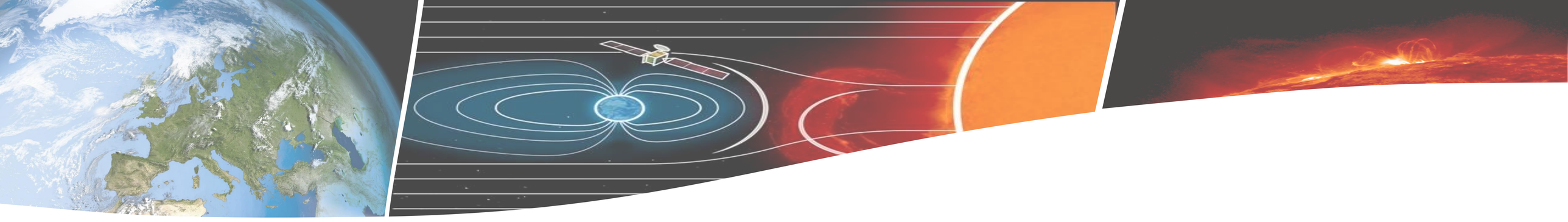

Impact of space weather on navigation and communication services used in aviation

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Motivation / Introduction

Space weather can cause significant disruption to technical infrastructure, resulting in increased security risks, economic losses and a reduced quality of life. For example, satellite-based communication and navigation services can be significantly impacted, limiting aviation safety and efficiency. Operators of such critical infrastructure are increasingly aware that extreme space weather events can have severe impacts on their systems. Therefore, the international civil aviation organization (ICAO) operates global Space Weather centers since 2019 with the aim to provide real time information and forecast to the aviation user community. We will present recent examples of space weather impact on navigation and communication services in aviation. We show how existing ADS message data used in aviation for flight routes control can significantly contribute to an improved understanding of the space weather impact. Automatic Dependent Surveillance (ADS) services defined by the International Civil Aviation Organization (ICAO) provide support for safe and efficient air traffic management and increase airspace capacity [1]. The messages are divided into ADS-A, ADS-B and ADS-C. The ADS-Addressed information are sent on request, whereas ADS-Broadcast and ADS-Contract sent continuously to provide information on aircraft, position and navigation. ADS-B messages are broadcasted directly by the airplane, whereas ADS-C information are provided also via satellite link, but only to the Air Traffic Service (ATS). The continuous data in high resolution can be used to identify Space Weather effects on communication (data gaps) and navigation (position errors). The impact of such deviations on aircraft operations are most probably not critical for moderate events, but provide more insight about space weather events and their impact on technical systems. The high temporal resolution and the global coverage of the position data allow a direct comparison with ionospheric information based on the Total Electron Content (TEC) or electron density measurements. In order to use the data to study the effects of space weather, a careful selection of data is required.

ADS-C

The ADS-C reports are sent in response to requests by air traffic service units or aeronautical operational control (AOC) facility ground systems. The contracts contain standard information (e.g. contract type and parameters for flight path), but specific information may also be sent according to the requested contracts. Additionally, the aircraft may send emergency reports if needed [1]. Of particular interest to the present study are the event contracts (E) which allow to request an ADS-C report when specific conditions occur. Several events can be reported in one contract categorized in different event types as shown in Figure 1.

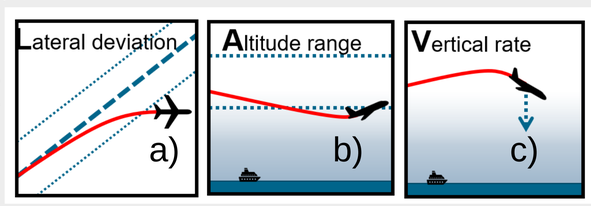

Figure 1: Shown are a a) Lateral deviation event, b) Altitude range change event and c) Vertical rate change event. Such events can cause an event contract (E).

An impact of severe weather and space weather on the number of event reports is expected, since reports of type E are transmitted when flight crews perform unplanned offsets resulting in deviations that exceed ADS-C thresholds. Thus, the spatial and temporal distribution of these reports is expected to be well correlated with storms or space weather. As example for space weather impacts we show in Figure 2 an active solar period around the 6th September 2017 in comparison to solar quiet conditions. Solar Flares are known for their impact on GNSS positioning services, especially when their spectrum contains a strong EUV component around 30 nm [2]. In Figure 2 we present the impact of the solar activity period on ADS-C in a region around New Zealand. The majority of the data correspond to aircraft passing through the Auckland airport (NZAA, 37.01˚S, 174.79˚E). The increase of the ratio between event and total number of messages indicates deviations in airplane positioning as result of the existing space weather conditions. In order to further investigate the impact large sets of the unfortunately restricted data are needed.

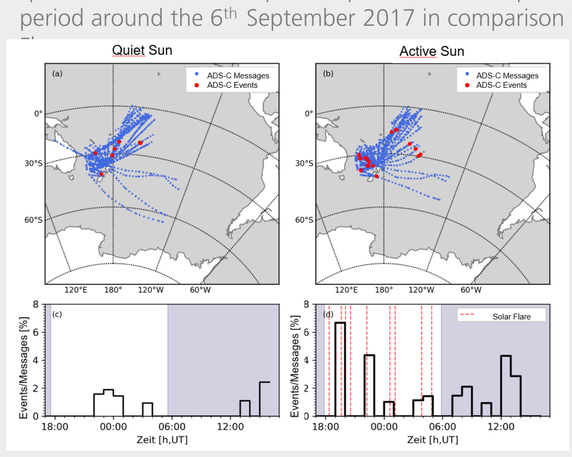

Figure 2: Periodic messages and event reports (A, L and V) for quiet and active solar conditions (top) as well as the respective event to message ratio in percent (bottom). Red dashed lines are Solar Flare events.

ADS-B

ADS-B messages are broadcasted directly by the airplane and contain aircraft information position information as well as speed information. There exist a global coverage and huge amount of data due to the intense world wide flight traffic. The data can be purchased or received on site if an appropriate receiver with antenna is set up. In Figure 3 a M-class Solar Flare on 1st of May 2023 is shown and the approximately 14000 ADS-B aircraft records from 13:02 to 13:09 UTC in which the flare occurred.

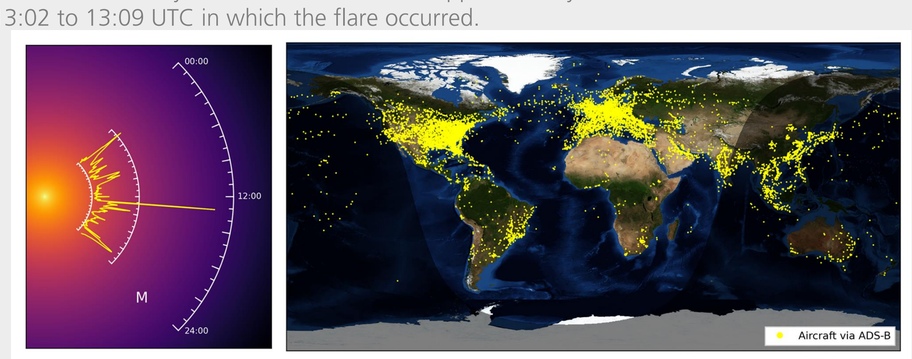

Figure 3: Class M Solar Flare on May 1st, 2023 (left) and the ADS-B aircraft records between 13:02 and 13:09 UTC, that were available around the Flare event (right).

Since Solar Flare can affect GNSS navigation and HF communication services [2], we expect impacts on ADS-B due to signal loss (UHF, SATCOM) and position errors (GNSS).
In Figure 4 we show the potential impact of the M-Class Solar Flare on ADS-B messages leading to data gaps and position errors. In addition the expected versus observed messages between 13:02 to 13:09 UTC (red area) are shown, where the reduced rate on observed messages might be an indicator for data gaps caused by the Solar Flare event.

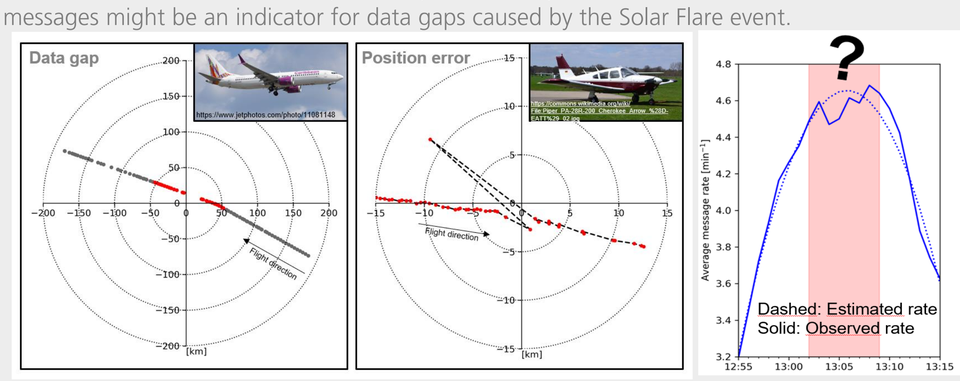

Figure 4: Shown are possible Space Weather impacts on airplane flight routes, where data gabs (a) or position errors (b) can occur. Red dots are ADS-B messages during 13:02 to 13:09 UTC around the M-Class Solar Flare on May 1st, 2023. The right plot (c) shows the estimated and observed rate of messages.

Outlook / Conclusion

Space Weather events can lead to impact on navigation and communication systems used in aviation. This impact is caused via disturbances in the ionosphere (e.g. gradients) affecting the radio signal propagation [2]. Existing Ionospheric Space Weather products, like Total Electron Content Maps or Electron density measurements show the actual ionospheric state, but provide no direct information about the impact on the positioning accuracy or communication quality. In order to overcome this situation the analysis of the globally available and statistical significant ADS information can be used. In the present work we have shown the impact of two Solar Flare events on ADS-B and ADS-C messages. However, in order to perform a more advanced analysis, also looking for different types of Space Weather events, a statistical significant data set is needed. Unfortunately in case of ADS-C the data are received by the Air Traffic Service and restricted. ADS-B can be purchased or received with own equipment and related costs. There are additional difficulties in using ADS-B flight information to investigate the space weather impact. One needs to select proper aircrafts types and routes in order to clearly identify a position error or data gap. Please keep in mind that flight track between different aircrafts can strongly deviate (Airplanes, Helicopter, Glider, Drones) or be impacted due to flight maneuvers (e.g. start or landing procedures). We conclude that future studies with more data will help to investigate the interactions between the Space Weather event, Ionospheric disturbances, navigation impairment and the "Faulty" ADS-B or ADS-C event messages as result. We will further investigate the Space Weather effects on ADS messages to learn more about space weather impact on technical systems. The recent conditions around the maximum of the solar activity cycle are optimal to learn more about the vulnerability of our technological systems and services.

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Deutsches Zentrum für Luft- und Raumfahrt

Acknowledgments:
We thank the Airways Corporation of New Zealand and the FAA William J. Hughes Technical Center for making the ADS-C records available. We thank Klaus Sievers (Vereinigung Cockpit) for forwarding the datasets and providing feedback. The ADS-B data is from the historical demo data set of ADS-B Exchange available under https://www.adsbexchange.com/products/historical-data/ .

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