Multi-criteria environmental impact assessment and optimisation of aircraft trajectories

Minimizing environmental impacts during different phases of flight

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***Abstract*—Air traffic management as currently under development by the Single European Sky ATM Research program SESAR has an important role to play in reducing environmental impact of aviation, in addition to the improvements to be derived from new aircraft and engine technologies. Modelling capabilities are required to allow a multi-dimensional environmental impact assessment. This study presents a concept for a multi-criteria environmental assessment of aircraft trajectories as developed within the Exploratory Research Project ATM4E (SESAR2020). In that context we present ideas on future implementation of such advanced meteorological services into air traffic management and trajectory planning by relying on environmental change functions (ECFs). These ECFs represent environmental impact due to changes in air quality, noise and climate impact. In a case study for Europe prototype ECFs are implemented and a performance assessment of aircraft trajectories is performed for a one-day traffic sample. For a single flight fuel-optimal versus climate-optimized trajectory solution is evaluated using prototypic ECFs and identifying mitigation potential. The ultimate goal of such a concept is to make available a comprehensive assessment framework for environmental performance of aircraft operations, by providing key performance indicators on climate impact, air quality and noise, as well as a tool for environmental optimisation of aircraft trajectories. This framework would allow studying and characterising changes in traffic flows due to environmental optimisation, as well as studying trade-offs between distinct strategic measures.**

Keywords-air traffic management, environment, climate impact, air quality, environmental impact mitigation, ATMF, environmental change functions, advanced MET services.

I. INTRODUCTION [1]

Comprehensive assessment of the environmental aspects of flight movements is of increasing interest to the aviation sector as a potential input for developing sustainable aviation strategies that consider climate impact, air quality and noise issues simultaneously. Consideration of environmental aspects in en-route flight planning is generally not operational practice apart from the economic goal to minimise fuel use and hence to reduce CO_2 emissions. Note that non-operational, i.e., research-related optimization tools include estimates for climate impacts in route optimization (e.g., [1]). However, only recently climate impact indicators were considered in more detail, which take into account more than mere emission amounts, for example contrail occurrence and ozone changes from NO_x emissions [2–8]. The reasons for this include a low TRL (technology readiness level) of a flight planning method that considers a multi-criteria environmental impact assessment and remaining uncertainty on strategic metrics of environmental impact to motivate environmental flight planning.

Aircraft trajectory optimisation has already started in the 1960s [9] while during the last decades development of approaches has been strongly supported by increasing capabilities of high performance computing. Optimisation tools exist that incorporate more detailed aircraft performance data, that consider meteorological data, e.g., wind and humidity, and that perform a full 4D optimisation. In common practice, route optimisation is driven by cost minimisation, hence those environmental aspects which translate into cash operating costs (COC), are taken into account. E.g., emissions of carbon dioxide enter into route optimisation as they directly correlate to fuel consumption. Other environmental impacts enter in COC optimisation through charges, e.g., noise or nitrogen oxide (NO_x) emissions near an airport in case of associated airport charges.

However, besides CO_2 climate impact, air traffic contributes to anthropogenic warming also by non-CO_2 impacts which are strongly dependent on the location, altitude, and time of emission. Overall, air traffic emissions contribute to anthropogenic warming by around 5% through CO_2 and non-CO_2 impacts [10,11] including contrail cirrus. Aviation stakeholders, European and national authorities implemented a series of initiatives that comprise in their workprogrammes the intention to make future aviation sustainable, e.g., the

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European Commission implemented under its Framework Programmes, CleanSky Joint Technology Initiative (JTI), 'green' aeronautical projects and SESAR2020 Joint Undertaking (JU). Previous research has shown that changing aircraft trajectories to avoid climate sensitive regions has the potential to reduce the climate impact of aviation [12]. Studies which focus on individual impact types e.g., [2,3,13–15] presented trade-offs between climate-optimised and cost-optimised trajectories for various regions of the earth (cross-polar, North Atlantic, Pacific traffic). More recent studies similarly exploited benefit and costs of contrails avoidance by analysing an aircraft trajectory [16] or tested route optimisation for climate optimisation [17]. Research aims to enhance our understanding of the environmental impacts of ATM operations and how they can be minimized during different flight phases.

The objective of this paper is (1) to present a concept for multi-criteria environmental assessment of aircraft trajectories, (2) to introduce meteorological (MET) data products which represent environmental impact at given location and time, so called environmental change functions, which we consider as advanced meteorological information which should be made available via ATM information infrastructure. Finally, (3) we apply the concept by presenting (a) a trajectory optimisation under cost-optimal conditions, providing environmental performance data for the assessment of aircraft trajectories using prototype environmental change functions (ECFs) and (b) an environmental optimisation of climate impact.

II. Environmental Impact assessment Of Aviation

Aviation emissions change the atmospheric concentration of chemical components and hence disturb the radiative balance in the atmosphere and subsequently contribute to climate change. At the same time changes in concentrations of atmospheric components can cause an impact on local and regional air quality. Finally, aviation emits noise which influences noise levels at ground. As aviation emissions undergo complex physical and chemical transformation processes, the specific impact of aviation emissions depends on time and location of emission due to influence of e.g., background conditions, radiation and other meteorological parameters.

A. *Climate impact of aviation*

An assessment of climate impact of aviation requires knowledge generated by complex chemistry climate models, which simulate comprehensive atmospheric transformation processes and subsequently provide quantitative estimates on changes of the radiative balance and impact on climate. The study presented relies on an integrative measure which directly connects aviation emission to their climate impact [1-2]. This concept was applied to climate impact assessments in earlier studies [18], by using the initial cost function concept [19] which relied on cost functions pre-calculated with the comprehensive general circulation model EMAC [23] in a Lagrangian approach under specific meteorological conditions. Expanding this concept to a set of environmental impacts introduces the term environmental change function (ECF). A more comprehensive overview including a detailed description of how to generate ECFs is provided in [20].

Climate change functions depend on time and location of emission as the synoptical situations plays an important role, due to influence of e.g., background conditions, radiation and other meteorological parameters. For climate impact, one way to generate these ECF is to provide them as an annual mean change function, which are then climatological climate change functions. Another option is to generate them individually for a specific weather situation, or in conjunction with linking specific weather situation to an archetypical weather pattern as done for the North Atlantic Flight corridor within REACT4C, by deriving them from meteorological key parameters. A third option is to derive algorithmic ECFs (aECFs) which estimate the ECFs based on readily available MET info, i.e., temperature, humidity, vorticity, and background concentrations (meteorological key parameters).

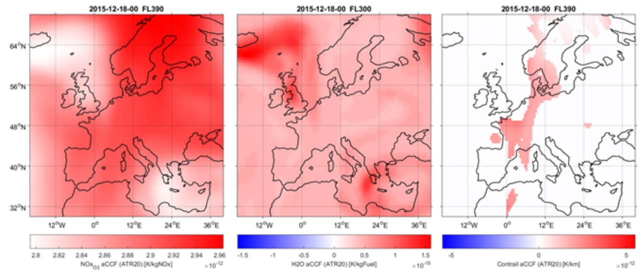

Figure 1. Algorithmic ECFs as Average Temperature Response (ATR) for case study 19 Dec 2015 for water vapour (*left*), nitrogen oxides (ozone, *middle*) and contrail formation (*right*).

In ATM4E we propose and test the applicability of aECFs (Section III.1), as algorithms allow online generation of ECF from meteorological forecast data which is crucial for future implementation. These climate change functions are calculated for aviation emissions having a direct or an indirect climate impact. Carbon dioxide, water vapour, particulate matter and contrail induced cloudiness (CiC) are among those having direct radiative and climate impact. Emissions with indirect radiative impact are nitrogen oxides (NO_x) and particles. Hence, these ECFs are varying with location (position and altitude) and time and date of emission. We refer to average temperature response (ATR) as climate metric (Fig.1), but do not refer to other possible climate metrics, in order to improve readability of the paper. ATR is computed by averaging the surface temperature response during the considered period, assuming sustained emissions with respective routing strategy applied during the whole period, e.g. two distinct periods, 20 and 100 years. However alternative climate metrics can be used in our overall concept in a similar way.

B. *Local and regional environmental impacts of aviation*

Aircraft operations near the ground produce an assortment of gaseous and particulate air contaminants that affect local air quality levels and potentially human health. Atmospheric concentrations found at surface level depend on emission strength but also on synoptic situation and associated physical and chemical mechanisms active in a specific region. In a polluted background atmosphere, aviation can contribute to exceedance of air quality limits, while in an unpolluted background atmosphere aircraft operations will cause less exceedances of air quality limits.

In addition, aircraft operations increase noise levels especially in localities over which aircraft are climbing out of and descending into airports. Noise is recognized from the WHO (World Health Organization) as a threat to human health and is probably the most significant concern for the residents of communities neighbouring airport. Minimizing the number of people significantly disturbed by aircraft noise is one of ICAO's main priorities and one of the industry's key environmental goals.

In this study we expand a modelling concept for climate optimisation to additionally comprise local impacts, air quality and noise issues, leading to a multi-dimensional, and multi-criteria, environmental assessment and optimisation of aircraft trajectories. In that context we introduce environmental change functions (ECF), as well as an efficient method to derive ECFs from standard meteorology data.

C. Aircraft trajectories optimisation

The concept of environmental assessment presented here relies on trajectory calculation within two distinct trajectory optimisation tools, in order e.g. to study influence of trajectory optimisation on air traffic flows, and to identify mitigation potential of environmental optimisation.

The stand-alone model Trajectory Optimisation Module (TOM) is used for trajectory management and optimisation receiving input data on air traffic (city pairs), standard MET data and algorithmic ECFs on environmental impacts. TOM applies optimal control techniques in order to determine continuously optimised four-dimensional aircraft trajectories. For verification purposes we apply purposes a module for aircraft trajectory assessment and optimisation has been integrated in a global climate-chemistry model working interactively during atmospheric calculations.

Second, for verification purposes this module AirTraf is compared to another trajectory calculation model FAST. AirTraf is a module which has been integrated in a global climate-chemistry model working interactively during atmospheric calculations. AirTraf (version 1.0) [21,22]) was developed as a verification tool for climate optimised routing strategies by analysing individual routing options for given city pairs. AirTraf is a submodel of the ECHAM/MESSy Atmospheric Chemistry (EMAC) model [23,24] (ECHAM5 version 5.3.02, MESSy version 2.52) and simulates global air traffic (online) which is able to simulate aircraft trajectories under individual optimisation criteria. An aircraft performance model and International Civil Aviation Organization (ICAO) engine performance data [25] are used. A global air traffic plan is used and both short- and long-term simulations are performed taking into account the individual departure times. The Genetic Algorithm optimises flight trajectories with respect to a selected routing option, taking account of the local weather conditions for every flight, and finds an optimal trajectory including altitude changes.

III. Environmental Change functions for ATM

A prerequisite for environmental assessment and optimization of aircraft trajectories is to develop an interface how to make available environmental impact information during aircraft trajectory planning (ATM). For this purpose we define a concept how to establish an interface between ATM and environmental impact information, further developing the so-called climate cost function approach presented in [20,26].

A flowchart (Fig. 1) shows how standard MET information is complimented with algorithmic ECFs in order to be made available for trajectory optimisation, as advanced MET information service. Performance assessment of aircraft trajectories then comprises environmental performance data beside performance data, e.g., on fuel and time efficiency.

For the impact function which describes environmental impact of an aviation emission, we use first order approximation in a Taylor series. This mathematical description can be transformed to represent an overall objective function for trajectory calculation in this study by a penalty function approach as shown in [20]. As environmental impact of aviation emissions depends strongly on meteorological conditions, comprising physical and chemical parameters, provision of this advanced information is integrated as MET information service for the specific application of environmental performance.

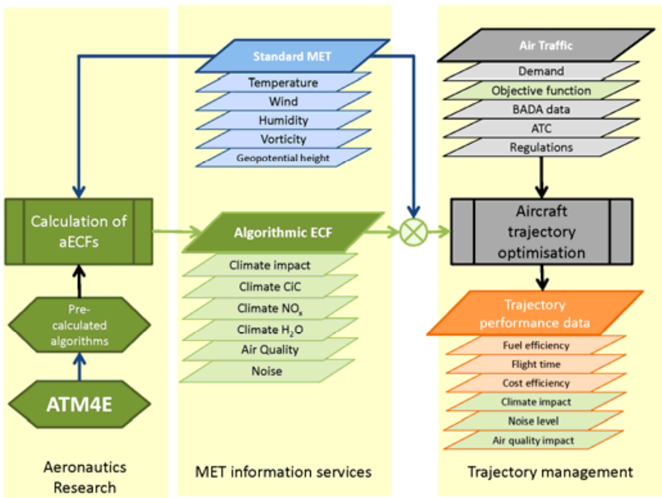

Figure 2. Flowchart of Environmental Assessment of ATM using ATM4E algorithmic environmental change functions (aECF) concept, elements introduced by ATM4E highlighted in green (from [20].

A. Algorithmic weather-dependent Environmental change functions

The climate change and environmental change functions show a strong dependence on meteorological situation on a synoptical scale, hence they are weather-dependent. For that purpose high-quality meteorological information can be used for an accurate generation of such weather-dependent ECFs, which then reflect specific meteorological situation. As presented in [27], different approaches to determine these weather-dependent ECFs exist, i.e., either using MET information to classify synoptical situation according to archetypical weather patterns, as performed within earlier studies [28]. Alternatively, algorithmic ECFs can be developed by using directly spatially and temporally resolved standard MET information available, e.g., provided by a System Wide Information Management (SWIM) as implemented within SESAR, to derive environmental change associated to aviation emission as 4-dimensional functions. Algorithms are used to establish such link between meteorological key parameters and associated environmental impact, which were identified from comprehensive analysis of environmental impact at a specific location and associated prevailing meteorological conditions. Hence, we define the term algorithmic ECF (aECF) in order to describe such algorithms which enable to calculate ECF from basic MET information.

Development of such algorithms require fundamental understanding of atmospheric processes, statistical analysis and high-quality synoptical scale meteorological information, in order to identify and validate robust relationships, e.g., [29], which need to be in a next step integrated as interactive MET information product in ATM tools. Such aECFs rely on meteorological parameters, e.g., atmospheric temperature, relative humidity, geopotential height, potential vorticity, or boundary layer height, combined with e.g., atmospheric concentration and transformation of key chemical species as well as radiation.

B. Verification of algorithm based environmental change functions

Before these aECFs are used for trajectory optimization, a verification process is performed to ensure that the aECFs serve their purposes by comparing results from two distinct calculation procedures for the overall climate impact of an air traffic sample. The EMAC/AirTraf is an appropriate simulation tool since it combines the Earth-system model EMAC with the air traffic simulation model AirTraf. Similarly, aviation emission are integrated as 3 dimensional flux fields to the atmospheric chemistry model [23], affecting the chemical composition of the atmosphere, identified with a specific tagging scheme [30,31] and changing radiative balance, respectively. This verification procedure is performed to ensure that the overall ATR calculated based on the aECFs matches the ATR calculated from the calculated impact in the atmospheric chemistry model, hence allows performing a proof of concept for aECFs.

IV. Case Study: Environmental Assessment and Optimisation of AIR Traffic in Europe

We apply above concept for a multi-criteria environmental assessment of aviation operations in a case study for the European airspace, in order to provide environmental performance data and in order to test feasibility working towards environmental optimisation of air traffic operations. Results are shown for a European traffic sample, together with a sensitivity study on environmental optimisation of an aircraft trajectory.

A. Meteorological and Synoptical Information

As ECFs depend to a large extent on synoptical situation, particular focus was given on selecting candidate days in our case studies. For each day, contrail formation regions were identified using infrared satellite imagery and data from the ECMWF ERA-Interim re-analysis [32]. As indicator for photochemical activity in the atmosphere, the ozone production efficiency was determined with the ECHAM/MESSy atmospheric chemistry model. Additionally geopotential height was determined from ECMWF ERA-Interim re-analysis. For initial analysis, a meteorological situation is selected which represents a medium to high complexity of the meteorological environment which ATM is encountering, e.g. 18 Dec 2015. The 18th of December 2015 is selected as specific date for our case study. The day was characterised by a high-pressure ridge over Europe with the jet stream meandering for North.

B. Traffic sample and engine emissions

The air traffic over Europe on the selected day is used as a reference scenario for the optimization task in ATM4E. Further assumptions are made to filter the traffic data for a better processability. As ATM4E focuses on the European airspace, only intra-ECAC (European Civil Aviation Conference) flights are considered and only flights that can be modelled with aircraft performance data from EUROCONTROL's Base of Aircraft Data (BADA) 4.0 are taken into account. This required simplification reduces the amount of available seat kilometres (ASK) in the data set by only 8–9%, since especially large commercial aircraft representing major parts of ASK are included in BADA 4.0. Lastly, flights which depart before or arrive after 18 December 2015 are filtered out leading to a final dataset of 13,276 flights (from originally 28,337). In our study [20] computation of profiles in a numerical trajectory simulation tool is described in more detail.

C. Engine emission and environmental performance

In order to assess the environmental impact caused by the traffic sample and in order to prepare trajectory optimization, for the described reference flight set the overall performance parameters with respect to gaseous aircraft emissions, the provoked contrail formation and the overall climate impact are calculated.

TABLE I. PERFORMANCE PARAMETER OF EUROPEAN TRAFFIC SAMPLE: CUMULATED EMISSIONS AND DISTANCES: 18 DEC 2015; FROM [20]

	Performance Parameter		
	Parameter	***Amount***	***Unit***
EFF	Air distance[a]	$1.42 \cdot 10^{7}$	km
EFF ENV	Carbon dioxide CO_2	$1.50 \cdot 10^{8}$	kg
ENV	Nitrogen oxides NO_x	$7.20 \cdot 10^{5}$	kg
ENV	LAQ Nitrogen oxides (NO_x)	$0.52 \cdot 10^{4}$	kg
ENV	Distance contrailing	$6.8 \cdot 10^{5}$	km
ENV	Climate impact ATR_{20}	5.7(4.1-7.0)	10^{-3}mK
ENV	Climate impact ATR_{100}	16.7(12.1-20.3)	10^{-3}mK
ENV	Climate ATR_{20} non-CO_2/CO_2	20.0(13.9-24.8)	-
ENV	Climate ATR_{100} non-CO_2/CO_2	5.8(3.9-7.2)	-

a. Uncertainty of environmental indicators indicated in parenthesis.

Four-dimensional (longitude, latitude, altitude, time) emission inventories are generated by simulating every flight in the traffic scenario and determining the corresponding emission distribution. Fig. 3 shows the NO_x emission distribution at 12:00 p.m. UTC of the European traffic sample. Regions with potential persistent contrail formation were identified with a method relying on the Schmidt-Appleman criterion [33], and the contrail situation at 12:00 p.m. UTC is depicted in Fig. 3. From this criterion we calculate the distance flown under persistent contrail formation criteria shown in Table 1 by taking into account real weather conditions on that specific day, which corresponds to 5% of air distance in this representative traffic sample.

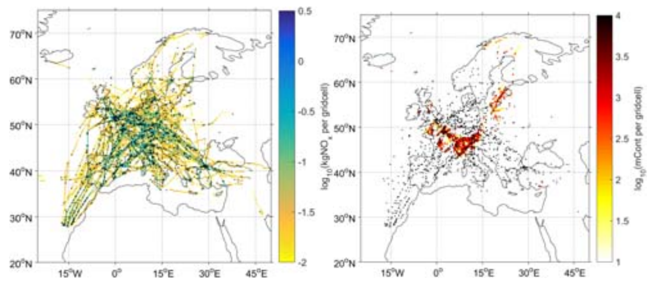

Figure 3. NO_x emissions (*left*) and persistent contrail formation distance (*right*) per gridcell (0.25 x 0.25) integrated over a time period of 20 s on 18 December 2015, 12:00 p.m. UTC. Single aircraft are represented as black dots (1216 in total) from [20].

Overall performance data of the traffic sample, comprising air distance travelled cumulated emissions as well as the distance in contrail areas are listed for the chosen reference day. Among environmental performance data the overall climate impact has been evaluated for two distinct climate impact metrics. ATRs over 20 and 100 years have been calculated under the assumption of sustained emissions, which means that routing decision is similar on each day over the time horizon. Ratios of climate impacts of non-CO_2 versus CO_2-impacts are calculated for ATR_{20} with 20.0, and for ATR_{100} with a lower value of 5.8. Uncertainty range provided refers to sensitivity study on seasonal cycle and annual mean ECFs.

For local air quality the increase of atmospheric NO_2 concentration is estimated using parametric study to investigate sensitivities assuming moderate advection of trace compounds and low atmospheric loss rate. We present mean and maximum values for several vertical layers, i.e., ground level, up to 3000 and 5000 feet. Mean NO_2 concentration is estimated to increase by about 0.3 to 0.4 $\mu g/m^3$, with maximum increase of hourly values in specific regions in the order of up to 10.6 $\mu g/m^3$.

D. *Cost-optimal versus climate-optimal trajectory optimisation*

Beside environmental assessment of aircraft trajectories, the framework can also be applied in an environmental optimisation by adapting corresponding objective functions used in TOM. For a flight from London Heathrow (LHR) to Istanbul (IST) aircraft trajectory was optimized under a series of objectives functions, by varying individual weights from fuel optimal case to climate-minimal solution. ECFs used in this optimisation, are prototypes which were calculated from AirClim climatological mean ECFs. The resulting Pareto front is shown in Fig. 4, together with trajectories from three distinct solutions, the reference case, and solutions for 1% and 5% percent fuel increase, resulting in a climate impact mitigation by reducing ATR by 12% and 25%, respectively.

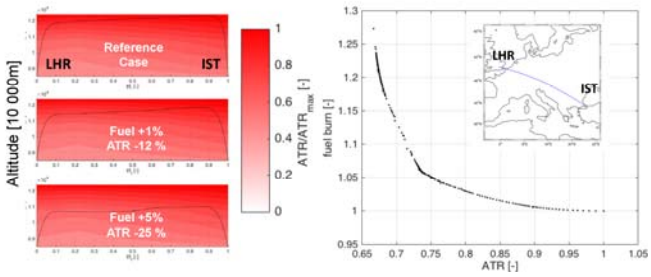

Figure 4. Evaluation of fuel-optimal versus climate-optimal solution, by using prototype ECFs for flight from London Heathrow (LHR) to Istanbul (IST) showing Pareto front (right). Trajectories (left) for reference case (top), fuel increase of 1% (middle) and 5% (bottom) with relative strength of total ATR shown as shading.ng

V. DEVELOPMENT OF MET PRODUCTS ON ENVIRONMENT

The ATM4E approach on environmental flight planning requires that verified advanced MET information are implemented in flight planning, providing the impact of a local emission on climate, air quality and noise. For that purpose ATM4E develops verified aECFs, which allow to provide among MET services both (standard) weather forecast information and advanced MET information, i.e. aECFs (Fig. 1). This advanced MET information can be distributed with standard MET information, e.g., in a SWIM concept, while taking legislation into account in terms of objective function and flight planning. There is the possibility to implement algorithm-based environmental change functions into national weather forecast models, which then provide advanced information via services to users, allowing for an environmental flight planning, as well as short-term tactical adaptations to the aircraft trajectory. Having available ECFs during flight planning also offers the ability to environmentally assess the actually executed flight and to record the data for e.g., environmental legislative purpose.

It is proposed to use ECFs as interface between environmental expertise (derived from models) and air traffic management tools, in order to represent environmental impact in air trajectory models, instead of code integration in a flight planning tool. An interface (function) has the advantage that, first, complex and comprehensive systems and models, e.g., climate-chemistry model with coupled homogeneous and heterogeneous atmospheric chemistry, is used for ECF generation. Second, any updates due to scientific understanding or political decision, e.g., on time horizon of climate impact metric being considered, is integrated by simply replacing (mathematical formulation) of a specific aECF function.

Such advanced MET information offers the possibility to determine key performance indicators in the key performance area environment (KP05). Quantitative indicators providing information on climate impact, air quality impact and noise level can be derived by implementing aECFs in flight planning.

VI. Discussion

An environmental assessment of aircraft trajectories during ATM can be performed, if algorithmic environmental change functions (aECFs) are developed, which consider actual weather conditions. Synoptical scale pattern determine regions with high and low sensitivity to aircraft emissions, hence determine climate change functions. Making available algorithms which establish linkage between MET information and environmental impact is a pre-requisite for an efficient generation of ECFs. A concept relying on aECFs brings as advantage that consequently environmental assessment of aircraft trajectories are not limited to match weather pattern which correspond to archetypical pattern, but for each synoptical situation corresponding advanced MET data products on climate and environmental impact can be generated.

Environmental performance data of European traffic sample in the case study (18 December 2015) showed that overall climate impact is composed of both CO_2 and non-CO_2 impacts, with non-negligible non-CO_2 effects about 5–20 times higher than CO_2 impacts alone, depending on climate metric calculated. For longer time horizon this ratio tends to lower values, going down from about 20 to about 6, when comparing a time horizon of 20 and 100 years, respectively.

In terms of implementation of such concept described, additional environmental MET information data products need to be made available to ATM. Hence complexity of the ATM environment due to meteorology needs to be transferred via MET information into the ATM infrastructure, making sure that ATM is having available high quality information for efficient flight planning. Within the SESAR 2020 Master Plan such information is made available system-wide via the SWIM infrastructure, where MET is one component in it, as is e.g., AIM information.

VII. Summary and Conclusion

This paper presents overall concept for a multi-criteria environmental assessment framework relying on environmental change functions (ECFs), as is currently under development in the European project ATM4E which is part of Exploratory Research within SESAR2020 research programme. Models and methods required are described, which are used to quantify environmental impacts and plan aircraft trajectories. Concept of ECFs is presented in detail and methods how to generate are described. We present a case study for a traffic sample over Europe which is applied on a candidate day using real weather conditions. Initial findings are presented using prototype ECFs. We provide an estimate for importance of non-CO_2 using ATR as climate metric, with a ratio of non-CO_2 to CO_2 impacts on climate between 6 and 20, for time horizon 20 and 100 years, respectively. From climate-optimisation of a single-flight trajectory, using prototype ECFs, an estimate of climate impact mitigation potential is calculated in the order of 12% and 25%, for fuel increase of 1% and 5% respectively. For LAQ we selected as environmental performance indicator in this initial case study the increase of atmospheric NO_2 concentrations, performing sensitivity tests for different air quality indicators, e.g., using either daily or hourly peak concentrations.

The innovative aspect in this study is to present a quantitative assessment of environmental performance indicators for a trajectory optimisation of a European traffic sample, representing a comprehensive framework for a multi-criteria environmental assessment framework, which comprises both climate impacts and local and regional environmental impacts. Such an assessment framework allows to be used for an analysis of overall environmental performance of a set of aircraft trajectories, but also an optimisation under individual objective functions and weighting factors, to support strategic decision making in the sense of a decision support system.

A novel aspect is the combination with an Earth-System model for online verification of algorithmic environmental change functions and proposed routing strategies when minimizing environmental impacts. The concept presented here relies on identification and effective implementation of aECFs in flight planning tools as advanced MET services providing a flexible interface to comprehensive calculation of environmental impacts of aviation emissions. For establishing required set of individual aECFs representing individual effects of aviation climate and environmental impact, comprehensive assessments of atmospheric and environmental impacts are required. Such assessments require suitable atmospheric chemistry and physics modelling tools being applied. They subsequently need to consider and identify key atmospheric parameters in order to eventually provide mathematical formulation of aECFs, which can then be implemented in an expanded ATM aircraft trajectory optimisation tool.

This concept lays the basis for performing route optimisation in the European airspace using advanced MET information in the light of environmental assessment and optimisation of aircraft movements in Europe. Ultimately, this will lead to a strategic roadmap of how to implement such a multi-criteria and multi-dimensional environmental assessment and optimisation framework into current ATM infrastructure by integrating tailored MET components, in order to make future aviation sustainable.

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