Come fly with us: services provided by the Space Weather Education Centre

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Abstract
The Solar-Terrestrial Centre of Excellence brings together and supports sun-space-earth research and services present at the federal level in Belgium. In 2019, the STCE was a founding member of a European network, PECASUS, that provides space weather services for civil aviation. Our expertise in solar observations and research combined with the experience of our Global Navigation Satellite System and solar particle radiation group proved to be crucial.

The STCE also strongly invests in education and training as these are a backbone of quality research and services, and therefore created the Space Weather Education Centre. This centre offers the Space Weather Introductory Course covering the Sun, solar storms, heliosphere, ionosphere, magnetosphere, instruments and methods to observe solar and space weather activity, as well as reading and interpreting our space weather bulletins. This course is taught to future space weather advisory staff, both military and civilian. It is based upon the STCE's expertise gained through scientific research, involvement in space missions and space weather monitoring, and on its forecasting capabilities. The course is given by qualified staff.

In addition to the Space Weather Introductory Course, the STCE has been and remains involved in a wide range of outreach activities, from public lectures, over dedicated classes and workshops at schools, organization of public events like open doors, publications in popular journals and on online media, scientific newsletters and press releases, to the participation in science festivals and the organization of events for the scientific community.

In this paper, we present more details of our educational programme, reflect on the methodologies used, and provide an overview of the obtained results.

Keywords
Space weather, outreach, education, aviation

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Acronyms/Abbreviations

BIRA-IASB *Royal Belgian Institute for Space Aeronomy*

GNSS *Global Navigation Satellite System*

JSWSC *Journal for Space Weather and Space Climate*

KNMI *Koninklijk Nederlands Meteorologisch Instituut*

PROBA2 *Project for On-Board Autonomy*

RMI *Royal Meteorological Institute of Belgium*

RNLAF *Royal Netherlands Air Force*

ROB *Royal Observatory of Belgium*

STCE *Solar-Terrestrial Centre of Excellence*

SWEC *Space Weather Education Centre*

SWIC *Space Weather Introductory Course*

1. Introduction

The Solar-Terrestrial Centre of Excellence (STCE) brings together research, expertise, and services regarding sun-space-earth sciences that are present in the three institutes located on the Belgian Space Pole: the Royal Observatory of Belgium (ROB), the Royal Meteorological Institute of Belgium (RMI) and the Royal Belgian Institute for Space Aeronomy (BIRA-IASB). This overarching structure creates synergies, new collaborations and an increased visibility for the Belgian expertise in these fields.

An important focus of the STCE activities is on space weather, which describes the conditions in space in the vicinity of Earth under the influence of solar activity.

When the STCE was founded in 2006, a communication, education and public outreach cell was included to address the clear need for information about space weather. At that time, the societal awareness of space weather and its effects on biological and technological systems was still very low. As a result, the STCE strongly invests in education relying on a firm academic and service experience. Our Space Weather Education Centre (SWEC) [1] offers tailored courses and dedicated training modules. Through its activities and expertise, SWEC raises awareness of the existence and consequences of space weather effects to third parties. Companies with space related activities, companies with an interest in navigation and radio-communication, energy plants, and the aviation industry are important targets.

In this paper we present a number of educational activities undertaken by the STCE, with a focus on the Space Weather Introductory Course (SWIC).

2. The STCE communication, education and public outreach cell

To spark interest in space weather, solar and atmospheric sciences, we address scientists, students, professionals and non-professionals, children and the general public; and target each of those groups with the most appropriate tools.

The broad public are citizens with no formal scientific solar education and not linked professionally to solar research. The STCE communicates with this target audience through websites, press releases and news articles, educational packages, face-to-face encounters such as open doors and public talks, social networking and science fairs. One example of a popular educational package set up by the STCE is 'PROBA2@School' [2]. In this project we targeted Flemish schools (both on primary and secondary level) and offered tailored workshops concerning space weather and the second Project for On-Board Autonomy (PROBA2) satellite [3], ranging from 1 hour up to 3 days in duration.

Communication with the solar scientific community occurs mostly through interactive websites, meetings, scientific articles, the weekly STCE newsletter [4], and user guides combined in our Space Weather Shop [5]. The STCE also operates the Editorial Office of the Journal for Space Weather and Space Climate (JSWSC - [6])

These user guides are also of interest to the non-solar scientific community affected by space weather, such as aviation advisory staff. The shop provides an excellent introduction to the topic, which users can digest at their own pace. For those who need more in-depth training on space weather and its effects, we provide the Space Weather Introductory Course.

3. Space Weather Introductory Course

The SWIC was initiated in 2016 on request of the Dutch and German military forces who wanted a space weather course for their space officers and weather forecasters. The main goal of the course was that the participants would gather a basic understanding of space weather and learn to correctly interpret the URSIgram or similar daily space weather bulletins, to relay the necessary info and warnings to the field personnel. As such, they

were called "space weather operators", and the logo for the SWIC originates from there (Figure 1).

Figure 1. SWIC Logo

The Koninklijk Nederlands Meteorologisch Instituut (KNMI) joined in the development of the course shortly after. Now also the duty officers of the PECASUS [7] service follow the SWIC. PECASUS provides advisories on enhanced space weather activity for civil aviation. The STCE supports this service in the form of the SWIC, which is open to all PECASUS partners. The first SWIC took place in May 2017, with the fourteenth edition in March 2022. No courses took place in 2020 due to the outbreak of the COVID pandemic. In total, already more than 100 trainees took part in this course.

The course is intended as an entry course on space weather. It provides an elementary overview of the relevant aspects of space weather without invoking complicated background physics. The course is intended for meteorologists and space staff that will be providing space weather information to military and civilian end users.

Aside from individual participation, it is also possible for an institute to request a SWIC to be organized for their employees. Depending on their academic level, the institute can choose to refresh certain physical and mathematical basics to allow the trainees an easier understanding of the SWIC's main portion. This is called the pre-SWIC and is given by the requesting institute itself. Similarly, this institute may also elect to educate the trainees on the space weather effects on the specific equipment they handle (e.g. the military). This so-called post-SWIC takes place after the main SWIC and is again the responsibility of the requesting institute. For obvious reasons, the pre- and post-SWIC are not a systematic part of the main SWIC.

The introductory course can be extended with topical modules or tailored to the specific needs, background level and interests of the participants. An end user from the aviation or telecommunication sector, for example, has other needs than a space weather forecaster in a solar research centre.

The programme focuses on gaining knowledge by fact-learning and training skills through easily accessible methods like repetition and games. The on-site editions include a visit to the beating heart of our service centre and a 'Meet & Greet' with scientists and forecasters. SWIC has the tools to evaluate the participants and can provide an examination certificate.

The SWIC is taught by qualified and experienced staff with extensive expertise in relevant domains such as scientific research, solar physics, space weather, forecasting, engineering, communication and outreach, and teaching.

Due to the COVID pandemic, the courses planned in 2020 were canceled as participants were unable to travel to the STCE. From 2021 onwards, we restarted with a fully online version of the course. The encounters with STCE scientists were replaced by guest lectures and the exercises were reinvented using existing, easily-accessible online tools. The added benefit of having a fully online version of the course is that it allows us to reach an audience that cannot easily travel to Belgium. We organized for example a tailored course for members of the United States Air Force for whom travelling to Belgium for a 3-day course is too time-consuming. Online participation is also advantageous for environmental and climate reasons and to avoid extra financial costs. We plan to continue organizing the SWIC alternating between online and on-site editions.

3.1. Course Contents

The content focuses on space weather and the effects on man-made infrastructure and its functionality.

We discuss solar eruptions of very high-energy matter and electromagnetic radiation, which inject massive amounts of energy in the Earth's magnetosphere and ionosphere leading to pronounced impact on navigation, communication and energy transport.

The basic concepts and drivers of space weather are described first, with an added overview of the different sensors used to monitor the activity. From the Sun, we move to the magnetosphere, thermosphere and

ionosphere and discuss how they are impacted. The impacts on aviation specifically, in particular in the framework of PECASUS, is described in much detail on the last day of the course.

By the end of the course, the trainees understand the basics of space weather and know about the potential impact on technology. The students are also able to understand and interpret the space weather information provided by the space weather forecast centers.

3.2. Didactic Methods

The SWIC caters to a very diverse public, which are not always trained extensively in mathematics and physics. While we only expect a medium secondary school knowledge of mathematics and physics, most of the participants have working experience in weather forecasting or engineering, and have an interest in natural and technical sciences. From time to time we have participants that are working as civil servants in risk assessment. Their knowledge of physics is usually limited, and then we adapt the course accordingly by expanding more on the basic principles. Everyone is required to have a good working knowledge of English since that is the teaching language.

In the course we focus on the physical principles of space weather without working out the details mathematically. There are little to no equations shown in the course notes. All principles and concepts are explained verbally and with graphics and movies, making use of comparisons to known concepts wherever possible. We intentionally keep the number of participants low (up to 8 trainees per SWIC in the more recent editions) such that we can monitor their understanding and progress closely.

The on-site course comprises three days, while the online course is spread out over four days. There is a huge amount of material for the students to absorb. We found that when teaching online it is harder for the students to concentrate for an extended period of time, also because we cannot do site visits in this case, which tend to make the day somewhat lighter. Therefore, we spread the online course over more days. For the on-site course the trainees have to travel to the STCE and so it is best to comprise it into fewer days to reduce the total time spent on the course.

Starting 2022, the concluding online evaluation of the course was moved to the week after, so that there is more teaching time left and the trainees have more time to study the course material before being tested. Throughout this week the teaching staff is available to answer any remaining questions.

In the course of a lecture day, we alternate between didactical methods and tools. The basic principles of space weather are mostly explained through direct teaching, aided by presentations. The three experienced teachers that are responsible for the bulk of the course collaborate closely to harmonise their presentations. They also make sure to involve the audience through questioning and interactive slides, and encourage questions from the trainees. The program alternates these teaching periods with exercises, games and recapitulation moments. The main concepts and principles are repeated constantly such that the students can absorb the theory simply by attending the course. The trainees also have their own job to attend to and will have little free moments to spend on studying outside of the course time. We anticipate this by including the repetition in the course program.

The exercises include hands-on material where the students work with real-life space weather data and learn to interpret them. The games such as pictionary, taboo, ringing sunspots [8] and bingo are meant as a moment to relax and bond, but also serve as an opportunity for questions, recapitulation and repetition. During these exercises we can correct any misinterpretations as well. Additionally, each course day starts with a recapitulation of the previous day and a Q&A session.

For the online version of the exercises, we use Google Jamboards [9], which are free interactive whiteboards on which the students can work together. The courses are taught using the Zoom teleconference software [10] and we use many of the interactive features there such as the annotation option to make explanatory drawings, the breakout rooms to allow students to work on the exercises in small groups and the poll feature for quick tests. The final evaluation of the trainees takes place online through the STCE website.

The slides of the presentations are provided to the students and serve as course notes. They are accompanied by explanatory text, of which the content is much broader than what was discussed during the course itself and which includes useful links. The slides serve as a

reference for the trainees when executing their future job interpreting space weather forecasts.

4. Discussion, feedback and reflections

Throughout the SWIC, much attention is spent on feedback from the students. At the end of each day and at the end of the course, we ask the trainees for their reflections, comments and suggestions. For the students that prefer to share their opinion in private, we invite them to do so once more when we deliver them the course certificate. The teaching staff can easily be contacted by the trainees and actively encourage the students to reach out with questions and feedback.

Throughout the years, this open attitude has allowed us to improve the course, for example in refining the order in which the different subjects are tackled and adding extra course time at the start to introduce basic concepts that are needed throughout the course.

Also, when transitioning to the online version, the feedback of the students was much needed, for example on which online tools were easy to use and accessible to them. Note that some work in restricted environments where the installation of new software is not allowed.

After each edition, the teaching staff holds a meeting to critically evaluate the SWIC and to plan the next one. In these meetings exercises and course material are fine-tuned. One of the decisions that came out of them is to decrease the number of participants in the more recent editions, allowing for a closer monitoring of the students as well as more interaction between them.

5. Conclusions and Outlook

The SWIC has been a major success for the STCE, allowing us to reach a new public of meteorologists and aviation staff. The STCE already had a strong position in public outreach and communication towards the solar scientific community, yet it is very hard to cross the borders to other disciplines. Space weather is by definition an interdisciplinary science with a broad range of impacts. Through the SWIC, we can raise the awareness of other research institutes, companies and nations to space weather threats. The continued interest in the course shows there is a real need for this training. To our knowledge, there is no equivalent to it in Europe, even worldwide.

In the future we plan to diverge to tailored courses. In 2021 we organized a custom SWIC for the United States Air Force, focusing in a limited time span on the topics that were of most use to them. We plan to continue on this route by providing, in addition to the regular SWIC that is now on point, one-day topical SWICs focussing on ionosphere, aviation or high-frequency communication. A one-day, specialized course may also attract interested trainees that are unable to free up multiple days in their busy work schedule.

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