Executive Summary

SOARS, the **Space weather Operations Airline Risk Service**, is one of the Service Development Activities (SDA) of ESA's Space Weather Applications Pilot Projects. The SOARS project has been examining the effects space weather has on the aviation industry, determining the impacts on flight and ground operations, evaluating the risks involved and developing prototype space weather services.

The aviation industry is affected by space weather through a number of different effects and on a range of timescales. Some space weather effects can have a serious impact on the industry while others are just an inconvenience; it is also easier to forecast some effects than others. In addition, airlines are not affected equally – there are significant dependencies on where an airline is based and the route system it operates. As a consequence the environment is more complex than for many other sectors and the geographic dependence of some effects means that one solution does not fit all airlines.

The SOARS project has tried to explore these issues to determine what form of space weather forecasting service is possible and needed by the aviation industry.

During the course of the project, the emphasis placed on different aspect of the problem has evolved. This is in part due to a better understanding of the nature of the effects and how relate to aircraft operations, but it is also a consequence of the realization of what is possible/feasible when creating a space weather service. In addition, in Europe the degree of concern about cosmic radiation has reduced amongst many of those responsible for assessing the exposure of aircrews as the understanding of the risks involved has increased, and the effectiveness of the monitoring procedures has been demonstrated.

Our initial ideas were driven by an assessment of user requirements. In trying to define the scope of a space weather service we looked at exactly how badly the effects affect the ability of an airline to operate safely; we also looked in detail at what space weather products already existed and how useful they were for forecasting.

As a consequence of the changes in our understanding, we have had to go back and re-evaluate the effects, re-examine their impact on operations the risks associated with them, and determine which effects can be managed by mitigating the effects indirectly, and which we must learn to live with. From this we have drawn conclusion on what capabilities a core service needs to address.

The effects of space weather on the aviation industry differ from those caused by terrestrial weather and the associated risks are therefore different. Even so, the responses to space weather effects are essentially similar to those of terrestrial weather phenomena – delays, diversions and possibly cancellations. It is therefore beneficial if space weather information is expressed and disseminated in ways that are familiar to the airlines.

While safety and security are paramount, civil aviation is a very competitive business. Any impacts to operations are potentially expensive and it is essential that a service is able to minimize them. Airlines are used to making changes to their flight plans in response to congestion, severe terrestrial weather, etc. However the extent and duration of some space weather effects and difficulties in forecasting them can makes changes more difficult to implement.

The science of meteorology is well established and a comprehensive monitoring and forecasting system is in place. Terrestrial weather phenomena can be observed as they develop over hours, even days. Conditions that might lead to severe weather conditions can often be anticipated based on a wealth of observation made over many decades; in many cases the effects of the season and changes to global circulation patterns are responsible for long-term variations.

For space weather, forecasting capabilities are very different. Space weather effects can affect a much larger area that terrestrial weather, can occur with very little warning and can sometimes last much longer than terrestrial weather phenomena. The monitoring systems for space weather can at best be described as patchy and the organization at an international level to support forecasting is absent. The science does not afford the ability to predict some effects; for others, we know that something will occur, but not necessarily the details.

The occurrence and intensity of space weather effects varies with time and location. There is a dependence on current and recent solar activity, phase of the solar cycle, etc. Also, existing conditions in the Earth's magnetosphere and ionosphere and the relation of a location to the geomagnetic pole, local noon, etc. can all influence the severity of an effect or whether it is even experienced.

Many of the consequences of the exposure to radiation are better handle as offline issues. How to address immediate and delayed space weather effects is more difficult, particularly in how they affect operations and operational planning.

Under normal conditions, the bulk of the exposure of aircrew to cosmic radiation is due to galactic cosmic rays; cosmic rays from solar activity though intense are a relatively rare occurrence. We have found that Europe has shown that an effective programme of dose assessment is a good way to manage radiation exposure; similarly, good designs and the careful selection of components are a good way to mitigate the effects of radiation on electronics.

Immediate effects result from electromagnetic emissions from solar flares. Their onset can be very sudden and we are only able to forecast probabilities that they will occur; this make it almost impossible to include in forecasts that can be used in planning and the sudden onset presents logistical problems in terms of response during a flight.

Delayed effects are those caused by plasma that is ejected from the Sun and interacts with the Earth's magnetosphere and ionosphere. Because of the time taken for the material to complete its journey, there is at least a possibility the effects can be forecast; the main difficulties are the uncertainty of how quickly the material is moving and details of the plasma properties - e.g. density and magnetic field. Some delayed effects can persist for days and affect large areas, the higher and middle magnetic latitudes being mainly affected.

Where possible the SOARS project has drawn on existing capabilities. There are already several quite good sources of space weather information available but there are related to the area coverage and currency of the data. There is also limited information of where and exactly when effects will occur and their intensity.

Some issues could be improved by making changes to the way that data are gathered. However, we have found that there are fundamental problems associated with providing forecasts on the timescales needed by aviation; it is also particularly difficult to precisely identify when and where effects will occur in advance. This is a consequence of the basic difference between terrestrial weather and space weather – that the latter being caused by a stimulus external to the Earth's environment that is affected by conditions in transit to the Earth.

There may be a limited ability to respond to space weather effects en-route especially since a large number of aircraft could be affected over an extended area. However, warnings given sufficiently in advance could significantly reduce the costs associated with diversions.

Given that there are limitations in what a space weather service might be able to achieve, we have examined where the greatest cost savings could be found through developing new capabilities. This, with all the other information we have gathered, has helped us identify which services are essential and should be the core of any future aviation space weather service.