# Rational Protection of Airline Passengers from the Threat of Exposure to Solar Flares —Quantifying the risk of economic loss enables the formulation of optimal aircraft operation guidelines—


**Summary**

Professor Yousuke Yamashiki, SIC Human Spaceology Center, Graduate School of Advanced Integrated Studies in Human Survivability, Kyoto University (corresponding author), Ms. Moe Fujita (first author), Aioi Nissay Dowa Insurance Co. Ltd of MS&AD Insurance Group Holdings, Inc.(Former Graduate Student of GSAIS), Dr. Tatsuhiko Sato, Director, Nuclear Science and Engineering Research Center, Japan Atomic Energy Agency (JAEA) (also SIC specially appointed professor at GSAIS, Kyoto University), and Dr. Susumu Saito, Principal Researcher, Electronic Navigation Research Institute (ENRI), National Institute of Maritime, Port and Aviation Technology (MPAT) to study solar flares. The research group analyzed the frequency and intensity of solar flares that have occurred over the past 2000 years, as well as four-dimensional spatial time series data of solar radiation dose rates obtained from the latest simulations. They succeeded in quantifying the risk of changing aircraft flight plans due to solar radiation exposure for the first time (see Fig. 1). Due to their research, it was found that the frequency of major solar flares that would require a reduction in flight altitude or cancellation is about once every 17 years, and the annual risk, taking into account the cost of countermeasures, is up to about $1,500 USD for a long-haul flight operating every day. This value is not as large as other aviation risks, such as volcanic eruptions, and suggests that air travelers can be reasonably protected from the threat of exposure due to solar flares. In the future, if it becomes possible to estimate the accumulated radiation dose on the route in real time, the risk can be further reduced to about one third. The results of this research are expected to be useful for the determination of guidelines for aircraft operations during solar flares and for the development of risk mitigation plan.

The results of this research will be published in the online edition of the British journal *Scientific Reports* (Nature Research Journal) on September 2, 2021 (GMT 10:00).


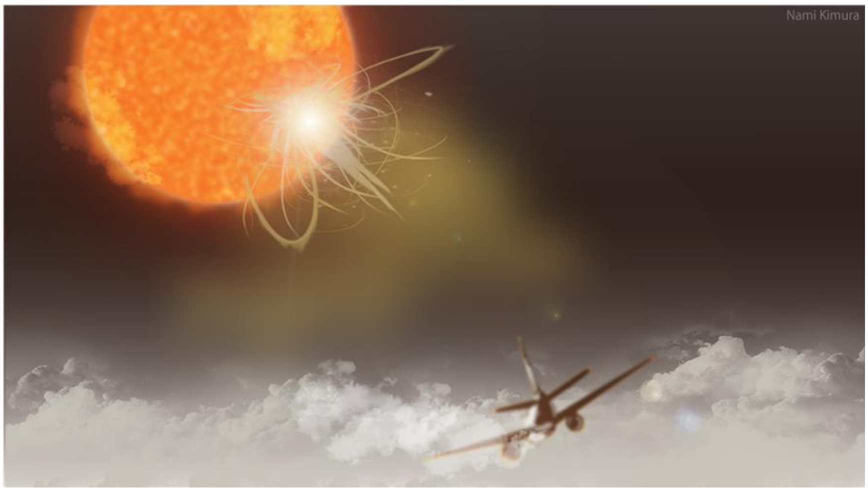


**Figure 1: Image of an aircraft lowering its altitude to avoid the threat of exposure from solar flares (illustrated by Nami Kimura)**

## 1. Background

Exposure to cosmic rays when on board an aircraft is an important topic, not only for airline workers such as flight attendants and pilots, but also for general passengers. In general, higher altitude and latitude of flights cause, higher radiation doses during flight time*1. The International Commission on Radiological Protection (ICRP) has recognized the exposure of cosmic radiation to airline workers as an occupational risk and has established updated guidance on radiation protection for all personnel involved. In addition, the Space Weather Information Service launched by the International Civil Aviation Organization (ICAO) in November 2019 provides information on space radiation exposure doses, along with communications and satellite positioning.

Galactic and solar rays' exposure air passengers to radiation The intensity of galactic cosmic rays varies with time but is usually at a low dose rate of less than 10 μSv/h at a standard cruising altitude (12 km). On the other hand, the intensity of solar radiation can suddenly increase if a large solar flare*2 occurs, and the dose rate can be extremely high, reaching more than 2 mSv/h in a short period. Taking into account that the annual exposure limit for the public is 1 mSv, it is advisable to take appropriate measures such as canceling flights or lowering the flight altitude during such large solar flares. In order to do so, it is necessary to estimate in advance the costs and effects of such measures. It is also necessary to evaluate the frequency of solar flares that require intervention in order to evaluate mitigation cost of such incidents in the future.

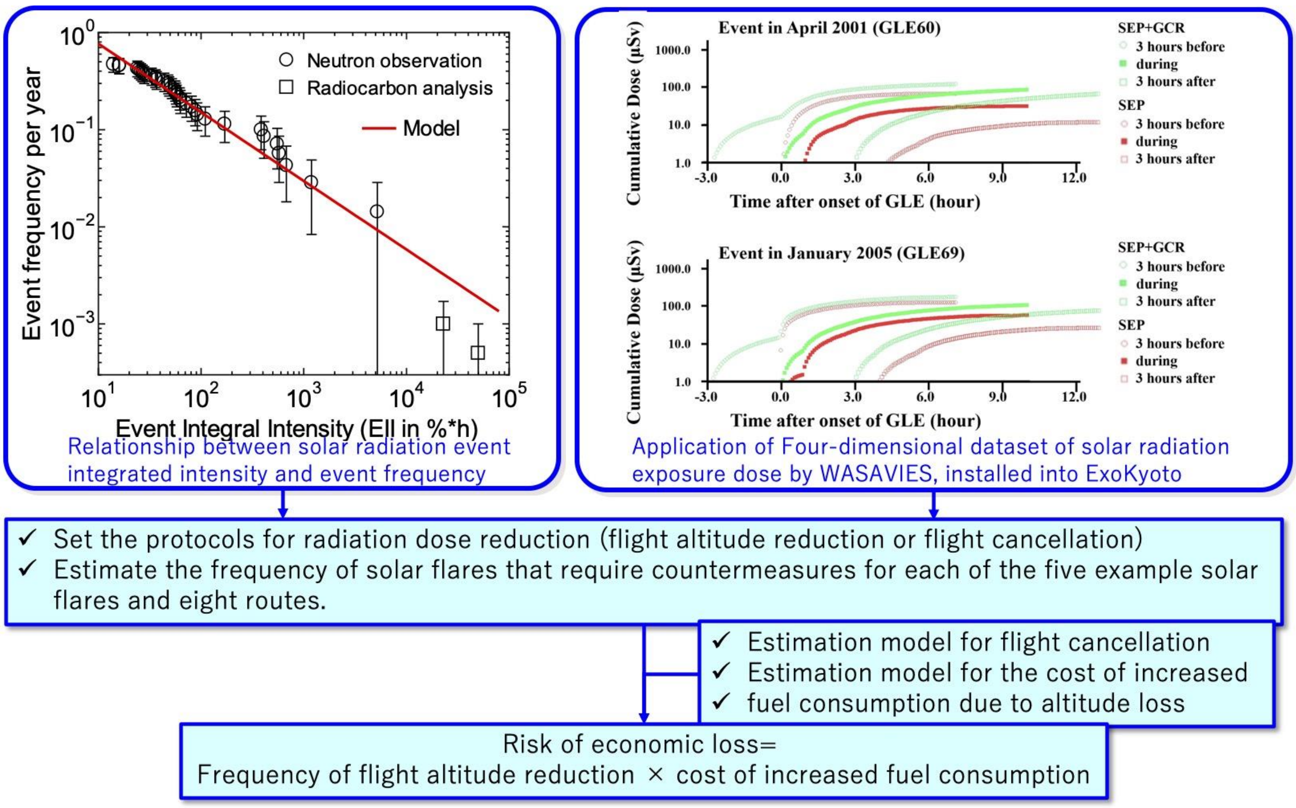


Figure 2: Outline of this study

## 2. Research methods and results

Our research group conducted the study in Fig. 2, and quantified the risk of economic loss associated with changes in aircraft operations. Specifically, we first evaluated the maximum integrated dose and dose rate for 80 incidents (five solar flares, eight flight paths, and two cruise altitudes (altitudes of 12 km and 9 km)) using 4D spatial time series data of solar radiation dose rates estimated using the solar radiation exposure warning system WASAVIES*3. The maximum integrated dose and dose rate for the 80 incidents were evaluated. We also quantified the connection between the frequency and intensity of solar flares that emit solar radiation over the past 2000 years based on cosmic-ray neutron observations*4 and radiocarbon analysis results*5. We proposed a new index, in addition to the Event Integral Intensity (EII)*4, which has been used as an index of solar radiation intensity. Our new index, Peak Event Intensity (PEI)*4, takes into account the effect of momentarily high intensity of solar radiation and analyzes it. By integrating these results, we estimated the frequency of solar flares with a maximum integrated dose exceeding 1 mSv or a maximum dose rate exceeding 80 μSv/h for each route condition. In our results, it was found that the frequency of solar flares in which radiation dose reduction measures are necessary, is about once every 47 years and about once every 17 years, respectively, when the above integrated dose and maximum dose rate are applied. 80 μSv/ h is the threshold dose rate classified as "severe" exposure in the ICAO Space Weather Advisory Information.

Furthermore, a protocol was formulated as a specific measure to reduce exposure doses. In this protocol, the altitude could be lowered to 9 km if operation was possible at this altitude but not at the standard cruising altitude (12 km). Also, flights would be cancelled if operation was not possible at a cruising altitude of 9 km because the altitude exceeded the threshold for radiation exposure. The economic loss (cost) of altitude reduction and flight cancellation was estimated. The economic loss risk was then evaluated by multiplying the estimated cost by the corresponding solar flare frequency. The maximum economic loss risk per year for daily long-distance flights was measured at about 500 US dollars and about 1,500 US dollars respectively, when the accumulated dose and the maximum dose rate are regulated. The amount is relatively low when compared to other aviation risk measures such as volcanic eruptions. Therefore, another important aspect of our study is that we have proved it is possible to reduce the exposure dose during air travel at a sufficiently low cost.

It is not possible to estimate the accumulated dose on a specific route during a solar flare with our current technology. Therefore, the maximum dose rate must be used for regulation (maximum risk of economic loss: approximately US$1,500). However, if our knowledge of solar flares expands in the future and we can predict accumulated dose on each route in real time, it will be possible to adjust the route based on the dose (maximum risk of economic loss: approximately US$500), which will further reduce the risk.

## ３．Ripple effects and future plans

This is the first study to quantify the risk of economic loss due to solar radiation exposure, and make it possible to determine the optimal guidelines for aircraft operations during solar flares as well as to develop risk mitigation plan. Additionally, because the risk of solar radiation exposure is expected to be higher in the space travel plans of Space X, Virgin Galactic, and Blue Origin, it will be even more important to quantify the risk using the method developed in this study, to propose measures to reduce the exposure, and to develop risk mitigation plan. However, in order to make concrete proposals, a more accurate risk assessment based on detailed operation plans is essential, and we will continue to conduct such research in cooperation with related organizations.

## ４．About research projects

Our work was supported by the following grants for scientific research (JP18H01569): from the Japan Society for the Promotion of Science and Ministry of Education, Culture, Sports, Science and Technology. It is also supported by the

Japan Manned Space Systems (JAMSS) Endowment.

The organization of our research and roles are as follows:

[Contributions]

・SIC Human Spaceology Center of Graduate School of Advanced Integrated Studies in Human Survivability (Shishu-Kan), Kyoto University

Coordination of the research, design of a radiation exposure assessment model and evaluation of the frequency of solar flares that cause radiation exposure and the risk of economic loss.

・Japan Atomic Energy Agency (JAEA)

Assessment of Aircraft Dose Using WASAVIES

・Electronic Navigation Research Institute (ENRI), National Institute of Maritime, Port and Aviation Technology (MPAT)

Evaluation of economic costs associated with aircraft operation and flight cancellation

[Company]

・Aioi Nissay Dowa Insurance Co., Ltd.

The first author is an employee in the company, and considering the use of these results.

・Japan Manned Space Systems Corporation (JAMSS)

Support for this research and utilization of the results for human space activities

・DMG Mori Co., Ltd.

Support for this research.

**＜Glossary＞**

***1 Exposure dose:**

The exposure dose unit is in sievert (Sv), which is an indicator of the effects of radiation exposure on the human body. In Japan, the Radiation Council have established a guideline in April 2006 that sets a target value for radiation dose at 5 mSv per year. However, this value is only applicable to airline crew members, for passengers and the public, the dose should not exceed the public dose limit (1 mSv per year).

**2 Solar flares:**

Solar flares are explosions on the surface of a star such as our sun. They are assumed to be caused by the sudden release of magnetic energy stored near sunspots on the surface. When a plasma eruption (coronal mass ejection, CME) associated with a solar flare hits the Earth, it can have a major impact on human life by causing magnetic storms, large-scale power outages, and disruptions in communication infrastructure. Sometimes, they also emit large amounts of solar radiation, causing radiation exposure to astronauts and airline crews.

***3 WASAVIES:**

WASAVIES is a warning system for solar radiation exposure developed mainly by the National Institute of Information and Communications Technology (NICT), the Japan Atomic Energy Agency (JAEA), and the National Institute of Polar Research (NIPR). The system downloads information about cosmic rays observed by satellites and on the ground in real time. When there is a sudden increase in the energy they produce, it automatically calculates the dose rate from solar radiation anywhere on Earth up to an altitude of 100 km from the Earth's surface, and releases the results on the website below. The results are forwarded to ICAO for delivery to airlines in various countries. In this study, we use the 4D spatial time series data of exposure dose rates calculated by WASAVIES for five different solar flares that had solar radiation emission in the 21st century.

https://wasavies.nict.go.jp/

***4 Cosmic Ray Neutron Observations:**

Cosmic ray neutrons have been observed continuously since the 1950s using ground-based neutron monitors. Usually, we observe neutrons from galactic cosmic rays, but when a large solar flare occurs, we also observe neutrons from solar radiation. Such events are called GLE (Ground Level Enhancement), and 72 GLEs have been observed so far. In this study, the solar radiation intensity during each GLE was indexed using the integral value of the neutron monitor count rate of increase (event integral intensity, EII) and its maximum value (peak event intensity, PEI), and the relationship with the event frequency was quantified.

***5Radiocarbon analysis:**

Radiocarbon analysis is technique to detect large solar flares that occurred in the past by measuring the concentration of radiocarbon (14C) in old trees and ice sheets. Radiocarbon is mainly produced by nuclear reactions caused by cosmic rays in the atmosphere, so its concentration can be used as an indicator of solar activity in the past. The intensity of the solar radiation was 130 times and 60 times higher than that of the January 2005 event, which were the highest intensity solar flare events that occurred in the 21st century. In this study, we quantified the relationship between solar radiation intensity and the frequency of solar flares, taking into account the occurrence of such huge solar flares.

**＜Researcher's Comments＞**

The results of this research are based on a Los Angeles to Narita flight during a solar storm in September 2017. Two years later, I felt that the issue of aircraft exposure needed to be discussed more deeply, I was able to actually evaluate it using WASAVIES by Sato et al. I then started this project with Ms. Moe Fujita, who was a doctoral student at the time, hoping that airlines would actively adopt these ideas in aircraft operations.

The first paper we submitted was rejected, but we finally made these results a year and four months after submission.

**＜Paper title and author＞**

Paper title：

Probabilistic Risk Assessment of Solar Particle Events Considering the Cost of Countermeasures to Reduce the Aviation Radiation Dose

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