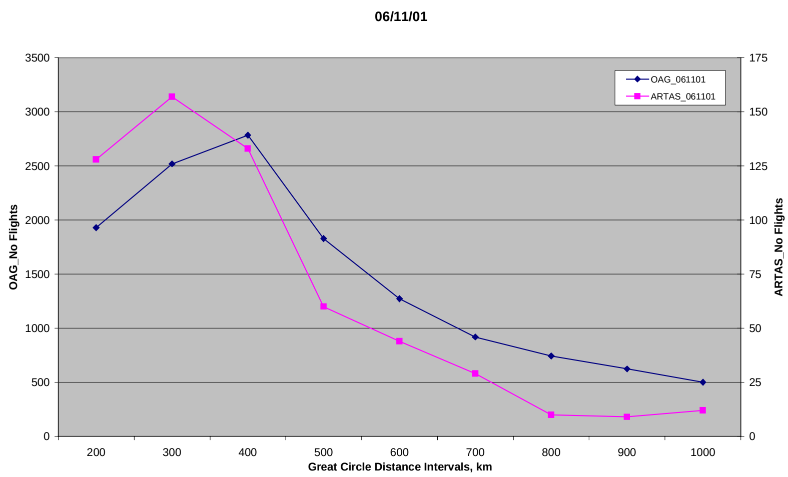


Figure 29: Traffic Distribution 07/11/01

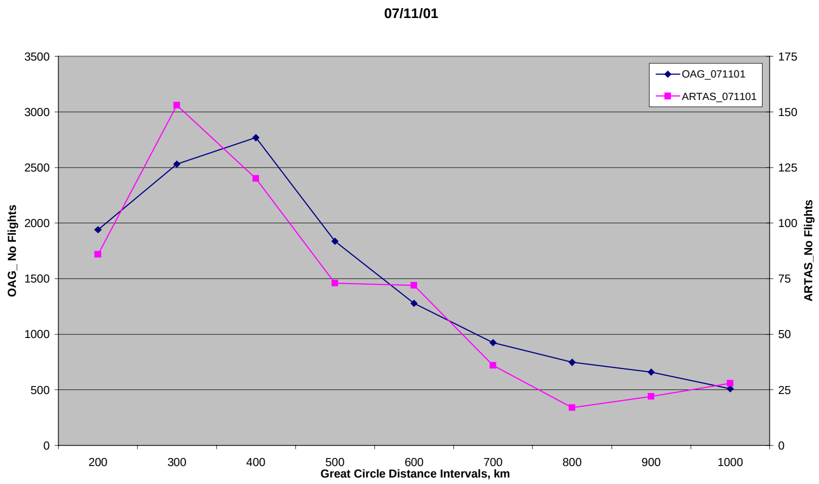
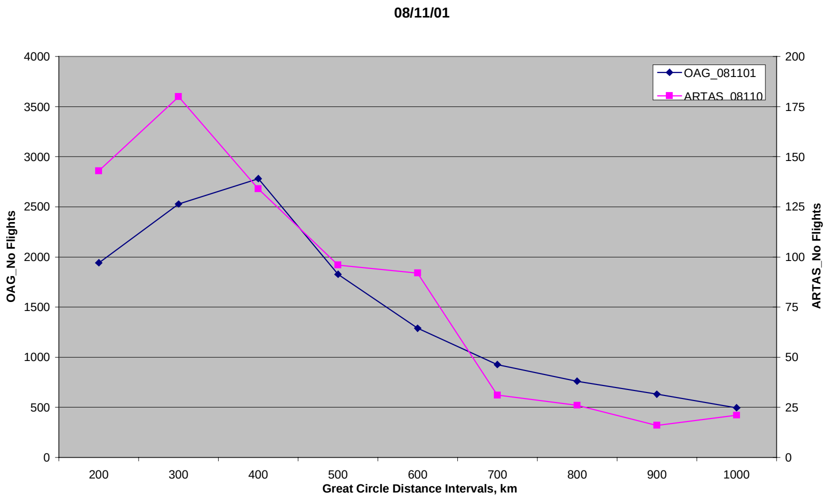


Figure 30: Traffic Distribution 08/11/01



Appendix 2 - ECAC and OAG countries

In the context of validating the traffic samples for the study the OAG database was used to select traffic in the European area. The OAG European selection of countries is not the same as ECAC area. This annexe shows the differences between the two lists. The table below shows the ECAC countries (European Conference for Civil Aviation) and the OAG European countries.

ECAC	OAG Europe
Albania	Albania
Armenia	
Austria	Austria
	Belarus
Belgium	Belgium
	Bosnia-Herzegovina
Bulgaria*	Bulgaria
Croatia*	Croatia
Cyprus*	
Czech Republic	Czech Republic
Denmark	Denmark
Estonia*	Estonia
Finland	Finland
France	France
Germany	Germany
Greece	Greece
Hungary	Hungary
Iceland	Iceland
Ireland	Ireland
Italy	Italy
	Kosovo
Latvia*	Latvia
Liechtenstein	Liechtenstein
Lithuania*	Lithuania
	Macedonia
Luxembourg	Luxembourg
Malta	
Moldova*	
Monaco	
Netherlands	Netherlands
Norway	Norway
Poland*	Poland
Portugal	Portugal
The former Yugoslav Republic of Macedonia*	
Romania	Romania
	Russia
	Sardinia
Slovakia*	Slovakia
Slovenia	Slovenia
Spain	Spain
Sweden	Sweden
Switzerland	Switzerland
Turkey	
Ukraine*	Ukraine
United Kingdom	United Kingdom
	Yugoslavia

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