Prediction of Geospace Radiation Environment and solar wind parameters

Coordinator: University of Sheffield

Jan 1, 2015-Dec. 31, 2018

extention to July 31, 2018

January 2016
January 2017
December 2017
August 2018

PROGRESS

- Grand Project to increase the Forecasting Capabilities of the geospace environment parameters from the SUN to Ground
- Ultimate goal: To give space weather users better predictions to decrease the causalities from the space environment in space and on the ground and increase the public awareness
- Also with the objective of creating European Forecasting Tool

Aim

(Project Annex)

Overall aim of the Project PROGRESS is to exploit the synergy of

- the complementary expertise available within partner groups,
- the available spacecraft, and
- ground based data,
- combined with state of art data assimilation methodologies

in order to develop an accurate and reliable forecast to prevent space weather hazards.

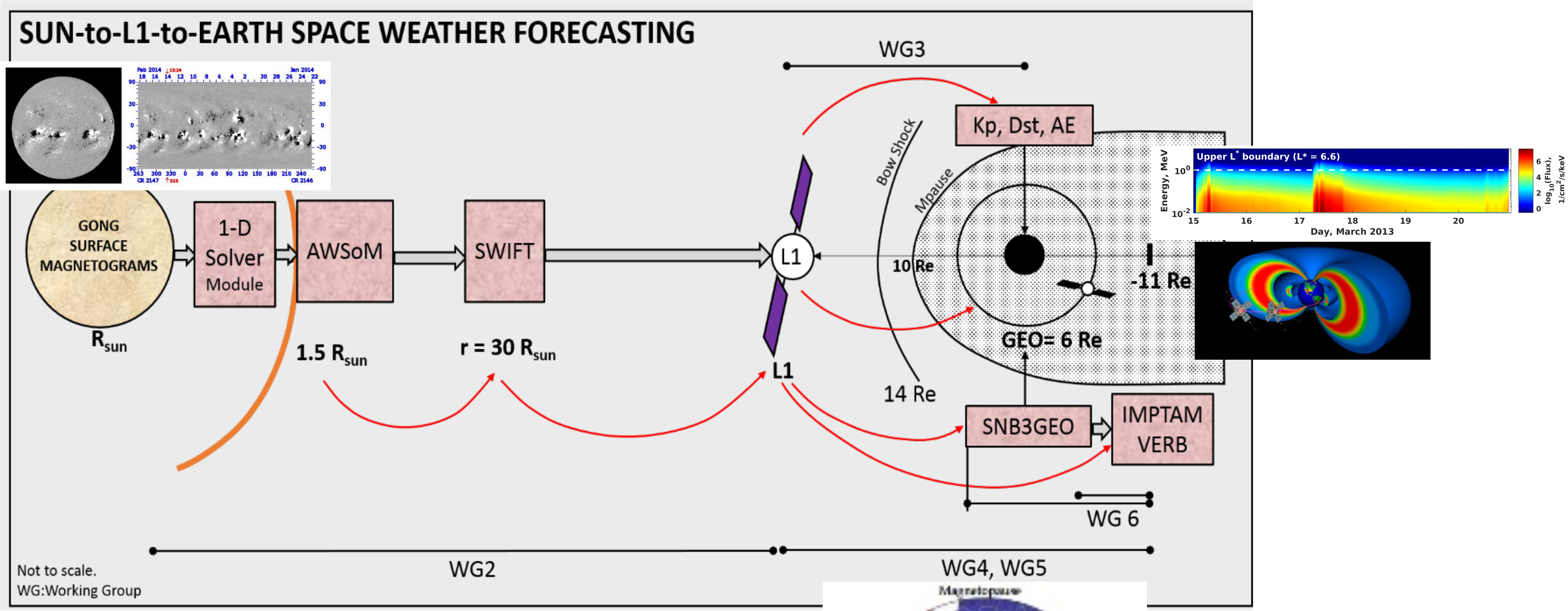
Hazards:

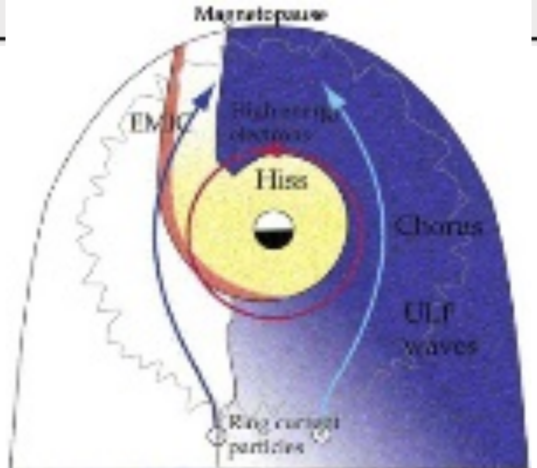
- Spacecraft
- GPS/GNSS communication
- GICs Electric Powers
- SEPS
- TIDs
- Aviation hazards
- ….

CAUTION

- Risk assesments
- Stragey development against hazards

Among the hazards:
Primarily Spacecraft charging





WAVE MODELS (characteristics)

GONG: **G**lobal **O**scillation **N**etwork **G**roup
AWSoM: **A**lfven **W**ave **So**lar **W**ind **M**odel
SWIFT: **S**olar **W**ind **F**orecasting **T**ool ?? (Spherical geometry inner-heliospheric MHD)
SNB3GEO:
IMPTAM: **I**nner **M**agnetosphere **P**article **T**ransport and **A**cceleration **M**odel
VERB:**V**ersatile **E**lectron **R**adiation **B**elt

PROGRESS MODELS

IMPROVED MODELS

- Kp, Dst, AE models
- WAVE Models (new data base)
- SNDBE3GEO
- IMPTAM
- VERB

NEWLY DEVELOPED MODELS

- Kp, Dst, AE models (models: IRF, USFD, SRI)

IMPROVED MODELS:

Nowcasting Capabilities

Temporal Resolutions

New data base

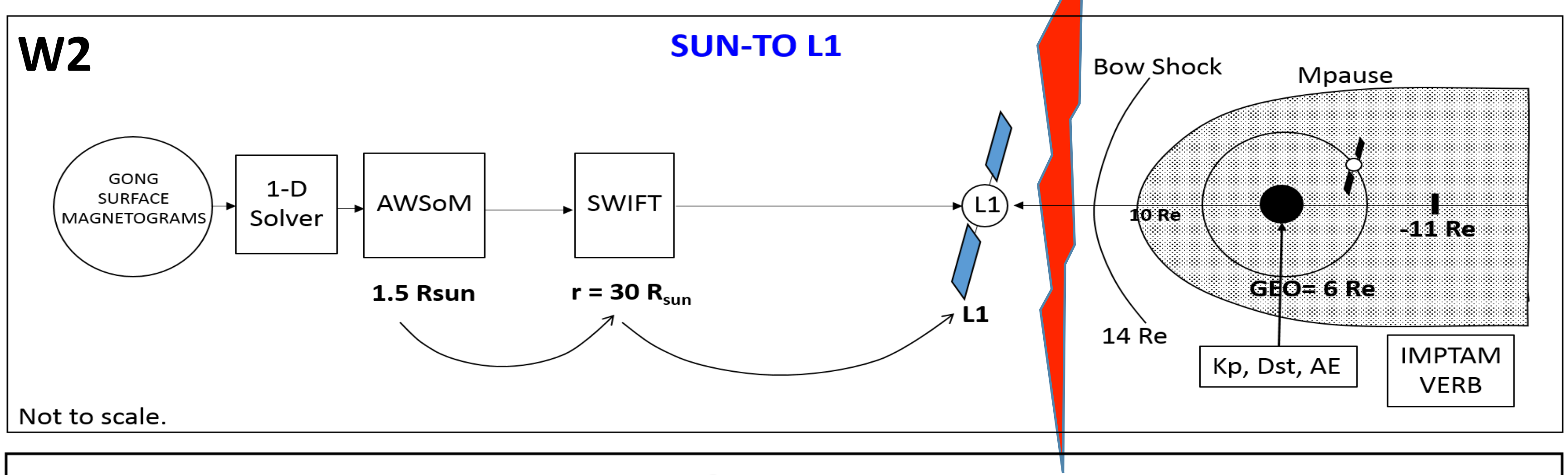
NEWLY DEVELOPED MODELS

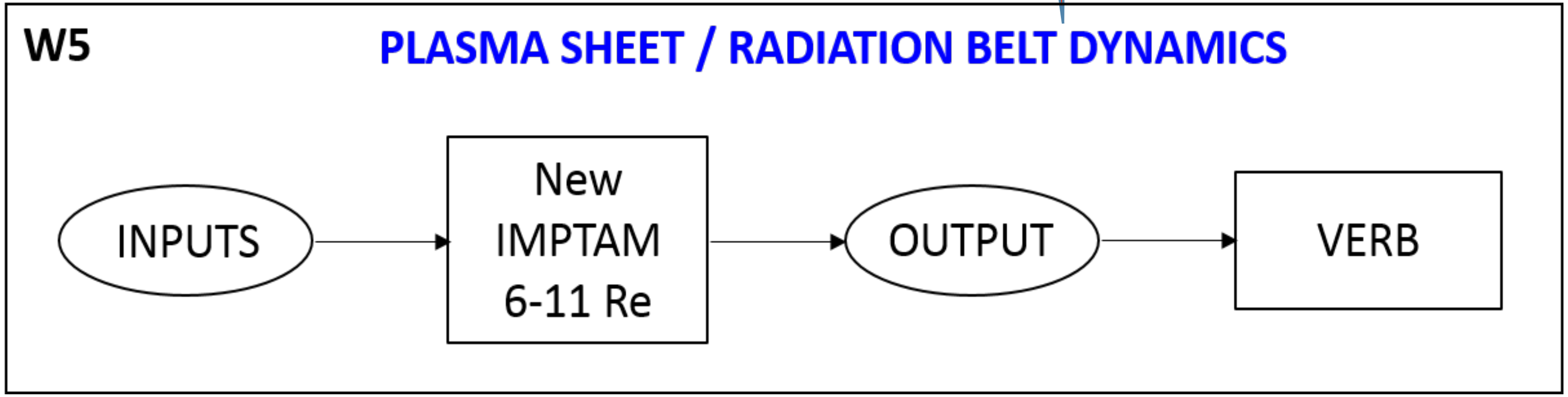
First time developed within PROGRESS

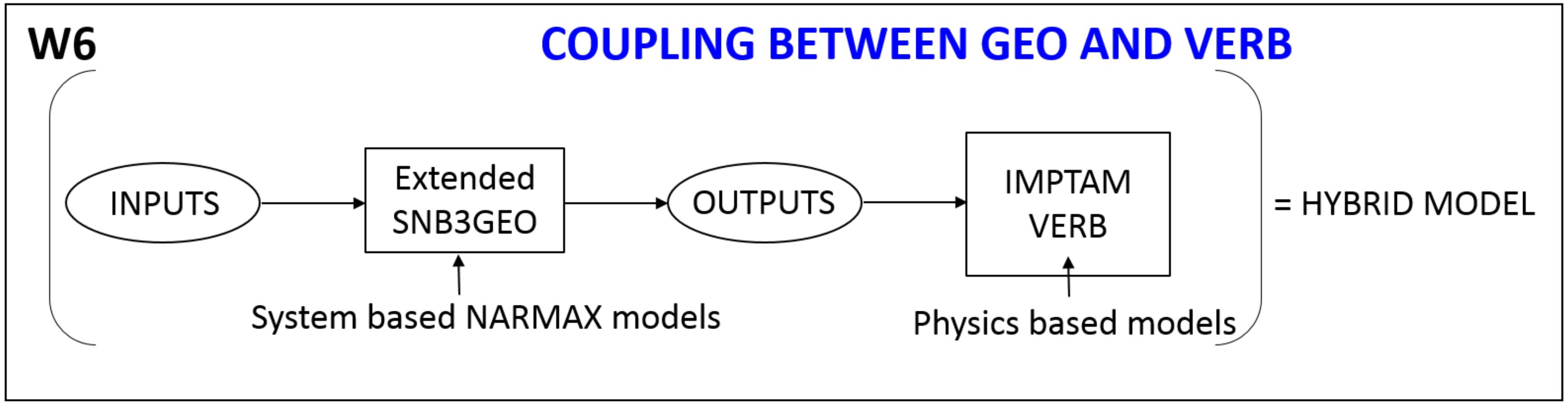
COMBINED MODELS

- AWSoM-SWIFT
- SNB3GEO-VERB
- IMPTAM-VERB

MODELS







W3

Kp, Dst, AE MODELS

W4

WAVE MODELS

Table 2: Models developed/modified within PROGESS.

WP	Models developed / modified	Notes on the description of process	Input	Output	Web
W2	AWSoM	1-D solver coupled into AWSoM	GONG magnetometer	Solar wind and IMF at L1	*http://ww.ccmc.gsfc.nasa.gov*
	SWIFT	Lare3 and Odin codes are used to convert to spherical	AWSoM solar wind and IMF at 30 Rsun	Solar wind and IMF at L1	*https://cfsa-pmw.warwick.ac.uk*
W3	**IRF-Kp-2017** **IRF-Dst-2017** **IRF-AE-2017** **USFD-Kp** **USFD-Dst** **SRI-Kp** **SRI-Dst** **SRI-AE**	ANN Bilinear; OSA and MPO RM and GP approach for both	Solar wind plasma and IMF	0 to 3 hour lagged Kp Dst AE	IRF USFD
W4	NARMAX (D.4.3)	Run to find the most influential solar wind and geomagnetic index parameters that affect the system.	Solar Wind Plasma and IMF	Hourly resolution particle flux at various energy levels and at GEO	*http://www.ssg.group.shef.ac.uk/USSW/UOSSW.html*
W5	Solar wind driven IMPTAM	To extend now-casting IMPTAM to forecasting eenergetic electrons in the plasma sheet and provide input for VERB	Solar wind velocity, density, IMF Bz	Low energy electron flux between 6-11 Re	*http://imptam.fmi.fi/*
W6	NARMAX with MISO (extended SNB3GEO) NARMAX MODEL with IOF algorithm	> 800 keV and > 2 MeV 5 new NARMAX model for 5 energy range of low energy electron flux	Solar wind velocity, density, –IMF Bz	Forecasted electron flux at various energy levels at GEO (6 Re)	*http://www.ssg.group.shef.ac.uk/USSW/UOSSW.html*
	VERB	Radıation Belt model with improved diffusion coeffiecients to forecast energetic electrons and couple with NARMAX-GEO and IMPTAM	Energetic particle flux at GEO Kp	Distribution of energetic particles within Rad Belt (L* dep.)	UCLA

What differs?

- Why needed?
  - AFFECTS (Advanced Forecast For Ensuring Communications Through Space) : 2011-2014
  - FLARECAST (FLARE ForeCASTing) : 2015-01-01 / 2017-12-31, three years
  - HESPERIA (High Energy Solar Particle Events foRecastIng and Analysis) : 2015-05-01 / 2017-04-30, two years
  - HELCATS (Heliospheric Cataloguing, Analysis and Techniques Service) : 2014-05-01 / 2017-04-30, three years
  - F-CHROMA (Flare Chromospheres: Observations, Models and Archives) : 2013-09-24 / 2017-01-01, four years
  - COMESEP (Coronal Mass Ejections and Solar Energetic Particles) : 2011-02-01 / 2014-01-31, three years
  - OTHER MODELS e.g. at CCMC base:
    - WSA and ENLIL FOR SW
    - SWFM FOR L1 and Magnetosphere
- How different
  - Methodology
  - Participants/Country/Institutions
  - Science question
  - Working domain
- What is accomplished?
  - Outputs
  - Spacecraft orbit tool
- Failures/things to improve

Methodology:
Several newly developed techniques, algorithms, approaches

Synergy between Data based System Identification models and Physics Based Models to reveal the dynamics

Participants: Collective work of 8 countries
Science: Among the many

- Increased scientific knowledge on

Coupling SW to Magnetosphere (Psheet, GEOenv.) and ground Radiation Belt physics and Dynamics

Implications: Spacecraft charging / Orbit tool

Country	# of inst
UK	2
Finland	1
France	1
Germany	1*
Russia	1*
Sweden	1
Ukraine	1
USA	1
8	9

- Global
- Comprehensive and
- Practical (tools)

QUICK SUMMARY ON WHAT HAVE BEEN DONE? OUTPUTS / PRODUCTS

HOW

- Search on available models
  - their characteristics, inputs, outputs, forecasting abilities
  - advantages and disadvantages
- Improve available models
- Develop new models
- VERIFICATION/VALIDATION
- Compare with observations
- Comparisons between models

FORECASTS

- The forecast of SW parameters and IMF at L1
  - Plasma: velocity, density, temperature, IMF Btot, Bx, By, Bz
- The forecast of geomagnetic indices on the ground
  - Kp
  - Dst
  - AE
- The forecast of radiation environment in the inner magnetosphere
  - Energetic electrons at various energy levels and at various radial distances

ENERGETIC PARTICLE FLUX FORECASTS AT DEFINED SPACECRAFT TRAJECTORIES

Specific Objectives

1. SOLAR (W2):
    - develop a European numerical MHD based model.
        - This will give direct simulation connection between observed photospheric drivers and solar wind parameters at L1
2. INDICES (W3):
    - use system science methodologies to develop new forecasting tools for geomagnetic indices and to assess the prediction efficiency of these new tools alongside those currently available to identify the most reliable techniques to predict the geomagnetic state of the magnetosphere, as expressed by geomagnetic indices, in relation to solar wind input conditions.
3. WAVES (W4):
    - Construct a new set of statistical wave models to describe th eplasma wave environment of inner magnetosphere that will accurately reflect the physics of teh Dynamics of the radiation belts under the influence of the solar wind.
    - These novel wave models will lead to more realistic tensors of diffusion coefficients that are critical for physics based models of the radiation belts.
4. IMPTAM (W5): Also W3(INDICES) and W6 (VERB)
    - Incorporate forecasting capabilities into the physics based numerical model for low energy electrons IMPTAM that currently is able to provide a now-cast only.
5. RADIATION BELTS (W6):
    - Develop a novel, reliable, and accurate forecast of the radiation environment in the region of radiation belts exploiting the fusion between data based models for high energy fluxes at geostatinary orbit SNB3GEO, IMPTAM, VERB, and state of the art data assimilation methodology. VERB: the most advanced model for high energy electrons in the radiation belts.
6. FUSION (W7)
    - To combine the prediction tools for geomagnetic indices and radiation environment within the magnetosphere with the forecast of solar wind parameters at L1 and upstream of the magnetosphere to significantly increase the advance time of the forecast.

TASKS

- **WP2 - Propagation of the Solar Wind from the Sun to L1**
  - **Task 2.1**: Convert Warwick MHD code into the spherical geometry SWIFT code.
  - **Task 2.2:** Make the AWSoM time accurate using hourly ingested magnetograms (using GONG data products)
  - **Task 2.3:** Extend SWIFT to a two-temperature model to allow shock heating of ions.
  - **Task 2.4:** Add improved electron heat transport Month 10-15 (UW, UM)
  - **Task 2.5**: Couple inner boundary of SWIFT to the Michigan AWSoM coronal model.
  - **Task 2.6:** Validate the AWSoM/SWIFT codes using historical magnetograms and ACE data.
  - **Task 2.7:** Run real-time test of predicted L1 variables based on coupled AWSoM/SWIFT codes.
  - **Task 2.8: Write developer and user manuals**
- **WP3 - Forecast of the evolution of geomagnetic indices**
  - **Task 3.1:** Survey of existing operational models forecasting Kp, Dst, and AE.
  - **Task 3.2:** Identify and collect relevant data.
  - **Task 3.3:** Evaluate and verify a set of selected existing models.
  - **Task 3.4:** Develop further existing Kp and Dst models.
  - **Task 3.5:** Develop new AE forecast models
  - **Task 3.6: Implement models for real-time operation.**
  - **Task 3.7: Development and testing of Guaranteed NARMAX and bi-linear models.**
- **WP4 - Development of new statistical wave models and the re-estimation of the quasilinear diffusion coefficients**
  - **Task 4.1:** Collection of data and the development of software for automatic identification of Chorus, hiss and equatorial magnetosonic emissions.
  - **Task 4.2:** Preparation of data sets for Error Reduction Ratio analysis.
  - **Task 4.3:** Error reduction analysis.
  - **Task 4.4:** Development of the Statistical Wave Models and corresponding tensors of diffusion coefficients.
- **WP5 - Low energy electrons model improvements to develop forecasting products**
  - **Task 5.1**: Developing a solar wind and IMF driven model for low energy electrons in the plasma sheet.
  - **Task 5.2:** Incorporating the proper diffusion coefficients into IMPTAM provided by VERB radiation belts model.
  - **Task 5.3: Providing the low energy seed population to VERB radiation belts model.**
  - **Task 5.4: Developing a trial version of forecast model for low energy electrons.**
- **WP6 - Forecast of the radiation belt environment**
  - **Task 6.1:** NARMAX modelling of energetic electron fluxes at GEO.
  - **Task 6.2:** Data assimilation extension for VERB.
  - **Task 6.3: Development of the coupled VERB-NARMAX model (VNC).**
- **WP7 - Fusion of forecasting tools**
  - **Task 7.1:** Implementation of models for geomagnetic indices and electron flux forecasts at USFD.
  - **Task 7.2: Implementation of VERB-NARMAX and VERB-IMPTAM models.**
  - **Task 7.3: Orbit tool.**
  - **Task 7.4: Environmental summary**

WP2 - Propagation of the Solar Wind from the Sun to L1

Task 2.1: Convert Warwick MHD code into the spherical geometry SWIFT code.

Task 2.2: Make the AWSoM time accurate using hourly ingested magnetograms (using GONG data products)

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Task 2.6: Validate the AWSoM/SWIFT codes using historical magnetograms and ACE data.

Task 2.7: Run real-time test of predicted L1 variables based on coupled AWSoM/SWIFT codes.

Task 2.8: Write developer and user manuals

EVALUATION/QUESTIONS

- New methodology??
- New data sets ??
- New models ??

- Advancing available models?
- How?

- What newly developed?
- Success?
- Where it fails?
- Why ? suggestions

WHAT IS ACCOMPLISED? WHERE ARE WE? OUTPUTS?

FAILURE POINTS / THINGS TO IMPROVE / SUGGESTIONS

WP3 - Forecast of the evolution of geomagnetic indices

- **Task 3.1:** Survey of existing operational models forecasting Kp, Dst, and AE.
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- **Task 3.3:** Evaluate and verify a set of selected existing models.
- **Task 3.4:** Develop further existing Kp and Dst models
- **Task 3.5:** Develop new AE forecast models
- **Task 3.6:** Implement models for real-time operation.
- **Task 3.7:** Development and testing of Guaranteed NARMAX and bi-linear models.

EVALUATION/QUESTIONS

- New methodology??
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WHAT IS ACCOMPLISED? WHERE ARE WE? OUTPUTS?

FAILURE POINTS / THINGS TO IMPROVE / SUGGESTIONS

WP4 - Development of new statistical wave models and the re-estimation of the quasilinear diffusion coefficients

- **Task 4.1:** Collection of data and the development of software for automatic identification of Chorus, hiss and equatorial magnetosonic emissions.
- **Task 4.2:** Preparation of data sets for Error Reduction Ratio analysis.
- **Task 4.3:** Error reduction analysis.
- **Task 4.4:** Development of the Statistical Wave Models and corresponding tensors of diffusion coefficients.

EVALUATION/QUESTIONS

- New methodology??
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WHAT IS ACCOMPLISED? WHERE ARE WE? OUTPUTS?

FAILURE POINTS / THINGS TO IMPROVE / SUGGESTIONS

WP5 - Low energy electrons model improvements to develop forecasting products

- **Task 5.1**: Developing a solar wind and IMF driven model for low energy electrons in the plasma sheet.
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EVALUATION/QUESTIONS

- New methodology??
- New data sets ??
- New models ??

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- How?

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- Why ? suggestions

WHAT IS ACCOMPLISED? WHERE ARE WE? OUTPUTS?

FAILURE POINTS / THINGS TO IMPROVE / SUGGESTIONS

WP6 - Forecast of the radiation belt environment

- **Task 6.1:** NARMAX modelling of energetic electron fluxes at GEO.
- **Task 6.2:** Data assimilation extension for VERB.
- **Task 6.3:** Development of the coupled VERB-NARMAX model (VNC).

EVALUATION/QUESTIONS

- New methodology??
- New data sets ??
- New models ??

- Advancing available models?
- How?

- What newly developed?
- Success?
- Where it fails?
- Why ? suggestions

WHAT IS ACCOMPLISED? WHERE ARE WE? OUTPUTS?

FAILURE POINTS / THINGS TO IMPROVE / SUGGESTIONS

WP7 - Fusion of forecasting tools

- **Task 7.1:** Implementation of models for geomagnetic indices and electron flux forecasts at USFD.
- **Task 7.2**: Implementation of VERB-NARMAX and VERB-IMPTAM models.
- **Task 7.3:** Orbit tool.
- **Task 7.4**: Environmental summary

EVALUATION/QUESTIONS

- New methodology??
- New data sets ??
- New models ??

- Advancing available models?
- How?

- What newly developed?
- Success?
- Where it fails?
- Why ? suggestions

WHAT IS ACCOMPLISED? WHERE ARE WE? OUTPUTS?

FAILURE POINTS / THINGS TO IMPROVE / SUGGESTIONS

DELIVERABLES FOR REVIEW 4 (Aug 2-3, 2018)

FIRST TIME REVIEWS AS OF JUL 30 (not including revised versions of the previous submissions)

	Tasks			Deliverable Title	Due	Type	Ext.
D1.3		WP1	USFD	Minutes of Final Stakeholder meeting	36	R.	
D2.3	Task-2.8	WP2	UW	SWIFT Documentation	36	R.	
D3.6	Task-4.4	WP3	IRF	Real-Time model implementation	36	R.	
D5.3	Task-5.2	WP5	FMI	The VERB-IMPTAM low energy seed population	26	R.	37
D5.4	Task-5.4	WP5	FMI	Trial version of forecast model for low energy electrons	36	R.	
D6.3	Task-6.3	WP6	USFD	Results of the VNC model and two methods of model coupling	30	R	38
D7.2	Task-7.2	WP7	USFD	Forecasts of the energetic electron populations within the inner magnetosphere (Implementing of VERB-NARMAX and VERB-IMPTAM models)	33	R.	40
D7.3	Task-7.3	WP7	USFD	On-orbit forecasts of the energetic electron populations (orbit tool)	30	R.	37
D7.4	Task-7.4	WP7	USFD	Summary of the space weather environment (Environmental summary)	36	R.	43
D3.7	Task-3.7	WP3	SRI, USFD, IRF	Development and testing of Guaranteed NARMAX and bi-linear models	43	R.	new

TODAY

- To hear about the latest Deliverables and
- To see the products from the PROGRESS Project.
- …

WP2 - Propagation of the Solar Wind from the Sun to L1

- **WP2 - Propagation of the Solar Wind from the Sun to L1** [Months: 1-36], **UW**, USFD, UM
  Work package leader: T. D. Arber (UW)
  Participants: K. Bennett (UW), B. van der Holst (UM), M. Liemohn (UM), Post-Doc (UM)

- **Background:**
- Accurate forecast of the southward interplanetary magnetic field (IMF) is critically important, as it allows for space weather predictions of the intensity of the ensuing geomagnetic storm and would minimize false alarms. In the coming years, the Sun's activity will decline towards solar minimum. During solar minimum, the geomagnetic and auroral activity is mostly due to southward Bz of Corotating Interaction Region (CIR) events. For space weather operational forecast it is critically important to have reliable knowledge of the IMF Bz and other solar wind parameter at L1 before these are measured in situ. This work package will deliver this data by coupling magnetograms of the solar surface to coronal physics models (AWSoM – Alfven Wave Solar Atmosphere Model). These coronal physics simulations will provide the key MHD input parameters to a solar wind inner heliospheric code with the codes coupled at about 30 solar radii. The inner heliospheric codes (SWIFT - Solar Wind Flux Transfer) will use two-temperature MHD to transport the magnetic flux and fluid variables in spherical geometry out to L1 and beyond where they can be used as drivers for space weather predictions. UW has MHD shock capturing codes that are optimized for 3D Cartesian grids, the Lare3d code, and 2D arbitrary geometry ALE grids, the Odin code. SWIFT will combine features of both of these codes by using a fixed, but spherical, grid which extends radially from ~30 solar radii out to at least L1. This will take advantage of the optimized scheme for fixed grids of Lare3d combined with the two-temperature, arbitrary grid MHD schemes used in the more general Odin code. UM has a solar coronal model (AWSoM) that uses magnetograms to simulate the full three-dimensional magnetic field topology and plasma state of the corona. AWSoM uses a stretched spherical grid to resolve the upper chromosphere, transition region and corona accurately. AWSoM is part of the overarching Space Weather Modeling Framework (SWMF), which can couple various space weather models in one single tool. SWMF will be used to couple the AWSoM corona model to the University of Warwick SWIFT model for the inner heliosphere.

WP2 - Propagation of the Solar Wind from the Sun to L1

- Specific tasks:
- **Task 2.1**: Convert Warwick MHD code into the spherical geometry SWIFT code. Month 1-6 (UW)
- **Task 2.2:** Make the AWSoM time accurate using hourly ingested magnetograms (using GONG data products) Month 1-9 (UM)
- **Task 2.3:** Extend SWIFT to a two-temperature model to allow shock heating of ions. Month 7-9 (UW)
- **Task 2.4:** Add improved electron heat transport Month 10-15 (UW, UM)
- **Task 2.5**: Couple inner boundary of SWIFT to the Michigan AWSoM coronal model. Month 16-21 (UW, UM)
- **Task 2.6:** Validate the AWSoM/SWIFT codes using historical magnetograms and ACE data. Month 19-27 (UW, UM, USD)
- **Task 2.7:** Run real-time test of predicted L1 variables based on coupled AWSoM/SWIFT codes. Month 25-36 (UW, UM)
- **Task 2.8**: Write developer and user manuals. Month 31-36 (UW, UM)

WP3 - Forecast of the evolution of geomagnetic indices

- **WP3 - Forecast of the evolution of geomagnetic indices** [Months: 1-43] **IRF**, USFD, SRI NASU-NSAU
  Work package leader: P. Wintoft (IRF)
  Participants: S. Walker (USFD), V. Yatsenko (SRI NASU-NSAU)

- **Background:**

- This WP concerns improvement and new development of models based on data driven modelling, such as CNN and NARMAX. Existing models for Dst and Kp will be analysed and verified with the aim of finding weaknesses and to suggest improvements. Solar wind and geomagnetic indices shall also be analysed in order to develop models for the identification of features, such as (but not limited to) shocks, sudden commencements, and substorms. Such categorisation will aid the model development and verification, and can also serve as alternative approach to models providing numerical input-output mapping. In addition to the development of Dst and Kp models new models will be developed to forecast AE. The models will be implemented for real-time operation at IRF and data and plots will be provided on a web server.

WP3 - Forecast of the evolution of geomagnetic indices

- Specific tasks:
- **Task 3.1:** Survey of existing operational models forecasting Kp, Dst, and AE. Month 1-3 (IRF,USFD**,** SRI NASU-NSAU)
- **Task 3.2:** Identify and collect relevant data. Month 4-6 (IRF)
- **Task 3.3:** Evaluate and verify a set of selected existing models. Month 7-9 (IRF, USFD, SRI NASU-NSAU)
- **Task 3.4:** Develop further existing Kp and Dst models. Month 10-24 (IRF, USFD, SRI NASU-NSAU)
- **Task 3.5:** Develop new AE forecast models Month 16-30 (IRF, USFD, SRI NASU-NSAU)
- **Task 3.6:** Implement models for real-time operation. Month 28-36 (IRF, USFD**,** SRI NASU-NSAU)
- **Task 3.7:** Development and testing of Guaranteed NARMAX and bi-linear models. Month 41-43 (SRI NASU-NSAU, USFD, IRF)

WP4 - Development of new statistical wave models and the re-estimation of the quasilinear diffusion coefficients

- **WP4 - Development of new statistical wave models and the re-estimation of the quasilinear diffusion coefficients.** [Months: 1-24] **CNRS**, USFD, GFZ
  Work package leader: V. Krasnoselskikh (CNRS/LPC2E)
  Participants: Y. Shpritz (SIST/UW/GPZ), S. Walker (USFD)
- **Background:**
- Statistical wave models for Chorus, hiss and equatorial magnetosonic mode are required to calculate the tensors of quasilinear diffusion coefficients that numerical codes such as VERB use to model the evolution of particle fluxes within the inner magnetosphere. Current models are parameterised by location and geomagnetic indices. This assumes that the wave distribution in the magnetosphere is independent of preceding evolution of the magnetosphere. There is no experimental basis to assume that the spatial wave distribution in the main phase of a particular storm is the same as during the recovery phase of the same or another storm if these periods are characterised by the same values of geomagnetic indices. In addition it is known that statistically the velocity and the density of the solar wind have greater influence on the energetic electrons fluxes at GEO than other parameters such as geomagnetic indices [Paulikas and Blake 1979; Blake et al., 1997; Lyatsky and Khazanov 2008; Reeves, et al., 2011; Balikhin, et al., 2011; Boynton, et al., 2013]. Since the solar wind velocity and density are statistically related to the dynamics of energetic fluxes, their inclusion to the set of organizing parameters of statistical wave models should be investigated. The technical problem that needs to be solved is to determine the time delay (time lag) between the change in, say, the solar wind velocity upstream of the magnetosphere and the possible effect of these changes on the wave distribution at a particular location. A similar problem exists for the determination of which time lags for previous values of the geomagnetic indices should be used to organise the statistical wave model. To overcome these problems the Error Reduction Ratio (ERR) analysis, which is the part of the NARMAX methodology, will be employed to identify the set of solar wind parameters and geomagnetic indices that affect the spatial distribution of key magnetospheric emissions. A distinct set of organizing parameters will be identified for each type of waves: chorus, hiss and equatorial magnetosonic waves. The resulting newly parameterised statistical wave models will provide a more realistic view of the occurrence of plasma waves within the magnetosphere and their association with solar wind perturbations. These new models will then be used to calculate new and more realistic sets of tensors of quasilinear diffusion coefficients and hence improve the forecasting ability of physical models such as VERB and IMPTAM.

WP4 - Development of new statistical wave models and the re-estimation of the quasilinear diffusion coefficients

Specific tasks:

- **Task 4.1:** Collection of data and the development of software for automatic identification of Chorus, hiss and equatorial magnetosonic emissions. Month 1-2 (CNRS/LPC2E, USFD)
- **Task 4.2:** Preparation of data sets for Error Reduction Ratio analysis. Month 3-6 (CNRS/LPC2E, USFD)
- **Task 4.3:** Error reduction analysis. Month 7-10 (USFD)
- **Task 4.4:** Development of the Statistical Wave Models and corresponding tensors of diffusion coefficients. Month 11-24 (CNRS/LPC2E, SIST/UW/GPZ)

WP5 - Low energy electrons model improvements to develop forecasting products

- **WP5 - Low energy electrons model improvements to develop forecasting products** [Months: 1-36] **FMI**, USFD, GFZ
  Work package leader: N. Ganushkina (FMI)
  Participants: Y. Shprits (SIST/UW/GFZ), (USFD)
- **Background:**
- The distribution of low energy electrons, the seed population (10 to few hundreds of keV), is critically important for radiation belt dynamics. This seed population is further accelerated to MeV energies by various processes. The electron flux at these energies is important for surface charging. The electron flux is largely determined by convective and inductive electric fields and varies significantly with substorm activity driven by the solar wind. Wave-particle interactions are very effective in precipitating electrons at energies of few hundred keV. Satellite measurements cannot provide continuous measurements at 10 to a few hundreds of keV at all MLT and L-shells. It is necessary to have a model that is able to specify the electron flux for all L shells for a given solar wind input and to provide the output of this model as an input for higher-energy radiation belt modeling. With the development of the Inner Magnetosphere Particle Transport and Acceleration model (IMPTAM) for low energy particles in the inner magnetosphere [Ganushkina et al., 2005, 2006, 2012] and the VERB full-diffusion code [Shprits et al., 2006b; 2008a, b], the computational view on the low energy electron fluxes important for radiation belts at L=2-10 is now feasible.
- Specific tasks:
- **Task 5.1**: Developing a solar wind and IMF driven model for low energy electrons in the plasma sheet. Month 1-12 (FMI, USFD)
- **Task 5.2:** Incorporating the proper diffusion coefficients into IMPTAM provided by VERB radiation belts model. Month 12-24 (FMI, SIST/UW/GFZ).
- **Task 5.3:** Providing the low energy seed population to VERB radiation belts model. Month 24-30 (FMI, SIST/UW/GFZ).
- **Task 5.4:** Developing a trial version of forecast model for low energy electrons. Month 24-36 (FMI, USFD, SIST/UW/GFZ, UM, IRF)

WP6 - Forecast of the radiation belt environment

- **WP6 - Forecast of the radiation belt environment** [Months: 1-30] **USFD**, FMI, UW, Skoltech, GFZ
  Work package leader: M. Balikhin (USFD)
  Participants: Y. Shprits (SIST/UW/GFZ), N. Ganushkina (FMI)
- **Background:**
- WP6 is devoted to pioneering development of a novel forecasting technique that is based on the fusion of empiric models deduced by NARMAX the most powerful and robust technique of the System Science [Balikhin et al., 2011, Boynton et al., 2013], the most advanced physics based numerical model of radiation belts VERB full-diffusion code [Shprits et al., 2006b; 2008a, b], and state of the art methodology of data assimilation. Data assimilation techniques can be used to improve the results of numerical models by incorporating physical measurements in order to constrain the output, These methods enable an optimal combination of model results and sparse measurements from various sources such as those available from satellites. Data assimilation enables the filling of temporal and spatial gaps left by sparse in-situ measurements by combining measurements from different spacecraft whose instrumental characteristics are quite different. PROGRESS will use data assimilation techniques, based on Kalman filters, to improve the forecasts produced by VERB. Current physics based models have the advantage of being able to model the processes in the whole region of the radiation belts. However, the complexity of radiation belt dynamics involves a chain of simultaneous processes operating over an enormous range of space scales from scales of wave-particle interactions to the scale of magnetopause shadowing, hinders the performance of current physics based models. The data based SNB3GEO model provides reliable forecast at GEO but because of the lack of continuous data outside GEO cannot be extended in the whole region of the radiation belts. In this WP we will significantly improve both models by extending range of energies predicted SNB3GEO and increasing its rate of prediction. WP6 will follow the ideology of meteorological forecasts by incorporating data assimilation methodologies to exploit the vast quantity of data from the fleet of the magnetospheric spacecraft. In addition, the novel advanced tensors of the diffusion coefficients that will be developed in WP4 will be incorporated in the VERB code. The ultimate goal of WP6 is couple the data based NARMAX methodology with the first principle based approach utilized by VERB to the develop a hybrid model that will have advantages of the both: forecast accuracy matching that of SNB3GEO and spatial coverage of VERB.
- Specific tasks:
- **Task 6.1:** NARMAX modelling of energetic electron fluxes at GEO. Month 1-6 (USFD)
- **Task 6.2:** Data assimilation extension for VERB. Month 1-26 (SIST/UW/GFZ).
- **Task 6.3:** Development of the coupled VERB-NARMAX model (VNC). Month 7-30 (USFD, SIST/UW/GFZ)

WP7 - Fusion of forecasting tools

- **WP7 - Fusion of forecasting tools** [Months: 18-36] **USFD**, FMI, UW, IRF, GFZ
  Work package leader: S. Walker (USFD)
  Participants: UW, FMI, IRF
- **Background:**
- Data fusion is the methodology of combining inputs from different sources in such a way that the output of this process results in a data set that is more complete, accurate, and reliable than any of the individual input data sources. Work packages 2 - 6 involve the development of individual models to forecast space weather events. Each model provides some forecast of how the particular parameter modelled will evolve in the near future. In WP 7 we will bring them all together, within a single system, to generate a more complete picture of the evolution of the magnetosphere in general and the radiation belts in particular. Thus, all of the results from the project will be available from within a single interface accessed from the project web site.
- Specific tasks:
- **Task 7.1:** Implementation of models for geomagnetic indices and electron flux forecasts at USFD. Month 18-30 (USFD,IRF)
- **Task 7.2**: Implementation of VERB-NARMAX and VERB-IMPTAM models. Month 22-33 (USFD,SIST/UW/GFZ)
- **Task 7.3:** Orbit tool. Month 27-30 (USFD,SIST/UW/GFZ,FMI)
- **Task 7.4**: Environmental summary Month 30-36 (USFD)

WP8 - Dissemination

- **WP8 - Dissemination** [Months: 1-36] **USFD**, FMI, UW, Skoltech, UM, SRI NASU-NSAU , CNRS, IRF, GFZ
  Work package leader: R. von Fay-Siebenburgen (USFD)
  Participants: All partners
- **Background:**
- The timely dissemination of results is an essential activity of project PROGRESS. The level and content of any dissemination activity needs to be targeted to the specific audience for whom the results are intended in order to maximize their benefit. The target audiences identified include the project participants, scientists working in the fields addressed by this project, stakeholders, and the general public. Identification of the various groups will enable dissemination activities to be specifically tailored to maximise the information flow.
- Specific tasks:

- Establish project web site for public and project only access.
- Identify any newsworthy space weather events how they fit within the work of the Project
- Identify potential stakeholders, inviting them to join the project as members of the SAB.
- Record all science publications and presentations and, subject to copyright, make them available via the project web page.
- Coordinate the activities of project PROGRESS with other EU funded projects, the ESA Space Situational Awareness programme, and the ESA Space Weather Working Team.
- Presentations of results at scientific meetings such as AGU, EGU, COSPAR, ESWW.
- Organisation/joint organisation of specific conference sessions.
- Organisation of summer school to introduce students to space weather, its effects, how to model its effects, and the results of the Project.

Objective

- The smooth functioning of the European economy and the welfare of its citizens depends upon an ever-growing set of services and facilities that are reliant on space and ground based infrastructure. Examples include communications (radio, TV, mobile phones), navigation of aircraft and private transport via GPS, and service industries (e.g. banking). These services, however, can be adversely affected by the space weather hazards. The forecasting of space weather hazards, driven by the dynamical processes originating on the sun, is critical to the mitigation of their negative effects.
- This proposal brings world leading groups in the fields of space physics and systems science in order to develop an accurate and reliable forecast system for space weather.
- It combines their individual strengths to significantly improve the current modelling capabilities within Europe and to produce a set of forecast tools to accurately predict the occurrence and severity of space weather events.
- **Within project PROGRESS we will develop an European tool to forecast the solar wind parameters just upstream of the Earth's magnetosphere**.
- We will develop a comprehensive set of forecasting tools for geomagnetic indices.
- We will combine the most accurate data based forecast of electron fluxes at GEO with the most comprehensive physics based model of the radiation belts currently available to deliver a reliable forecast of radiation environment in the radiation belts.
- This project will deliver these individual forecast tools together with a unified tool that combines the forecasting tools with the prediction of the solar wind parameters at L1 to substantially increase the lead-time of space weather forecasts.

Participants

ILMATIETEEN LAITOS, Finland

THE UNIVERSITY OF WARWICK, United Kingdom

SKOLKOVO INSTITUTE OF SCIENCE AND TECHNOLOGY, Russia

UNIVERSITY OF MICHIGAN THE REGENTS OF THE UNIVERSITY OF MICHIGAN, United States

SPACE RESEARCH INSTITUTE OF THE NATIONAL ACADEMY OF SCIENCES OF UKRAINE AND THE NATIONAL SPACE AGENCY OF UKRAINE, Ukraine

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS, France

INSTITUTET FOR RYMDFYSIK, Sweden

HELMHOLTZ ZENTRUM POTSDAM DEUTSCHESGEOFORSCHUNGSZENTRUM GFZ, Germany

Country	# of inst
Finland	1
UK	2
Russia	1
USA	1
Ukraine	1
France	1
Sweden	1
Germany	1
	9