Ecological and digital transition: Systemic Design in SMEs open innovation processes

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How space technologies can address the impact of climate change on aeronautic and the aviation

Marianna Valente[1a]

[1]Department of Production and Management, Politecnico di Torino, Torino

[a]marianna.valente@polito.it

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Abstract. Aviation and flight management are strictly influenced by environmental conditions. Greater variability of the climate and the atmospheric phenomena carries greater risks for air navigation and increase cancellations and delay. An increase in the frequency and intensity of storms, torrential rains, hailstorms, fog, wind gusts, and other meteorological events may lead to a reduction in flight times and from a design point of view an increase in the weight of the aircraft, to counteract higher loads in operation. All of this could produce rising management and operational costs, as well as a reduction in profit. The instruments for remote monitoring as satellites, ground stations, and other technologies allow to collect data about several climate parameters such as temperature, humidity, rainfalls, wind patterns, etc. This data could be analyzed to obtain useful information to improve flights managements and airport services. Moreover, Artificial intelligence (AI) can be used to elaborate this information in real-time. This it makes possible to have more accurate forecasts and update the mathematical model for weather forecasting.

Introduction

Climate change is an urgent and growing global crisis. It is the result of human activities such as burning fossil fuels, deforestation, and agricultural production that emit greenhouse gases into the atmosphere, trapping heat and leading to extreme weather events such as floods, droughts, and hurricanes. Climate change is already having an impact on communities around the globe, and its effects are expected to worsen as temperatures continue to rise.

The effects of climate change are widespread and cannot be ignored. It is an interdisciplinary issue, and its effects are felt in almost every aspect of our lives. From public health to energy security, from food security to water availability. Climate change is leading to a wide range of consequences for the environment, society, and the economy. It is essential to understand the science behind this problem, take steps to reduce our contributions to it, and support policies to help mitigate its effects.

Climate change is also a major concern in the aviation industry. Air travel is one of the fastest-growing sources of greenhouse gas emissions, and international aviation emissions are expected to rise massively in the next decades. To reduce the environmental impact of air travel, the aviation industry is exploring new technologies and alternative fuels, as well as implementing measures such as carbon offsets and fuel efficiency standards to reduce emissions. It is also important to adopt policies that incentivize airlines to reduce their emissions and invest in more sustainable practices. Moreover, aircraft performances are strictly conditioned by environmental phenomena, therefore climate changes have a heavy impact on it.

One area that is increasingly becoming important in the fight against climate change is the Space sector. Space technology has the potential to help us better understand climate change and develop new solutions to reduce our emissions. Satellites provide us with data on global temperatures, sea level rise, and other factors that can support us to learn the effects of climate change. They can also track changes in the atmosphere, such as the amount of carbon dioxide, ozone, etc.

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Observation satellites are the most suitable to collect data and monitor climate events. For example, the NASA-led Orbiting Carbon Observatory-2 mission uses a satellite to measure carbon dioxide levels in the atmosphere [1]. This data can then be used to inform policy decisions and help us identify areas where emissions need to be reduced.

In addition, space technology can also be used to develop new solutions to reduce our emissions. For example, solar panels on spacecraft can be used to generate electricity, and technologies developed for human exploration could be applied to research new forms of energy on Earth, such as new, smaller nuclear fission reactors [2]. These technologies can be crucial on the ground to reduce our reliance on fossil fuels and reduce the number of polluting gases.

Aviation and climate change

Climate change impacts aeronautics and aviation in all aspects, from the design phases to traffic and airport management. Eurocontrol has analyzed in detail the consequences of various meteorological changes on the civil aviation sector.

Observing the sea level rise in Europe (Fig.1), from 1993 to 2019 the trend is rising across the whole mainland.

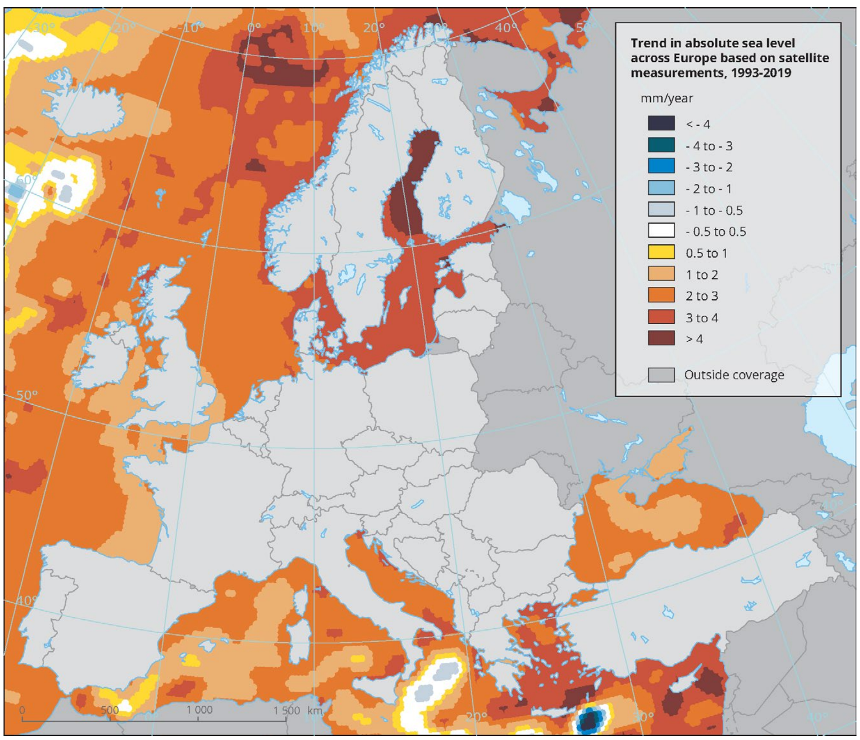

Figure 1. Absolute Sea level trend in Europe from 1993 to 2019 (Source: European Environment Agency https://www.eea.europa.eu/data-and-maps/find/global#c12=sea%20level%20&b_start=0)

The sea level rise increases the risk of flooding along the coastlines. This could be also enlarged by an increase in storm frequency and intensity. The ECAC region (the widest grouping of Member States of any European organization dealing with civil aviation, being currently composed of 44 Member States) is dense with coastal airports, and many of these had already adopted more efficient water drainage measures. A study [3], conducted using the Geographic Information System (GIS) simulations, revealed that, in the ECAC region, two-thirds of the airports are expected to be at risk of marine flooding in the event of a storm surge during the period up to 2090. 91% of these are small airports with less than 10,000 flights for years. Nevertheless, they are crucial for civil aviation e not only, because they have a key role in the development of local tourism and the economy in general.

Materials Research Proceedings 33 (2023) 247-253 https://doi.org/10.21741/9781644902677-36

Convective cells, unexpected storms, and wind shear are among the most frequent causes of en-route and arrival delays. These phenomena are easily predictable and more common in specific geographic areas. For instance, in the Mediterranean zone, convective events are the most widespread reason for en-route delays. In the next years, these events are projected to be increased in intensity. Moreover, extreme rainfall days are predicted to rise across northern Europe but decrease across southern Europe, causing an increment in the duration of delays. It is difficult to predict, in the long period, the effects of this on traffic management, taking into account both the variability of wind intensity and the interaction with other meteorological conditions. Nevertheless, it is clear that the ATM (air traffic management) will have to face an increase in the delay and will have to take action in time for reprogramming the routes [4,5].

From a structural point of view, if the gust intensity will increase, also the load on the aircraft rises. As a consequence, the airframe should be stiffer with an increase in the empty weight. This could lead to a reduced fuel storage capacity or a smaller number of passengers on board.

In addition, changes in wind patterns could result in major route changes. Some of them may be congested or less feasible than others, overloading the work of the ATM. Furthermore, changes in routes and the flight envelope, for safety reasons, imply the need to obtain a new flight certification for the aircraft, with huge costs for the airlines, both for the documents themselves, but also because the vehicle should remain in the hangar for a long time.

Climate change with the temperature increasing, alterations in weather patterns, and the environment of locations worldwide, can also affect the tourism demand, geographically or as time shifts or a combination of both [6]. Considering the ECAC region, in central Europe, a rise in tourists is projected in the autumn months (September, October, and November). While in the south of Europe, there will be a small decrease in summer tourism, but an increase both in the autumn and spring months. Other regions such as north Spain and Scandinavia will become more favorable all year. Overall, the mountain areas will suffer most from the temperature rise, especially the ski resorts that will increasingly have to employ artificial snow, while the bathing areas will be available for a longer period, with a reduction in demand in the warmer months (June, July, August) where there is the hottest temperature peak.

According to a study conducted by Eurocontrol [7] Stakeholders increasingly recognize that both the European aviation sector and European ATM have taken steps to adjust to climate change, but more must be done. A majority of respondents to this survey believe the sector has implemented some adaptation measures (Figure 2). Just 6% of participants think the sector has not analyzed adaptation.

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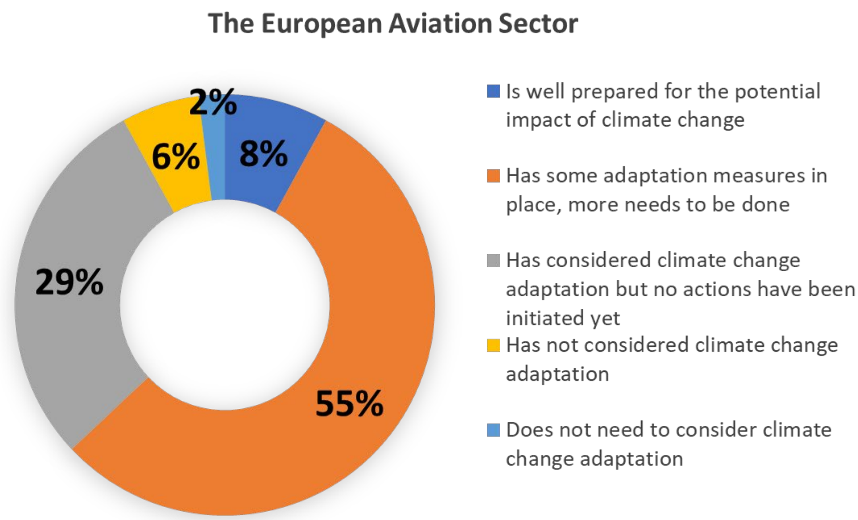

Figure 2. (N = 63) Stakeholder perceptions of the level of preparedness for the potential impacts of climate change for the entire European Aviation sector. Data from [7].

Regarding European ATM, 60% of respondents concluded that certain adaptation measures are in existence (Figure 3). Just a little part of the participants claimed that European ATM has not contemplated adjustment. Awareness is increasing, and more organizations are undertaking action. However, it must be determined if the appropriate measures are being implemented promptly or if we need to expedite action.

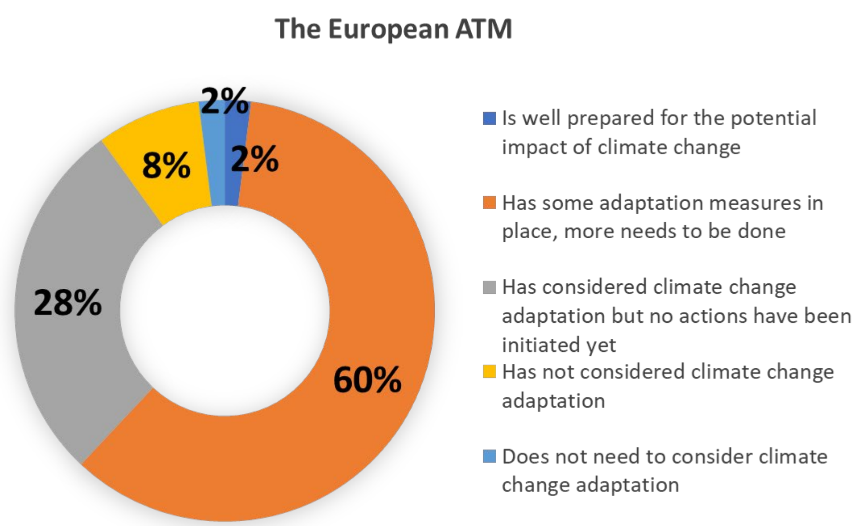

Figure 3. (N = 50) Stakeholder perceptions of the level of preparedness for the potential impacts of climate change for the European Air Traffic Management (ATM). Data from [7].

Space technologies to mitigate the impact.

There are many space technologies and Earth observation missions to collect and provide climate data to support aviation. Considerable efforts are being made to monitor the as best as possible the meteorological events to improve our knowledge and forecasting models. Not only aviation could have benefited, from these data, but also agriculture or meteorological stations could be the end user of the information. Moreover, real-time monitoring helps to manage potential catastrophic events, such as tsunamis, floods, and landslides, to take action on time, limiting the victims.

Among the most dangerous and difficult to observe phenomena, there are convective cells. These systems are characterized by cumulonimbus clouds and occur frequently in tropical and subtropical zones. The convective cell takes place often with severe wind gusts, heavy rainfall, and thunderstorms. These events are sudden and short-lived, and could potentially damage the aircraft compromising flight safety.

Recent missions are being developed to study convective systems, using C-band or Ka-band radar, radiometers, or spectrometers. One of the most innovative is Raincube, a 3U CubeSat equipped with a Ka-band nadir pointing radar, with a deployable antenna [8]. The satellite, measuring the brightness temperature, detects the presence and size of the convective cells. As a negative aspect, it does not have a system to search and track the cells, so the radar could only spot the cell if the satellite flew over. Moreover, Raincube operated in LEO, therefore it is not possible to study the evolution of the system but only the instantaneous situation.

Another important mission, similar to the previous one, was TEMPEST-D, launched in 2018 and operational until 2021. The satellite was a CubeSat 6U, equipped with a microwave radiometer to observe the evolution of storm clouds [9]. To evaluate the storm intensity and the hazard of meteorological events, it measured the brightness temperature, with less accuracy than Ka-band radar but with a wider swath of 825km [10]. The final goal of the mission was to validate the performance of the payload, so a TEMPEST constellation could be developed, in LEO, to examine not only the intensity but also the time evolution of short events as convective cells.

Over the years, many other missions have been developed for the study of these phenomena, with different payload performances related to the aspect that scientists wanted to measure. La and Messager (2022) presented several instruments in LEO that acquire data and estimate ocean surface convective winds [11]. Sentinel-1 Synthetic Aperture Radar (SAR), for instance, offers a high spatial resolution to observe the gust wind, while with ASCAT scatterometer and SMAP radiometer, it is possible to observe the phenomenon at a larger scale.

Thanks to this data collected by satellites over the years, it is possible to develop and update the mathematical models of forecasting, which implemented in the cockpit can prove to be a valuable resource. An innovative method for storm forecasting was introduced [12], based on the global GLD360 lighting data and information from Meteosat, a geostationary satellite. They defined three levels of severity for the cumulonimbus, related to the brightness temperature of the water vapor. Then, the method evaluates the atmospheric motion vectors by analyzing two consecutive images captured by satellite and extrapolating the data by comparing them. This method was implemented on board a few aircraft and the pilots reported that they had the forecasting data 15-20 minutes later than the scans satellite, (usually this period is 30-60 minutes). However, some improvements are necessary to reduce the period between the two scans, delete the parallax errors, etc.

Many precision mathematical models have been developed and are being updated also to support air traffic management (ATM). A mathematical model that uses statistical data collected from satellites to model storms stochastically was developed [13]. This model is combined with an optimal trajectory planning algorithm. The resulting aircraft trajectories maximize the likelihood of reaching a waypoint while avoiding hazards, given the potential uncertainties due to wind disturbances and in those not-safe flight patterns caused by uncertainties in the data of thunderstorms.

A new study [14] explored the potential of lightning data assimilation with the Weather Research and Forecasting model (WRF) from an air traffic management (ATM) perspective for the first time in Europe, using Milano Malpensa as a case study. The authors highlighted the positive impact of lightning using three different methods for convective and stratiform precipitation and emphasized that the assimilation of different data types can provide a reliable forecast in terms of spatial and temporal accuracy which meets ATM requirements.

Moreover, according to the SESAR European ATM Master plans [15] a crucial concept for the future ATM is trajectory-based operations (TBO). This system allows the aircraft to update autonomously the trajectory both to satisfy business needs, such as less fuel consumption and time-saving and to avoid potentially hazardous events. To adopt successfully the TBO it is necessary to reduce the uncertainty associated with the aircraft motion and weather development. Nowadays, the aircraft tracking system is based on the Automatic Depending Surveillance-Broadcast system (ADS-B), which adopts terrestrial antennae to provide information about the vehicle, except in the polar and ocean zones. To address this gap, a satellite constellation is necessary. A parametric study [16] was conducted into the design of a custom ADS-B Satellite constellation, to obtain a low-cost satellite constellation that provides ADS-B coverage equal to or better than the ground antenna. From the first analyses of the work, emerged that using a higher number of satellites at a higher altitude, a more reliable ADS-B coverage of the trans-oceanic flight route is achieved.

Methods like this, which exploit satellite aircraft communication, are increasingly being implemented, making safer flights and more dangerous weather events more easily predictable.

Conclusion

The effects of climate change on the aviation industry are expected to worsen in the future, leading to more delays and cancellations, increased fuel costs, and more frequent and disruptive extreme weather events. To mitigate the effects of climate change on the aviation industry, airlines must take proactive measures such as improving aircraft efficiency, investing in renewable energy sources, and implementing sustainable operational practices. Governments should also recognize that the aviation industry is vulnerable to climate change and provide incentives for airlines to reduce their emissions. By taking proactive steps to mitigate the impacts of climate change on the aviation industry, airlines can protect their operations and help to reduce the overall emissions of the aviation industry. On the other hand, space technologies provide a lot of information about environmental changes. Nevertheless, huge efforts are necessary to improve the forecasting abilities of sudden and strong events as convective cells. Satellite constellations in low Earth orbit could be a trade-off solution to achieve high accuracy and to measure the phenomenon‘s local aspects. At the same time, using a “train” of satellites allows one to obtain an image sequence, to observe the temporal evolution of the events. As a negative aspect, managing a constellation of small satellites it is not that simple, a more complex instrument on board is necessary to synchronize the “train”, and the cost of the satellite increases.

Finally, communication in real time between satellites and aircraft could play a crucial resource to address sudden events, responsively and avoiding possible injury.

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