Radiation Belt Environmental Indicators for the Safety of Space Assets

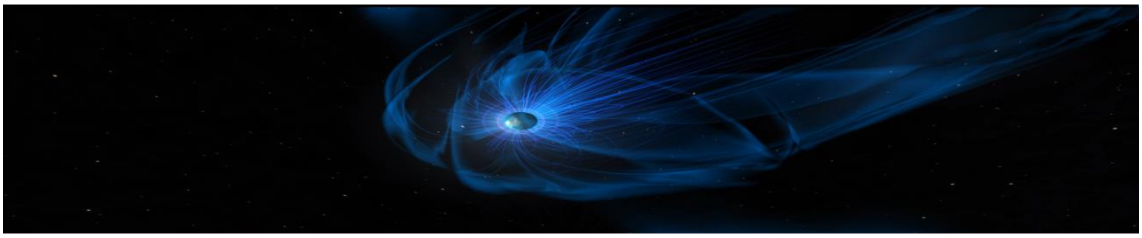
SafeSpace Newsletter

Issue 1

The first six months of SafeSpace

...Outer space, once a region of spirited international competition, is also a region of international cooperation (James Alfred Van Allen)

The **SafeSpace: Radiation Belt Environmental Indicators for the Safety of Space Assets project** *was launched in January 2020. This comprehensive EU-funded project aims at advancing space weather nowcasting and forecasting capabilities and, consequently, at contributing to the safety of space assets through the transition of powerful tools from research to operations (R2O). To ensure an efficient and optimized transfer from science to application, we have foreseen close collaboration between academia (National and Kapodistrian University of Athens - NKUA, Office National d'Etudes et de Recherches Aérospatiales – ONERA, Katholieke Universiteit Leuven – KUL, Institute of Atmospheric Physics Ustav Fyziky Atmosfery AV CR, v.v.i. – IAP, Centre National de la Recherche Scientifique - CNRS, Institut royal d'Aéronomie Spatiale de Belgique Royal Belgian Institute for Space Aeronomy – IASB-BIRA), a major European space industry (Thales Alenia Space – España- TAS) and a space-oriented SME (Space Applications & Research Consultancy Sandberg & Co Private Company - SPARC). The SafeSpace Consortium shall improve radiation belt modelling through the incorporation into an existing physical model of processes and parameters that are of major importance to radiation belt dynamics. In order to set up a prototype of a new space weather service dedicated to Earth-orbiting satellites, end users' requirements related to ionizing particles in space will be defined by TAS – in consultation with other end users.*



The Kick-Off Meeting of SafeSpace

The SafeSpace Kick-off Meeting (KOM) took place in Athens, on January 21, 2020. The KOM was hosted in the historic neoclassical building "Kostis Palamas", which was erected in 1857 and serves as Cultural Centre and Lounge of the University of Athens.

At the KOM opening the Rector of the National and Kapodistrian University of Athens Prof. Meletios Athanasios Dimopoulos expressed his support towards research and welcomed the leading scientists coming from high-profile universities, research institutes as well as specialized companies active in space, across Europe.

*During the KOM, 32 participants from all consortium partners, the Project Officer Andrej Rožkov (European Commission) and representatives of **the Galileo Control Centre** and of OHB Hellas, had the chance to meet in person for the first time and commence a very productive collaboration in light of the upcoming demanding project's tasks. All work package leaders presented their 3-year action plan and shared ideas and valuable experience on how to best serve the project's aims.*

The topic of space weather and the significance of this European project also attracted the attention of media representatives, who provided extensive coverage through national press (now available on the SafeSpace website: https://www.safespace-h2020.eu/press-media/)

Group picture at the SafeSpace KOM

Project Progress and Outcomes

Because of the Covid-19 pandemic, the SafeSpace Consortium has been working mostly remotely. Teleconference meetings have been held both regularly (at least once per month) for all (technical and administrative) aspects of the project. In this time of unprecedented working conditions, we have managed to keep the schedule of the project's work plan and we are happy to inform you about the outcomes of the first six months of SafeSpace. This newsletter will be bi-annual, summarizing the progress and main outcomes of the project.

Propagating geoeffective solar wind structures to Earth (CNRS, KULeuven, ONERA, IAP)

The goal of this task is to construct a pipeline that permits to propagate and thus forecast potentially harmful solar wind perturbations all the way from the solar surface to near Earth.

We have started by focusing on a set of numerical codes that will permit a fast forecasting of interplanetary structures known as Corotating Interaction Regions (CIRS). The forecasting of Coronal Mass Ejections (CMEs) is planned for the next year. We have worked on the technical aspects of the codes, in order to make them as robust as possible before implementation in the pipeline. We have also worked on the interfaces between the various codes involved, and which concern: solar corona reconstruction (PFSS), solar wind acceleration (Multi-VP), 1D and 3D MHD heliospheric propagation (1DMHD and EUHFORIA), and the devise of Neural Network coupling functions for energy input into the magnetosphere. The first 6 months of the project have permitted to identify, and to start implementing, all the required adaptations of the codes and future developments to ensure clean interfaces, robustness and rapidity.

Several active solar periods have already been simulated to perform a first try at a forecasting pipeline. The outputs from this task consist in ensemble time series – with error estimates – used as inputs in the other project tasks, in particular the modeling of the radiation belts.

Near Sun solar wind modeling with the Multi-VP code

The modelling of the acceleration of the solar wind near Sun is based on the use of the Multi-VP code (Pinto and Rouillard, 2017 The Astrophysical Journal, 838:89 (15pp), doi: 10.3847/1538-4357/aa6398). Multi-VP is a new type of solar wind model, which takes a coronal magnetic field map as input, computes a collection of individual solar wind streams spanning a region of interest of the solar atmosphere from 1 to ~30 solar radii at any instant desired in quasi-real time, while keeping a good physical description of plasma heating, cooling and acceleration mechanisms (Pinto et al. 2009, Astron. Astrophys., 497, 537, *doi: 10.1051/0004-6361/200811183). MULTI-VP provides as output the full set of bulk physical parameters of the emerging wind based solely on physics principles (wind speed, density, temperature and magnetic field). A key innovation consists in the treatment of the solar wind as an ensemble of flows guided along the magnetic field in the low-beta corona, hence neglecting the cross-field interactions and simplifying the full MHD problem. The model was thoroughly calibrated against white-light imagery and in-situ spacecraft data.*

CIR propagation to Earth using one-dimensional MHD modeling

The one-dimensional magnetohydrodynamic (MHD) used for SafeSpace (1D MHD, Tao et al., 2005, J. Geophys. Res., 110, A11208, doi:10.1029/2004JA010959) models solar wind propagation primarily for the purpose of predicting the properties and evolution of Corotating Interaction Regions (CIRs). This model was so far mainly used for propagating solar wind observations at Earth to other solar system planets (e.g., the HelioPropa service provided by CDPP, http://heliopropa.irap.omp.eu/). For this project, the 1D MHD model is used to propagate the solar wind from near-Sun to Earth using solar wind solutions provided by the Multi-VP code at 0.14 AU. To prepare for this task, we have performed numerous tests of the connection between MULTI-VP and the 1D MHD model by comparing the outputs with sample observations at L1. An example result is shown in Figure 1. We have also provided preliminary results of the Multi-VP – 1D-MHD code coupling for testing the neural network model prediction of the Kp index, as planned in future tasks of the project.

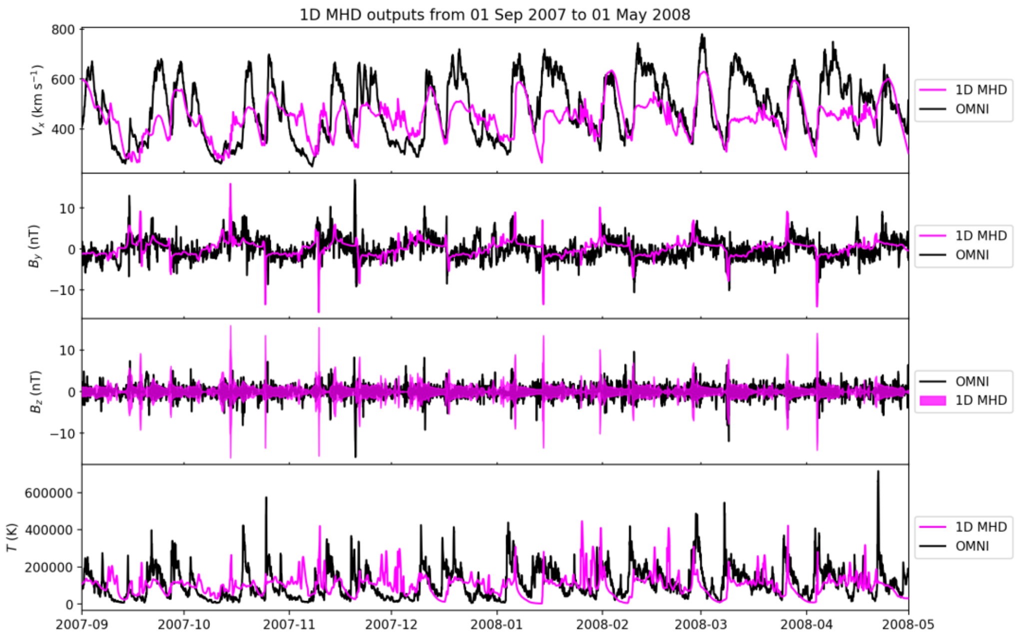


Figure 1: Example outputs from the 1D MHD model at 1 AU using inputs from the MULTI-VP model at 0.14 AU. The model outputs are in purple while the observations from the OMNI database are in black. CIR patterns are noticeable in the velocity (first panel) and tangential magnetic field (By, second panel), in particular.

CIR propagation to Earth using three-dimensional MHD modeling

The EUropean Heliospheric FORecasting Information Asset (EUHFORIA, Pomoell and Poedts, 2018, J. of Space Weather and Space Climate, 8, A35, doi: https://doi.org/10.1051/swsc/2018020) models solar wind and coronal mass ejections (CMEs) all the way from the Sun to 2 AU. An example simulation is shown in Figure 2. It consists of two different domains; the coronal part, which extends from the solar surface to 0.1 AU and the heliospheric part, which covers the spatial domain from 0.1 AU onwards. For the reconstruction of the global solar corona, the empirical Wang-Sheeley-Arge (WSA, Arge et al, 2004 J. Atmosph. and Solar-Terrestrial Phys., 66, 1295, doi: 10.1016/j.jastp.2004.03.018.) model is currently used, in combination with the potential field source surface (PFSS) model and the Schatten current sheet (SCS) model, in order to reconstruct the magnetic field up to 0.1 AU and produce the plasma boundary conditions required by the 3D MHD heliospheric part to initiate. In the framework of the ongoing validation of the solar wind modeling with EUHFORIA, we implemented and tested a different coronal model, the so-called MULTI-VP model (Pinto and Rouillard, 2017). First results and comparisons of EUHFORIA modeled outputs at Earth, produced by employing the WSA and MULTI-VP coronal models, have been performed and have proven promising. While the first tasks of the project currently concern the propagation of CIRs to Earth, in later part of the project the EUHFORIA model will be used to propagate CMEs from Sun to Earth, also using MULTI-VP as input.

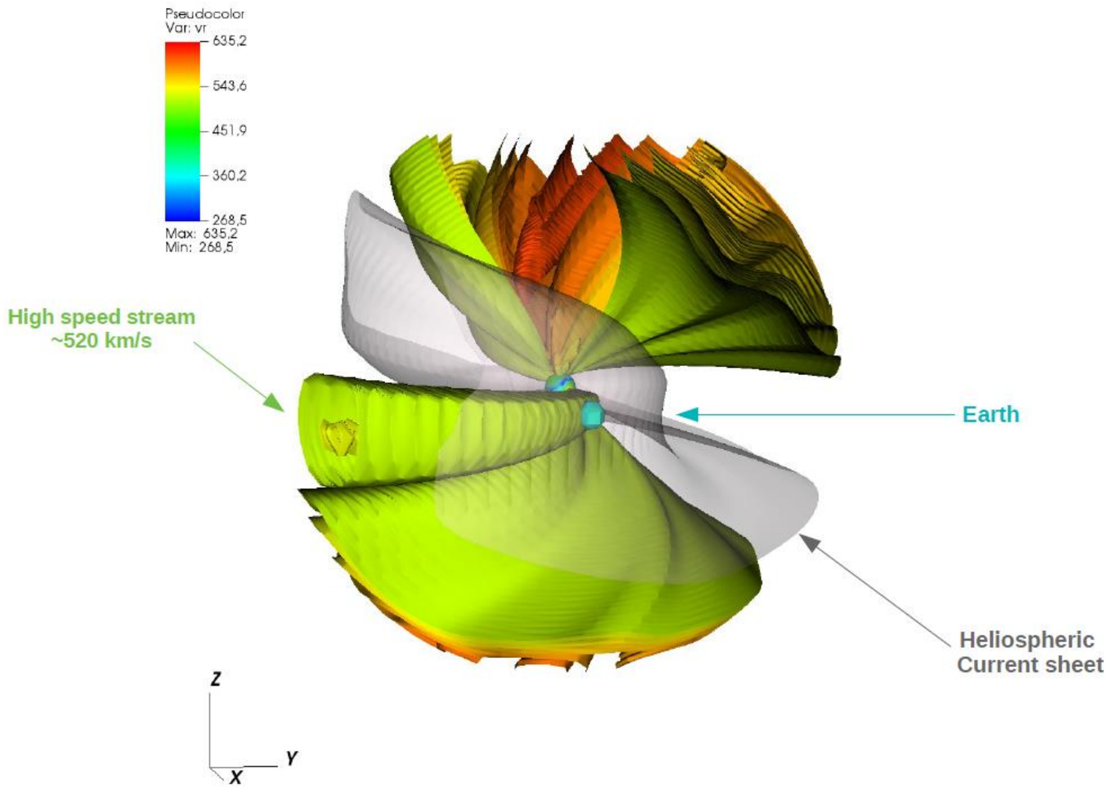


Figure 2. 3D visualization of the high-speed solar wind streams modelled by the coupled Multi-VP – EUHFORIA model.

Cold plasma density map (IASB, IAP)

The goal of this task is to build cold plasma density maps in the plasmasphere and plasmatrough as a function of geomagnetic activity and location, from a physics-based 3D dynamic model (SPM, SWIFF Plasmasphere Model) improved and completed with satellite data (Cluster and Van Allen Probes).

A new version of the SPM code has been prepared for implementation in the framework of the project. The electron density in the plasmasphere and plasmatrough is now determined in a spatio-temporal grid compatible to the input needed by the Salammbô code in following tasks of the project. The SPM code has also been improved by adding an interpolation mechanism to dynamically obtain additional equatorial plasmapause points when strong geomagnetic storms severely distort the plasmasphere limits. In these situations, less points are analytically evaluated for nighttime simulated hours and the interpolation procedure allows to better fill some extended regions without plasmapause, and consequently better evaluate the plasmasphere density limited by these pieces of plasmapause.

Two stormy periods were simulated (12-18 December 2013 and 15-17 March 2015) and the outputs were provided to the network. They contain text files and images of the electron density in the agreed spatio-temporal grid and the corresponding equatorial plasmapause locations. For example, the density is plotted below (Figure 3) as a function of L-MLT for the five different magnetic latitudes of the grid, before the March 2015 storm (a) and during the main phase of this storm (b). The plasmapause position in the magnetic equatorial plane is plotted (with black dots) in the top panels. The electron density in the plasmasphere and plasmatrough is also plotted in the equatorial (c) and meridian (d) plane.

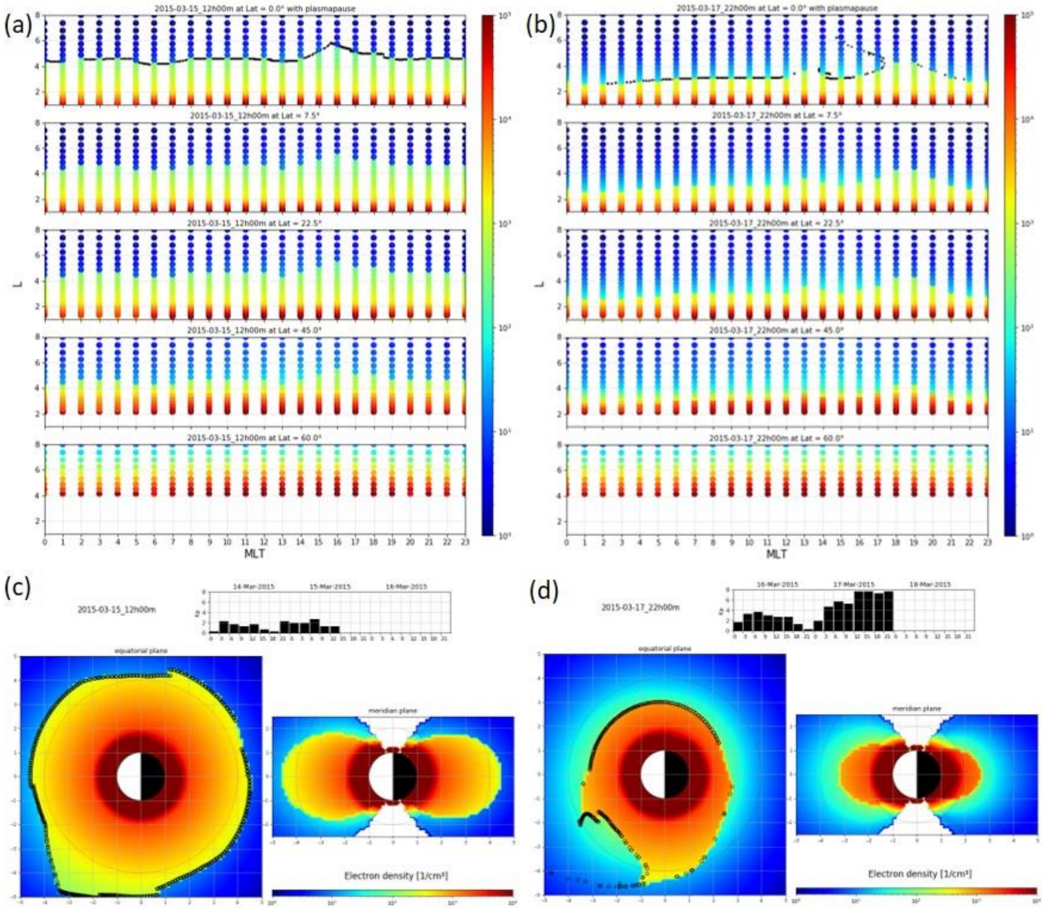


Figure 3. Electron density as a function of L-MLT for the five different magnetic latitudes of the grid (see details in the main text).

Impact of plasma density and waves on diffusion coefficients (IAP, ONERA, NKUA)

The goal of this task is the development of a prototype model of diffusion coefficients based on the estimated Power Spectral Density of various wave types (VLF and ULF) parameterized by solar wind drivers and geomagnetic activity indices.

Especially concerning the ULF based radial diffusion coefficients, the team has used in-situ magnetic and electric field measurements from the Van Allen Probes and THEMIS spacecraft towards the creation of a database which will include approximately 11 years of radial diffusion calculations. These coefficients will be parameterized with solar wind speed and pressure (which are known drivers of ULF waves) and with L.*

The following figure is an example of the importance of case-specific calculations of radial diffusion coefficients (black circles) during the famous St. Patrick's storm of 2015. As shown, even widely used empirical models (colored lines) cannot accurately estimate the variability of the coefficients which may introduce significant uncertainties to the simulation of the electron radiation environment.

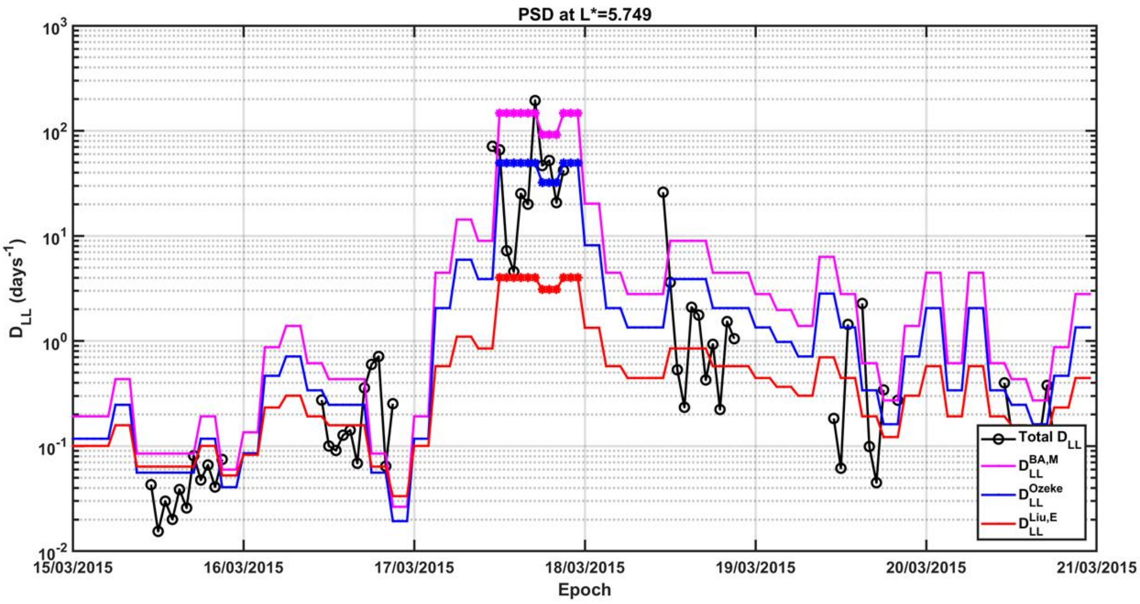


Figure 4. Radial diffusion coefficients (black circles) during the famous St. Patrick's storm of 2015.

Exploitation, dissemination and communication plan (NKUA)

SafeSpace includes a work package devoted to the exploitation and dissemination of results to the scientific community, the space industry and spacecraft operators, and furthermore the deployment of a range of communication tools, techniques and activities appropriate for different public audiences. The main objectives of the dissemination activities are to ensure increased visibility of SafeSpace as well as maximum impact from the research and development activities of the project. A detailed plan for the exploitation, dissemination and communication of project activities and results, was drafted in March 2020 and will be updated throughout the project lifetime, according to present conditions.

Web presence (NKUA, SPARC)

As part of the SafeSpace dissemination and communication activities, a user-friendly website (https://www.safespace-h2020.eu/) has been developed, through which the scientific community, stakeholders and the broad public can find information regarding project details, description, goals, participants, news and additional useful facts. The website is continuously updated with new information.

The present newsletter is one of the SafeSpace Communication Tools included in the dissemination plan.

SAFESPACE

"Radiation Belt Environmental Indicators for the Safety of Space Assets"

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COORDINATION

National and Kapodistrian University of Athens – NKUA

Prof. Dr. Ioannis A. Daglis,
Department of Physics,
Panepistimiopoli Zografou,
15784, Athens, Greece

PARTNERS

NKUA (Greece)
ONERA (France)
KULeuven (Belgium)
IAP (Czechia)
IASB (Belgium)
TAS-E (Spain)
CNRS (France)
SPARC (Greece)

CONTACT & SOCIAL MEDIA

SafeSpace
SafeSpace
safespacecoordination@gmail.com
iadaglis@phys.uoa.gr
emitsaku@phys.uoa.gr