PROTEC-1-2014: Space Weather

Grant agreement for: Research and Innovation action

Annex 1 - Description of Action

Action acronym: PROGRESS

Action full title: "Prediction of Geospace Radiation Environment and solar wind parameters"

Grant agreement no: 637302

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1.1. The project summary

Project Number [1]	637302	Project Acronym [2]	PROGRESS

One form per project

General information	
Project title [3]	Prediction of Geospace Radiation Environment and solar wind parameters
Starting date [4]	01/01/2015
Duration in months [5]	36
Call (part) identifier [6]	H2020-PROTEC-2014
Topic	PROTEC-1-2014 Space Weather
Fixed EC Keywords	Space weather
Free keywords	forecast, geomagnetic indices, electron fluxes, radiation belts, solar wind

Abstract [7]

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.

1.2. List of Beneficiaries

Project Number [1]	637302	Project Acronym [2]	PROGRESS

List of Beneficiaries

No	Name	Short name	Country	Project entry month[8]	Project exit month
1	THE UNIVERSITY OF SHEFFIELD	USFD	United Kingdom	1	36
2	ILMATIETEEN LAITOS	FMI	Finland	1	36
3	THE UNIVERSITY OF WARWICK	UW	United Kingdom	1	36
4	SKOLKOVO INSTITUTE OF SCIENCE AND TECHNOLOGY	Skoltech	Russian Federation	1	36
5	UNIVERSITY OF MICHIGAN THE REGENTS OF THE UNIVERSITY OF MICHIGAN	UM	United States	1	36
6	SPACE RESEARCH INSTITUTE OF THE NATIONAL ACADEMY OF SCIENCES OF UKRAINE AND THE NATIONAL SPACE AGENCY OF UKRAINE	SRI NASU-NSAU	Ukraine	1	36
7	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	CNRS	France	1	36
8	INSTITUTET FOR RYMDFYSIK	IRF	Sweden	1	36

1.3. Workplan Tables - Detailed implementation

1.3.1. WT1 List of work packages

WP Number [9]	WP Title	Lead beneficiary [10]	Person-months [11]	Start month [12]	End month [13]
WP1	Management	1 - USFD	9.00	1	36
WP2	Propagation of the Solar Wind from the Sun to L1	3 - UW	47.00	1	36
WP3	Forecast of the evolution of geomagnetic indices	8 - IRF	87.00	1	36
WP4	Development of new statistical wave models and the re-estimation of the quasilinear diffusion coefficients.	7 - CNRS	34.00	1	24
WP5	Low energy electrons model improvements to develop forecasting products	2 - FMI	41.00	1	36
WP6	Forecast of the radiation belt environment	1 - USFD	30.00	1	30
WP7	Fusion of forecasting tools	1 - USFD	18.00	18	36
WP8	Dissemination	1 - USFD	16.00	1	36
		Total	282.00		

1.3.2. WT2 list of deliverables

Deliverable Number [14]	Deliverable Title	WP number [9]	Lead beneficiary	Type [15]	Dissemination level [16]	Due Date (in months) [17]
D1.1	Minutes of First Stakeholder meeting	WP1	1 - USFD	Report	Confidential, only for members of the consortium (including the Commission Services)	14
D1.2	Minutes of Second Stakeholder meeting	WP1	1 - USFD	Report	Confidential, only for members of the consortium (including the Commission Services)	26
D1.3	Minutes of Final Stakeholder meeting	WP1	1 - USFD	Report	Confidential, only for members of the consortium (including the Commission Services)	36
D2.1	Conversion of SWIFT to spherical geometry	WP2	3 - UW	Report	Public	12
D2.2	The coupling of the AWSoM and SWIFT codes	WP2	3 - UW	Report	Public	20
D2.3	SWIFT documentation	WP2	3 - UW	Report	Public	36
D3.1	Existing Dst, Kp, and AEmodels	WP3	8 - IRF	Report	Public	3
D3.2	Collection of data sets	WP3	8 - IRF	Report	Public	6
D3.3	Model verification	WP3	8 - IRF	Report	Public	9
D3.4	Kp and Dst models	WP3	8 - IRF	Report	Public	24
D3.5	AE models	WP3	8 - IRF	Report	Public	30
D3.6	Real-time model implementation	WP3	8 - IRF	Report	Public	36
D4.1	Data availability and list of chosen locations for each wave emission	WP4	7 - CNRS	Report	Public	2
D4.2	The database of wave occurrence.	WP4	7 - CNRS	Report	Public	6
D4.3	Results of the Error Reduction Ratio analysis	WP4	7 - CNRS	Report	Public	10
D4.4	Final version of the statistical wave models	WP4	7 - CNRS	Report	Public	24

Deliverable Number [14]	**Deliverable Title**	**WP number** [9]	**Lead beneficiary**	**Type** [15]	**Dissemination level** [16]	**Due Date (in months)** [17]
D5.1	Solar wind drivers of low energy plasmasheet electrons	WP5	2 - FMI	Report	Public	12
D5.2	The incorporation of diffusion coefficients from VERB into IMPTAM	WP5	2 - FMI	Report	Public	24
D5.3	The VERB-IMPTAM low energy seed population	WP5	2 - FMI	Report	Public	26
D5.4	Trial version of forecast model for low energy electrons	WP5	2 - FMI	Report	Public	36
D6.1	NARMAX models of electron fluxes sat GEO	WP6	1 - USFD	Report	Public	6
D6.2	Use of data assimilation technique within VERB code model	WP6	4 - Skoltech	Report	Public	26
D6.3	Results of the VNC model and two methods of model couplings	WP6	1 - USFD	Report	Public	30
D7.1	The results of individual forecasts of geomagnetic indices	WP7	1 - USFD	Report	Public	30
D7.2	Forecasts of the energetic electron populations within the inner magnetosphere	WP7	1 - USFD	Report	Public	33
D7.3	On orbit forecasts of the energetic electron populations	WP7	1 - USFD	Report	Public	30
D7.4	Summary of the space weather environment	WP7	1 - USFD	Report	Public	36
D8.1	Project web site	WP8	1 - USFD	Websites, patents filling, etc.	Public	3
D8.2	Exploitation and Dissemination Plan	WP8	1 - USFD	Report	Public	24

1.3.3. WT3 Work package descriptions

Work package number [9]	WP1	**Lead beneficiary** [10]	1 - USFD
Work package title	Management		
Start month	1	**End month**	36

Objectives

To ensure the smooth running of scientific, administrative, and financial aspects of the project.

Description of work and role of partners

WP1 - Management [Months: 1-36]
USFD
Work package leader: R. von Fay-Siebenburgen (USFD)
Participants: Simon Walker (USFD)
Background:
Whilst the Scientific Steering Committee (chaired by the Project Coordinator) is responsible for the scientific direction of the project the day-to-day management of the project will be handled by the Project Manager (PM). The PM will ensure the timely dissemination of information to the Committees, Work Package Leaders, researchers, and other collaborators and help to maintain communications between all participants and other external bodies as required. The PM will also organise project related meetings such as SSC, SAB, as well as preparation for review meetings with the Commission. He will also provide editorial support where required and be responsible (in conjunction with the Coordinator) for the archiving of reports and other project related information.
Financial and contractual issues will be handled by the Coordinator/Project Manager in association with the University of Sheffield Research and Innovation Services (RIS) department. Over the years, RIS has helped to manage numerous EU projects within the framework of FP6 and FP7.

Specific Tasks:
- Organise, attend, and record meetings with the Scientific Steering Committee
- Organise, attend, and record meetings with the Stakeholder Advisory Board
- Organise, attend, and record meetings with the Commission
- Ensure dissemination of meeting reports to the project participants
- Produce end of year and end of project reports for the Commission
- Manage project funds and monitor participant spending
- Monitor progress of workpackages and submission of deliverables to the Commission

Summary of facilities available at host:
University infrastructure to support project management and financial management (RIS).
Summary of funding requirements:
Funding is required to support the Coordinator and Project Manager, together with travel and subsistence to enable them to attend project related meetings.

Participation per Partner

Partner number and short name	WP1 effort
1 - USFD	9.00
Total	9.00

List of deliverables

Deliverable Number [14]	Deliverable Title	Lead beneficiary	Type [15]	Dissemination level [16]	Due Date (in months) [17]
D1.1	Minutes of First Stakeholder meeting	1 - USFD	Report	Confidential, only for members of the consortium (including the Commission Services)	14
D1.2	Minutes of Second Stakeholder meeting	1 - USFD	Report	Confidential, only for members of the consortium (including the Commission Services)	26
D1.3	Minutes of Final Stakeholder meeting	1 - USFD	Report	Confidential, only for members of the consortium (including the Commission Services)	36

Description of deliverables

The deliverables represent the result of discussions between the Project and the Stakeholder Advisory Board on the direction of the Project and the applicability of its results from an industrial stand point.

D1.1 : Minutes of First Stakeholder meeting [14]

This report will be a record of discussions at the first Stakeholder Advisory Board meeting

D1.2 : Minutes of Second Stakeholder meeting [26]

This report will be a record of discussions at the second Stakeholder Advisory Board meeting

D1.3 : Minutes of Final Stakeholder meeting [36]

This report will be a record of discussions at the final Stakeholder Advisory Board meeting

Schedule of relevant Milestones

Milestone number [18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification

Work package number [9]	WP2	**Lead beneficiary** [10]	3 - UW
Work package title	Propagation of the Solar Wind from the Sun to L1		
Start month	1	**End month**	36

Objectives

Forecast of solar wind transients and solar wind parameters at L1: modelling, forecast and model validation

Description of work and role of partners

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 optimised 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 optimised 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.

Specific tasks:

Task 2.1 Convert Warwick MHD code into the spherical geometry SWIFT code.
Month 1-6 (UW)
The UW Lare3d code [Arber et al. 2001] is a Lagrangian remap code in Cartesian geometry. It is essential that this is converted to spherical geometry for solar wind studies. This work involves low-level changes to both the Lagrangian and remap steps. In addition the compatible, mimetic shock viscosity [Campbell et al. 2001] used for Lare3d needs to be customised for a fixed spherical grid. These developments will be logged through a UW maintained source control management (SCM) repository to which researchers at UM will have access.

Task 2.2 Make the AWSoM time accurate using hourly ingested magnetograms (using GONG data products)
Month 1-9 (UM)
AWSoM will be adapted to stream data from the GONG network and use this as a driver, interpolating magnetograms if needed, for real-time coronal simulations. This work will include the modelled turbulence and transport of AWSoM across the steep density/temperature gradients of the lower atmosphere requiring HPC resources

Task 2.3 Extend SWIFT to a two-temperature model to allow shock heating of ions.
Month 7-9 (UW)
Moving from single temperature to two-temperature models is essential to allow the ions to be heated by shocks. This requires two separate energy equations to be implemented in the Lagrangian phase in which the shock heating is applied

only to the ions. During the Lagrangian phase PdV heating will be distributed between species based on fractions of total pressure.

Task 2.4 Add improved electron heat transport
Month 10-15 (UW, UM)
With separate ion and electron temperatures it is now possible to improve the modelling of the electron transport. A common approach to use a saturated electron heat transport [J.V. Hollweg, 1978]. This will be compared with similar techniques used in high energy density physics [Schurtz et al. 2001] and the optimal scheme adopted.

Task 2.5 Couple inner boundary of SWIFT to the Michigan AWSoM coronal model.
Month 16-21 (UW, UM)
Output from the AWSoM code can be taken once the solar wind is super-Alfvenic and used to drive the inflow on the inner boundary of SWIFT. This requires rezoning data from mismatched grids and time-steps and will be handled via the SWMF coupling toolkit. At the end of this process the codes will be made available to other work packages via the Warwick SCM repository.

Task 2.6 Validate the AWSoM/SWIFT codes using historical magnetograms and ACE data.
Month 19-27 (UW, UM, USD)
Extensive validation of the coupled codes is essential for confidence of the whole forecast package. Using historical data from GONG to predict the corresponding data measurements from Mercury MESENGER, Venus Express, and ACE will allow the team to tune, optimise and validate the AWSoM/SWIFT codes.

Task 2.7 Run real-time test of predicted L1 variables based on coupled AWSoM/SWIFT codes.
Month 25-36 (UW, UM)
Begin real-time predictions with extensive runs of the MHD models stress test the codes, increase the confidence in the code validation and provide long-time series data for downstream magnetospheric work packages. For this data from GONG will be streamed into AWSoM whose output is then used to drive SWIFT. The final SWIFT output will be made available to other work packages via publically accessible ftp servers. The SWIFT code will run continuously on a dedicated server class workstation at UW. Throughout this time the codes will continue to be optimised for speed and resilience of data transfer as well as basic simulation accuracy. Real-time runs of AWSoM requires ~120 cores, real-time runs of SWIFT require ~10 cores of HPC.

Task 2.8 Write developer and user manuals.
Month 31-36 (UW, UM)
Throughout the code development required for PROGRESS the SWIFT code will maintain embedded Doxigen documentation. This level of documentation is ideal for developers but lacks the high level overview needed by users. In the final six moths a detailed user guide and fully documented validation tests will supplement this. Regression test suites for SWIFT will also be included as part of the documentation set.

Summary of facilities available at hosts:
Researchers at Warwick have access to a university 6000 core high bandwidth, low latency Linux cluster for testing, profiling and optimizing SWIFT. This is through Warwick's Centre for Scientific Computer of which Arber is a core member.

Summary of funding requirements:
Funding is required at Warwick to support code development (18 months Bennett and 8 months Arber). Travel for project meetings and annual reviews. We request funding for Arber and Bennett to visit UM for one week to work on code integration and validation.
Funding is required at UM to support code development (18 months unnamed Post-Doc, 1 month per year van der Holst, and 1 week per year Liemohn). Travel for annual reviews.

Participation per Partner

Partner number and short name	WP2 effort
1 - USFD	1.00
3 - UW	26.00
5 - UM	20.00

Partner number and short name	WP2 effort
Total	47.00

List of deliverables

Deliverable Number [14]	Deliverable Title	Lead beneficiary	Type [15]	Dissemination level [16]	Due Date (in months) [17]
D2.1	Conversion of SWIFT to spherical geometry	3 - UW	Report	Public	12
D2.2	The coupling of the AWSoM and SWIFT codes	3 - UW	Report	Public	20
D2.3	SWIFT documentation	3 - UW	Report	Public	36

Description of deliverables

The deliverables for WP2 document the important phases in the production and testing of the SWIFT code.

D2.1 : Conversion of SWIFT to spherical geometry [12]

This report outlines the process by which the SWIFT code is converted to use a spherical geometry.

D2.2 : The coupling of the AWSoM and SWIFT codes [20]

This report outlines the process of coupling the AWSoM and SWIFT codes.

D2.3 : SWIFT documentation [36]

This deliverable will provide full user and developer documentation plus regression test suite for the SWIFT code developed within Project PROGRESS.

Schedule of relevant Milestones

Milestone number [18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS5	Availabity of AWSoM/SWIFT for testing within the consortium.	3 - UW	20	The AWSoM/SWIFT generated as part of WP2 will be made available to consortium members for testing.

Work package number [9]	WP3	**Lead beneficiary** [10]	8 - IRF
Work package title	Forecast of the evolution of geomagnetic indices		
Start month	1	**End month**	36

Objectives

The objective of this WP is to provide forecast of Dst, KP and AE from L1 as measured by ACE.

Description of work and role of partners

WP3 - Forecast of the evolution of geomagnetic indices [Months: 1-36]
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.

Specific tasks:

Task 3.1 – Survey of existing operational models forecasting Kp, Dst, and AE.
Month 1-3 (IRF,USFD,SRI NASU-NSAU)
Identify existing operational Kp, Dst, and AE forecast models. Analyse their respective requirements and benefits considering, e.g. inputs, latency, lead time, and resources. Detailed knowledge is available for the models available to the team.

Task 3.2 - Identify and collect relevant data
Month 4-6 (IRF)
Collect historic real time ACE data, Science Level 2 ACE data, Kp, Dst, and AE. An SQL database shall be set up where the data are collected. Analyse data sets with respect to quality and coverage. Also include the coming DSCOVR spacecraft in the study.

Task 3.3 - Evaluate and verify a set of selected existing models.
Month 7-9 (IRF, USFD, SRI NASU-NSAU)
The models from Task 3.1 that are available to the team shall be verified using the datasets identified in Task 3.2. In this activity it is important to consider both science level data and real time data. This task also includes the identification and application of appropriate verification methodologies. As inputs methodologies from the meteorological domain [Jollife and Stephenson, 2012] and previous COST ES0803 Action [Wintoft et al., 2012] shall be used.

Task 3.4 - Develop further existing Kp and Dst models.
Month 10-24 (IRF, USFD, SRI NASU-NSAU)
The verification carried out in Task 3.3 will provide insights on how to improve existing Kp and Dst models. Classifications and categorisation methods will also be developed and applied with the purpose of improving existing models. The formulated verification strategy (Task 3.3) shall also be applied to the models.

Task 3.5 - Develop new AE forecast models
Month 16-30 (IRF, USFD, SRI NASU-NSAU)
As a first step to provide a baseline the model in Gleisner and Lundstedt [2001] shall be implemented and verified (Task 3.3). The classifications and categorisation methods (Task 3.4) shall also be applied to provide insight to appropriate parametrisation of the high resolution (minute) solar wind and AE data. E.g., the approach in Gleisner and Lundstedt [2001] was to use 10 minute averages, however, averages are not always the most suitable way of reducing the

complexity as important features may be missed. Again, the formulated verification strategy (Task 3.3) shall also be applied to the models.

Task 3.6 - Implement models for real-time operation.
Month 28-36 (IRF, USFD, SRI NASU-NSAU)
The improved and developed models shall be implemented for real time operation. The contributing institutes have long experience in this field. The data needed to drive the models shall be downloaded and stored in the database in real time. Various checks considering data quality and timeliness shall be implemented and mitigated. The output from the models shall be stored in the database and also provided over ftp/http. Simple web site with the forecasts shall be implemented tailored for this project.

Summary of facilities available at hosts:
IRF-Lund has all the necessary computing and software facilities to retrieve, store, and analyse solar-terrestrial and space weather data. Data are analysed using Matlab, IDL, and Mathematica. Several software tools have been developed to make statistical analysis, wavelet analysis, and neural network models. Since several years we store data in SQL databases, this facilitates an organised approach to data storage and greatly improves on the accessibility of data. Several models runs automatically and are accessible over the Internet. The models are typically implemented using Java, Gnuplot, Matlab, Python, BASH, PHP, or Perl, or a combination thereof.

Summary of funding requirements:
It is expected that two scientists from IRF will take part in this WP spending in total 34 man-months. One person will take part in the 7 planned PMs.

Participation per Partner

Partner number and short name	WP3 effort
1 - USFD	15.00
6 - SRI NASU-NSAU	38.00
8 - IRF	34.00
Total	87.00

List of deliverables

Deliverable Number [14]	Deliverable Title	Lead beneficiary	Type [15]	Dissemination level [16]	Due Date (in months) [17]
D3.1	Existing Dst, Kp, and AEmodels	8 - IRF	Report	Public	3
D3.2	Collection of data sets	8 - IRF	Report	Public	6
D3.3	Model verification	8 - IRF	Report	Public	9
D3.4	Kp and Dst models	8 - IRF	Report	Public	24
D3.5	AE models	8 - IRF	Report	Public	30
D3.6	Real-time model implementation	8 - IRF	Report	Public	36

Description of deliverables

The deliverables for WP3 provide reports on the current models for geomagnetic indices available at the beginning of the Project and the further development of these and also new models.

D3.1 : Existing Dst, Kp, and AEmodels [3]

This report provides a survey of the currently existing models for the geomagnetic indices Dst, Kp, and AE that are used for forecasts at the beginning of the Project.

D3.2 : Collection of data sets [6]

This report provides details regarding the collection of historical data sets that are required by the Dst, Kp, and AE models as well as the actual indices themselves for comparison with the model output.

D3.3 : Model verification [9]

This report outlines the results of the verification of the models previously identified in Task 3.1 using the data collected in Task 3.2 using various methodologies.

D3.4 : Kp and Dst models [24]

This report will discuss the further developments to existing Dst and Kp models.

D3.5 : AE models [30]

This report outlines the development and results of new models for the AE index.

D3.6 : Real-time model implementation [36]

This report will present details of the real time online operation of the Dst, Kp, and AE models.

Schedule of relevant Milestones

Milestone number [18]	**Milestone title**	**Lead beneficiary**	**Due Date (in months)**	**Means of verification**
MS2	Availability of models for Kp, Dst, and AE	8 - IRF	18	Availability of models for Kp, Dst, and AE

Work package number [9]	WP4	**Lead beneficiary** [10]	7 - CNRS
Work package title	Development of new statistical wave models and the re-estimation of the quasilinear diffusion coefficients.		
Start month	1	**End month**	24

Objectives

The objectives of this WP is to redevelop statistical wave models for whistler mode Chorus, hiss and equatorial magnetosonic waves, that are parameterised by geomagnetic index (KP,AE), solar wind velocity and density and accounts for the previous evolution these parameters.

Description of work and role of partners

WP4 - Development of new statistical wave models and the re-estimation of the quasilinear diffusion coefficients. [Months: 1-24]
CNRS, USFD, Skoltech
Work package leader: V. Krasnoselskikh (CNRS/LPC2E)

Participants: Y. Shpritz (Skoltech), 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.

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)
Wave data from Double Star-TC1 will be provided to LPC2E by USFD in addition to the data from DE-1, CRRES, POLAR, Akebono, Cluster, THEMIS, are already available in CNRS/LPC2E. This will be augmented with solar wind data sets freely available from NASA Omniweb, geomagnetic indices (Kp, Dst, AE) from the World Data Centre for geomagnetism in Kyoto. A representative subset of locations for each wave emission type (Chorus, hiss, equatorial magnetosonic) will be identified for the subsequent Error Reduction Analysis. This set of locations will be subdivided into two groups, one to use for the modelling and the other for model validation.

Task 4.2 Preparation of data sets for Error Reduction Ratio analysis

Month 3-6 (CNRS/LPC2E, USFD)
For each location determined in task 4.1 CNRS/LPC2E will use their software for the automatic detection of Chorus, hiss, and EMW to identify occurrences of the corresponding emission. Sufficient number of emission occurrences for reliable application of Error Reduction Analysis will be identified (at least a few thousands). For each emission type the database organised by location that contains the wave amplitude and time of their occurrence will be developed. It is known that the obliqueness of waves can crucially change the characteristics of particle diffusion and losses especially due to chorus waves [Artemiev et al., 2013], the parameterization will take this effect into account.

Task 4.3 Error reduction analysis.
Month 7-10 (USFD)
For each location the Error Reduction Ratio analysis will be employed to identify the parameters and associated time lags that have greatest influence on the magnitude of the corresponding emission. In the application of Error Reduction Ratio analysis wave magnitudes will be considered as outputs and solar wind velocity, density and geomagnetic indices as inputs. For each emission type the results of the Error Reduction Ratio analysis will be compared quantitatively to identify an optimal set of parameters that are effective at controlling the mode from a global perspective. The size of the set of final parameters will be small enough to ensure that the resulting wave models are statistically significant.

Task 4.4 Development of the Statistical Wave Models and corresponding tensors of diffusion coefficients.
Month 11-24 (CNRS/LPC2E, Skoltech)
Based on the final set of parameters identified by ERR from Task 4.3 the whole wave data set will be reanalysed to generate new statistical models for the occurrence of Chorus, hiss and EMW.

Summary of facilities available at hosts:
CNRS/LPC2E already possesses much of the data required for these tasks as well as the algorithms to identify different wave emissions. Recently our group has actively worked on creation of the data base of wave measurements onboard Cluster, THEMIS, Polar, DE and Akebono satellites in the Earth magnetosphere with special attention to the vicinity of the radiation belts. This data base contains information on the statistical distribution of wave observations, including the probability of observations, amplitude of electric and magnetic field distributions upon several parameters such as the L-shell, MLT, and geomagnetic indices.
The activities to be performed by CNRS/LPC2E in the course of this work package will undertaken in the form on a collaboration between the work package leader, V Krasnoselskikh, and Dr. Oleksiy Agapitov from the Space Sciences Laboratory, The University of California, Berkeley, USA. The tasks performed by Dr. Agapitov will be carried out gratis i.e. at no expense to the Commission.

Summary of funding requirements:
Salaries for V. Krasnoselskikh, researcher and student.
Travel and subsistence to attend project meetings
Travel and subsistence to attend scientific conferences for dissemination of results
Publication fees

Participation per Partner

Partner number and short name	WP4 effort
1 - USFD	6.00
4 - Skoltech	8.00
7 - CNRS	20.00
Total	34.00

List of deliverables

Deliverable Number [14]	**Deliverable Title**	**Lead beneficiary**	**Type** [15]	**Dissemination level** [16]	**Due Date (in months)** [17]
D4.1	Data availability and list of chosen locations for each wave emission	7 - CNRS	Report	Public	2
D4.2	The database of wave occurrence.	7 - CNRS	Report	Public	6
D4.3	Results of the Error Reduction Ratio analysis	7 - CNRS	Report	Public	10
D4.4	Final version of the statistical wave models	7 - CNRS	Report	Public	24

Description of deliverables

The deliverables associated with WP4 outline the data sets, methodology, and development of the statistical wave models

D4.1 : Data availability and list of chosen locations for each wave emission [2]

This report outlines the availability of data sets that will be used to construct the wave models and provide a list of the chosen locations at which the models are evaluated for each wave emission.

D4.2 : The database of wave occurrence. [6]

This report describes the organisation of the database to store information regarding the occurrence of the various modes of plasma wave activity.

D4.3 : Results of the Error Reduction Ratio analysis [10]

This deliverable is a journal paper ready for submission on the results of the Error Reduction Ratio analysis.

D4.4 : Final version of the statistical wave models [24]

This deliverable consists of the final version of the statistical wave models

Schedule of relevant Milestones

Milestone number [18]	**Milestone title**	**Lead beneficiary**	**Due Date (in months)**	**Means of verification**
MS3	Statistical wave models	7 - CNRS	24	Statistical wave models

Work package number [9]	WP5	**Lead beneficiary** [10]	2 - FMI
Work package title	Low energy electrons model improvements to develop forecasting products		
Start month	1	**End month**	36

Objectives

The objectives of WP 5 are:

- Develop an empirical solar wind and IMF driven model for low energy electrons in the plasma sheet;
- Adapt the IMPTAM to include proper diffusion coefficients provided by VERB radiation belts model;
- Provide the low energy seed population to VERB radiation belts model;
- Develop a trial version of forecast model for low energy electrons.

Description of work and role of partners

WP5 - Low energy electrons model improvements to develop forecasting products [Months: 1-36]
FMI, USFD, Skoltech
Work package leader: N. Ganushkina (FMI)

Participants: Y. Shpritz (Skoltech), (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)
Low energy electrons are followed in IMPTAM from the plasma sheet at 10 Re to the inner magnetosphere regions. It is crucially important to have accurate solar wind and IMF driven boundary conditions in the plasma sheet. So far, IMPTAM has been using kappa distribution function for electrons with n and T parameters adapted from the empirical model derived from Geotail data by Tsyganenko and Mukai [2003] for ions with the same number density Te/Ti = 0.2. Set like this, the model for boundary conditions has a number of limitations. We will construct an empirical model for boundary conditions for low energy (from a few to tens of keVs) electron fluxes at L=8-10 dependent on solar wind and IMF parameters using the available data from the satellites including Polar HYDRA DDEIS (10 eV-10 keV), Cluster PEACE (0.7 eV-32 keV), THEMIS ESA (eV-30 keV) and Allen probes HOPE (20 eV-45 keV). Geostationary measurements at GOES MAGED (40-150 keV), LANL MPA (3–45 keV) and SOPA (50-200 keV) (when available). will be used to verify the model when tracing the electrons with the developed boundary distribution at L=8-10 and comparing the modeled fluxes with the observed ones at 6.6 Re.

Task 5.2 – Incorporating the proper diffusion coefficients into IMPTAM provided by VERB radiation belts model
Month 12-24 (FMI, Skoltech)
Wave-particle interactions play an important role in the variations of the electron fluxes, they have to be incorporated into the IMPTAM model via diffusion coefficients. At present, only electron lifetimes are taken into account following Shprits et al. [2007]. However Shprits et. al.,[2007] accounted only for the first order resonance and used a very simplified model of waves. Lower energy electron scattering is dominated by the Landau resonance that is mission in this formulation. The proper incorporation of wave-particle interactions is now possible due to the existence of Full Diffusion Code (FDC) model [Shprits and Ni., 2009;], which provides the diffusion coefficients and can now calculate

them in a non-dipole field [Orlova et al., 2012]. The matrix of diffusion coefficients as a function of L-shell, pitch-angle, and energy for various levels of geomagnetic activity will be computed by FDC. Using the diffusion coefficients, we will parameterize the loss and the computed lifetimes will be included in to the IMPTAM code. We will solve the diffusion coefficents IMPTAM will solve the Fokker-Planck Equation with the diffusion coefficients provided by VERB model. Available data on low energy electron fluxes (< 300 keV) both at geostationary and inside will be compared to model output for selected events to verify the improved IMPTAM.

Task 5.3 – Providing the low energy seed population to VERB radiation belts model
Month 24-30 (FMI, Skoltech)
The maps in (L, MLT, pitch angle, energy) of low energy electrons will be constructed as output from the improved IMPTAM. Both quiet and disturbed events will be selected according to data availability and modelled and the model output will be compared to the observed electron fluxes to further model verification. The low energy electron maps for the modelled events will be provided to the VERB code as seed keV population for further accelerations to MeV energies. VERB code will utilize the seed population and make its own verification. The results of the IMPTAM will be validated against satellite observations and will be also compared with the NARMAX predictions. We will couple VERB with IMPTAM and validate the results against observations in the heart of the outer radiation belts. VERB-IMPTAM will form alternative to NARMAX-VERB combination of codes. The detailed comparison between the codes and validation will help us improve and validate IMPTAM.

Task 5.4 – Developing a trial version of forecast model for low energy electrons
Month 24-36 (FMI, USFD, UW, UM, IRF)
At present, IMPTAM is the only model that provides nowcast of low energy electrons (< 200 keV) in the inner magnetosphere. The model operates online under the SPACECAST project (http://fp7-spacecast.eu). It is driven by the real time solar wind parameters such as solar wind number density, total plasma bulk velocity and solar wind dynamic pressure, components of IMF and Dst index. Forecast capabilities for geomagnetic indices and SW and IMF developed in PROGRESS in WP1 and WP3 will make it possible to extent IMPTAM from simply a nowcast model to a forecast tool. IMPTAM considers the effects which substorm activity has upon the transport and acceleration of low energy electrons by launching an electromagnetic pulse at substorm onset times. It is very difficult to incorporate the substorm activity effects even for nowcast modeling. To launch a pulse at a substorm onset with a magnitude scaled by a peak value of AE index, the substorm timing and AE peaks must be forecasted. With the development of the forecasting tools in PROGRESS for AE index in WP3, the substorm activity effects will be properly taken into account. A trial version of forecast model for low energy electrons will be put online.

Summary of facilities available at hosts:
FMI has already developed the IMPTAM model, and has access to appropriate computing facilities for its operation.

Summary of funding requirements:
Salaries for N. Ganushkina and junior researcher at FMI, and Y. Shprits (Skoltech).
Travel funding for attendance at Project Meetings, science conferences for dissemination.
Publication fees.

Participation per Partner

Partner number and short name	WP5 effort
1 - USFD	6.00
2 - FMI	27.00
4 - Skoltech	8.00
Total	41.00

List of deliverables

Deliverable Number [14]	Deliverable Title	Lead beneficiary	Type [15]	Dissemination level [16]	Due Date (in months) [17]
D5.1	Solar wind drivers of low energy plasmasheet electrons	2 - FMI	Report	Public	12
D5.2	The incorporation of diffusion coefficients from VERB into IMPTAM	2 - FMI	Report	Public	24
D5.3	The VERB-IMPTAM low energy seed population	2 - FMI	Report	Public	26
D5.4	Trial version of forecast model for low energy electrons	2 - FMI	Report	Public	36

Description of deliverables

The deliverables for WP5 report key results in the process of coupling the VERB and IMPTAM simulation codes.

D5.1 : Solar wind drivers of low energy plasmasheet electrons [12]

This deliverable consists of a journal paper, ready for submission, discussing the solar wind and IMF driven model for low energy electrons in the plasma sheet

D5.2 : The incorporation of diffusion coefficients from VERB into IMPTAM [24]

This deliverable consists of a journal paper, ready for submission, discussing the results of incorporating of diffusion coefficients from VERB into IMPTAM

D5.3 : The VERB-IMPTAM low energy seed population [26]

This report will discuss the coupling of the VERB and IMPTAM models so that low energy seed population from IMPTAM is used to initialise the VERB radiation belt model for high energy electrons.

D5.4 : Trial version of forecast model for low energy electrons [36]

Report on the trial version of forecast model for low energy electrons

Schedule of relevant Milestones

Milestone number [18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS4	Fusion of VERB and IMPTAM	2 - FMI	24	Fusion of VERB and IMPTAM

Work package number [9]	WP6	**Lead beneficiary** [10]	1 - USFD
Work package title	Forecast of the radiation belt environment		
Start month	1	**End month**	30

Objectives

The objectives of WP 6 are:
- To extend of SNB3GEO model to various to lower energy electrons (down to lowest range of GOES 15 data 30-50 keV) and to increase rate of prediction from 1 day at present to 2 hours, maintaining the same prediction lead of time 24 hours.
- To enhance the performance of VERB model by employing the tensors of diffusion coefficients from WP4 and incorporating real time data assimilation methodology into VERB forecast.
- To develop the VERB-NARMAX Coupled (VNC) model that will integrate forecasts of SNB3GEO model at GEO as boundary conditions for VERB model.

Description of work and role of partners

WP6 - Forecast of the radiation belt environment [Months: 1-30]
USFD, FMI, Skoltech
Work package leader: M. Balikhin (USFD)

Participants: Y. Shpritz (Skoltech), 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)
Create a set on forecast models based on the NARMAX methodology to forecast the fluxes on energetic electrons in all energy ranges sampled by the GOES 13 satellite [Boynton et al, 2013]. We will use the same methodology used to create the models for electron fluxes with energies >800keV and >2Mev that currently operate is Sheffield (www.ssg.group.shef.ac.uk/USSW/2MeV_EF.html) and to increase the temporal resolution of the forecasts.

Task 6.2 –Data assimilation extension for VERB
Month 1-26 (Skoltech)

This task involves the development of a set of methods, based on the Kalman filter, to forecast the evolution of the radiation belts. Special attention will be paid to the development a set of identification methods for unknown noise statistics, such as the bias and covariance matrix of model errors. Additional refinements to these techniques will involve estimation of the observation error statistics, identification of the coefficients of proportionality characterising the dependence of observation errors on satellite observations, and the use of the backward optimal smoothing procedure applied to the forward Kalman filter estimates to improve our understanding of the key physical mechanisms.

Task 6.3 – Development of the coupled VERB-NARMAX model (VNC)
Month 7-30 (USFD, Skoltech)
Currently the VERB code utilises the boundary condition at constant L, e.g. L=7. The SNB3GEO provides the forecast at GEO, which corresponds to a range of L values. Two methods of coupling between VERB and SNB3GEO will be implemented. The first method will involve the adaption the VERB code to a boundary with variable L-shell that corresponds to GEO, and development of the interface between SNB3GEO and VERB. In the second method the output from SNB3GEO will be propagated and scaled to the surface of constant L (e.g. L=7). To assess the quality of the results, a number of periods of Van Allen probe data sets in which the radiation belts exhibited strong activity will be identified. The coupled VNC models resulting from both approaches will be assessed by the comparison of their predictions with measurements. As result more accurate of the versions of VNC will be identified.

Summary of facilities available at hosts:
Both USFD and Skoltech have sufficient computing facilities to perform the above listed tasks.
Summary of funding requirements:
Salary for R. Boynton. Travel and subsistence for dissemination.

Participation per Partner

Partner number and short name	WP6 effort
1 - USFD	18.00
2 - FMI	4.00
4 - Skoltech	8.00
Total	30.00

List of deliverables

Deliverable Number [14]	Deliverable Title	Lead beneficiary	Type [15]	Dissemination level [16]	Due Date (in months) [17]
D6.1	NARMAX models of electron fluxes sat GEO	1 - USFD	Report	Public	6
D6.2	Use of data assimilation technique within VERB code model	4 - Skoltech	Report	Public	26
D6.3	Results of the VNC model and two methods of model couplings	1 - USFD	Report	Public	30

Description of deliverables

The deliverables for WP6 report on the results of key stages in the coupling between the VERB (physical) model and the NARMAX (systems) models

D6.1 : NARMAX models of electron fluxes sat GEO [6]

This deliverable consists of a journal paper, ready for submission, discussing a set of NARMAX models for the fluxes of electrons at GEO for various energy ranges.

D6.2 : Use of data assimilation technique within VERB code model [26]

This deliverable, in the form of a journal paper, ready for submission, discusses the results of the incorporation of data assimilation technique into the VERB model and two methods of model couplings

D6.3 : Results of the VNC model and two methods of model couplings [30]

This deliverable, a journal paper ready for submission, discusses the results of the two coupling methods used in the VNC model.

Schedule of relevant Milestones

Milestone number [18]	**Milestone title**	**Lead beneficiary**	**Due Date (in months)**	**Means of verification**
MS1	NARMAX models for electrons at GEO	1 - USFD	6	NARMAX models for electrons at GEO
MS6	Fusion of NARMAX and VERB	1 - USFD	30	Fusion of NARMAX and VERB

Work package number [9]	WP7	**Lead beneficiary** [10]	1 - USFD
Work package title	Fusion of forecasting tools		
Start month	18	**End month**	36

Objectives

The objectives of WP 7 are:
- To collect the models developed in WP 3, implement them at USFD and the mirror site in the FMI and provide access to their forecasts via the project web page.
- To provide access to the forecasts of models developed in WP 4 via the project web page.
- To implement the VERB-NARMAX and VERB-IMPTAM models, developed in WP 5 and 6 at USFD, and provide access to their forecasts via the project web page.
- To develop a user friendly tool to calculate the integrated electron fluxes in various energy ranges along a user defined part of the orbit based on then past data to facilitate investigation of past spacecraft anomalies.
- To implement a traffic light system and create an automatic email circular (by free subscription) summarising the current space weather conditions and a forecast of their expected evolution.

Description of work and role of partners

WP7 - Fusion of forecasting tools [Months: 18-36]
USFD, FMI, UW, IRF
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. Workpackages 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)
The models for Dst and Kp, developed in WP 3 will be implemented at USFD. Initially the models will be driven using real time solar wind data from ACE/DSCOVR. Once their operation has been verified, the data interfaces will be modified to accept input from the SWIFT MHD solar wind simulation being developed in WP 2. A similar set of steps will be carried out to the models of AE when they become available. The activities of WP 6 will result in a number of NARMAX models for GEO and for the flux of high energy electrons in the radiation belts. The forecasts of these models will be displayed on the project web site, together with facilities to download the numerical values.

Task 7.2 – Implementation of VERB-NARMAX and VERB-IMPTAM models
Month 22-33 (USFD,Skoltech)
The VERB-NARMAX and VERB-IMPTAM models will be installed at USD and tested. Initially they will be driven using solar wind parameters from ACE/DSCOVR and forecasts of geomagnetic indices from the models developed in WP 3 and implemented at USFD. This output of these models will provide forecasts of the particle environment throughout the radiation belt region.

Task 7.3 – Orbit tool
Month 27-30 (USFD,Skoltech,FMI)
The VERB-NARMAX and VERB-IMPTAM models, implemented in task 7.2, will provide forecasts of the flux of electrons at various energies within the inner magnetosphere. This task will use these forecasts to determine the path integrated electron fluxes in various energy ranges encountered along the orbital path of a satellite.

Task 7.4 – Environmental summary
Month 30-36 (USFD)
In order to disseminate the results of the forecasts in a timely an email circular will be generated and circulated. It is envisaged that this circular will be distributed when forecasts show evidence of potentially hazardous conditions. The exact triggering factors will be defined as a result of meetings of the stakeholder advisory board. Subscription to the email list will be performed from the project web site.

Summary of facilities available at hosts:
USFD possesses the necessary hardware environment to perform these activities.

Summary of funding requirements:
Salary for S. Walker (USFD)
Travel and subsistence for dissemination of results.

Participation per Partner

Partner number and short name	WP7 effort
1 - USFD	10.00
2 - FMI	3.00
3 - UW	3.00
8 - IRF	2.00
Total	18.00

List of deliverables

Deliverable Number [14]	Deliverable Title	Lead beneficiary	Type [15]	Dissemination level [16]	Due Date (in months) [17]
D7.1	The results of individual forecasts of geomagnetic indices	1 - USFD	Report	Public	30
D7.2	Forecasts of the energetic electron populations within the inner magnetosphere	1 - USFD	Report	Public	33
D7.3	On orbit forecasts of the energetic electron populations	1 - USFD	Report	Public	30
D7.4	Summary of the space weather environment	1 - USFD	Report	Public	36

Description of deliverables

These deliverables report on the generation of tools for use by end users to obtain forecasts of the space weather environment.

D7.1 : The results of individual forecasts of geomagnetic indices [30]

This report and accompanying web pages outlines the implementation and display of individual forecasts of geomagnetic indices

D7.2 : Forecasts of the energetic electron populations within the inner magnetosphere [33]

This report discusses the implementation and use of web page displaying forecasts of the energetic electron populations within the inner magnetosphere.

D7.3 : On orbit forecasts of the energetic electron populations [30]

This report discusses the implementation and use of web page displaying forecasts of the energetic electron populations along a user selected satellite orbit

D7.4 : Summary of the space weather environment [36]

This report discusses the implementation and interpretation of a set of web pages that summarise the forecasts of the short term evolution of the space weather environment and the dissemination of this information to stakeholders.

Schedule of relevant Milestones

Milestone number [18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification

Work package number [9]	WP8	**Lead beneficiary** [10]	1 - USFD
Work package title	Dissemination		
Start month	1	**End month**	36

Objectives

The main objectives of this work package are to monitor the dissemination of results obtained by the project.

Description of work and role of partners

WP8 - Dissemination [Months: 1-36]
USFD, FMI, UW, Skoltech, UM, SRI NASU-NSAU , CNRS, IRF
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 maximise 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.

Summary of facilities available at hosts:
These tasks will be coordinated be the Project Coordinator and Project Manager. The web site will be hosted at USFD.

Summary of funding requirements:
Salaries for PC and PM. Travel and subsistence for all participants.

Participation per Partner

Partner number and short name	WP8 effort
1 - USFD	2.00
2 - FMI	2.00
3 - UW	2.00
4 - Skoltech	2.00
5 - UM	2.00
6 - SRI NASU-NSAU	2.00

Partner number and short name	WP8 effort
7 - CNRS	2.00
8 - IRF	2.00
Total	16.00

List of deliverables

Deliverable Number [14]	Deliverable Title	Lead beneficiary	Type [15]	Dissemination level [16]	Due Date (in months) [17]
D8.1	Project web site	1 - USFD	Websites, patents filling, etc.	Public	3
D8.2	Exploitation and Dissemination Plan	1 - USFD	Report	Public	24

Description of deliverables

This deliverables introduce the project web site and the facilities it provides and outline the methods used within the Project to ensure dissemination and exploitation of the results.

D8.1 : Project web site [3]

Project web site

D8.2 : Exploitation and Dissemination Plan [24]

This deliverable outlines the methods used by the project for the dissemination and exploitation of the results gained during the Project.

Schedule of relevant Milestones

Milestone number [18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification

1.3.4. WT4 List of milestones

Milestone number [18]	**Milestone title**	**WP number [9]**	**Lead beneficiary**	**Due Date (in months) [17]**	**Means of verification**
MS1	NARMAX models for electrons at GEO	WP6	1 - USFD	6	NARMAX models for electrons at GEO
MS2	Availability of models for Kp, Dst, and AE	WP3	8 - IRF	18	Availability of models for Kp, Dst, and AE
MS3	Statistical wave models	WP4	7 - CNRS	24	Statistical wave models
MS4	Fusion of VERB and IMPTAM	WP5	2 - FMI	24	Fusion of VERB and IMPTAM
MS5	Availabity of AWSoM/SWIFT for testing within the consortium.	WP2	3 - UW	20	The AWSoM/SWIFT generated as part of WP2 will be made available to consortium members for testing.
MS6	Fusion of NARMAX and VERB	WP6	1 - USFD	30	Fusion of NARMAX and VERB

1.3.5. WT5 Critical Implementation risks and mitigation actions

Risk number	Description of risk	WP Number	Proposed risk-mitigation measures
R1	Some of the Work Package Leaders may move to a different institution or post.	WP1, WP2, WP3, WP4, WP5, WP6, WP7, WP8	If possible, their input and involvement will be maintained as outlined in the work packages. Each Work Package Leader has a named deputy who can take over the leadership role. Each Team Leader will have a deputy who can take over their responsibilities.
R2	Some of key persons may leave the project	WP1, WP2, WP3, WP4, WP5, WP6, WP7, WP8	The responsibilities will be redistributed between the rest of the participants or a new person will be invited to the project, subject to the approval of the Project Officer.
R3	Participants disengagement. The deliverables will be compromised if one of the participants leaves the project.	WP1, WP2, WP3, WP4, WP5, WP6, WP7, WP8	All the participants in the consortium are large organisations. If all the members of a Team decide to quit the project, new persons from inside an organization may be found for the continuation of the work. If this is not possible, then a redeployment of teams within the project may be considered by the Steering Committee.
R4	Problem of data provision.	WP2, WP3, WP4, WP5, WP6, WP7	All data used within the project to create the data driven models are either publically accessible via the internet or provided by a dedicated team or data centre/archive whose task is to provide data accessibility.
R5	Problem of software and method development. Problem can arise if a person responsible for programming inside a WP leaves the project.	WP2, WP3, WP4, WP5, WP6	The project partners have sufficient experience within their teams to continue the work.
R6	Financial affairs. The funding for some participants may be lower than was planned owing to fluctuations in markets and exchange rates.	WP1, WP2, WP3, WP4, WP5, WP6, WP7, WP8	Resources can be redeployed between WPs if necessary.

Risk number	Description of risk	WP Number	Proposed risk-mitigation measures
R7	Delays in deliveries. There could be a number of technical or managerial reasons (some of them mentioned above) why deliverables will not be produced at the planned time.	WP2, WP3, WP4, WP5, WP6, WP7	WPs are designed with some buffer in the schedule to offer reasonable flexibility. Delays on deliverables related to data selection, software development, background model computation etc. will not introduce a substantial restriction in the progress of the project. The works are planned in such a way that the next steps can start before the previous deliverables would be accomplished. Effects of delay of deliverables on the main results may be rather serious. Work Package leaders will plan ahead to analyse the effects of slippage that might occur and develop detailed contingency plans to manage the risk. Where the deliverables lie of a critical path alternate action plans have been identified.

1.3.6. WT6 Summary of project effort in person-months

	WP1	**WP2**	**WP3**	**WP4**	**WP5**	**WP6**	**WP7**	**WP8**	**Total Person/Months per Participant**
1 - USFD	9	1	15	6	6	18	10	2	67
2 - FMI	0	0	0	0	27	4	3	2	36
3 - UW	0	26	0	0	0	0	3	2	31
4 - Skoltech	0	0	0	8	8	8	0	2	26
5 - UM	0	20	0	0	0	0	0	2	22
6 - SRI NASU-NSAU	0	0	38	0	0	0	0	2	40
7 - CNRS	0	0	0	20	0	0	0	2	22
· UO	0	0	0	0	0	0	0	0	0
8 - IRF	0	0	34	0	0	0	2	2	38
Total Person/Months	9	47	87	34	41	30	18	16	282

1.3.7. WT7 Tentative schedule of project reviews

Review number [19]	Tentative timing	Planned venue of review	Comments, if any
RV1	12	Brussels	Technical and financial review
RV2	24	Brussels	Technical review
RV3	36	Brussels	Final technical and financial review

1.4. Ethics Requirements

No ethics requirements indicated

1. Project number

The project number has been assigned by the Commission as the unique identifier for your project. It cannot be changed. The project number **should appear on each page of the grant agreement preparation documents (part A and part B)** to prevent errors during its handling.

2. Project acronym

Use the project acronym as given in the submitted proposal. It can generally not be changed. The same acronym **should appear on each page of the grant agreement preparation documents (part A and part B)** to prevent errors during its handling.

3. Project title

Use the title (preferably no longer than 200 characters) as indicated in the submitted proposal. Minor corrections are possible if agreed during the preparation of the grant agreement.

4. Starting date

Unless a specific (fixed) starting date is duly justified and agreed upon during the preparation of the Grant Agreement, the project will start on the first day of the month following the entry into force of the Grant Agreement (NB : entry into force = signature by the Commission). Please note that if a fixed starting date is used, you will be required to provide a written justification.

5. Duration

Insert the duration of the project in full months.

6. Call (part) identifier

The Call (part) identifier is the reference number given in the call or part of the call you were addressing, as indicated in the publication of the call in the Official Journal of the European Union. You have to use the identifier given by the Commission in the letter inviting to prepare the grant agreement.

7. Abstract

8. Project Entry Month

The month at which the participant joined the consortium, month 1 marking the start date of the project, and all other start dates being relative to this start date.

9. Work Package number

Work package number: WP1, WP2, WP3, ..., WPn

10. Lead beneficiary

This must be one of the beneficiaries in the grant (not a third party) - Number of the beneficiary leading the work in this work package

11. Person-months per work package

The total number of person-months allocated to each work package.

12. Start month

Relative start date for the work in the specific work packages, month 1 marking the start date of the project, and all other start dates being relative to this start date.

13. End month

Relative end date, month 1 marking the start date of the project, and all end dates being relative to this start date.

14. Deliverable number

Deliverable numbers: D1 - Dn

15. Type

Please indicate the type of the deliverable using one of the following codes:

R	Document, report
DEM	Demonstrator, pilot, prototype
DEC	Websites, patent fillings, videos, etc.
OTHER	

16. Dissemination level

Please indicate the dissemination level using one of the following codes:

PU Public

CO	Confidential, only for members of the consortium (including the Commission Services)
CI	Classified, as referred to in Commission Decision 2001/844/EC

17. Delivery date for Deliverable

Month in which the deliverables will be available, month 1 marking the start date of the project, and all delivery dates being relative to this start date.

18. Milestone number

Milestone number:MS1, MS2, ..., MSn

19. Review number

Review number: RV1, RV2, ..., RVn

20. Installation Number

Number progressively the installations of a same infrastructure. An installation is a part of an infrastructure that could be used independently from the rest.

21. Installation country

Code of the country where the installation is located or IO if the access provider (the beneficiary or linked third party) is an international organization, an ERIC or a similar legal entity.

22. Type of access

VA	if virtual access,
TA-uc	if trans-national access with access costs declared on the basis of unit cost,
TA-ac	if trans-national access with access costs declared as actual costs, and
TA-cb	if trans-national access with access costs declared as a combination of actual costs and costs on the basis of unit cost.

23. Access costs

Cost of the access provided under the project. For virtual access fill only the second column. For trans-national access fill one of the two columns or both according to the way access costs are declared. Trans-national access costs on the basis of unit cost will result from the unit cost by the quantity of access to be provided.

Horizon 2020

PROTEC-1-2014: Space Weather

Annex 1 – Description of Action
(Part B)

Grant agreement for: Research and Innovation action

Action acronym: PROGRESS

Action full title: "Prediction of Geospace Radiation Environment and Solar Wind Parameters"

Grant Agreement no: 637302

Table of Contents

2.1 Excellence

This proposal addresses the Horizon2020 call H2020-PROTEC-1-2014: Space Weather.

Just as weather can be expressed as a set of atmospheric parameters that are important not only for our comfort but also determine the conditions for the operation of technological systems on the ground and in the atmosphere, space weather is expressed by the set parameters relating to the near Earth environment that determine important conditions for many modern technological systems operating on the terrestrial surface (e.g. power grids), in the atmosphere (aviation) and in the space (satellites, manned missions). Functions provided by spacecraft (communication, navigation) are critical for our modern post industrial society. Even the global financial industry requires spacecraft services both for communications and the time synchronisation of transactions, relying heavily of GNSS as a reference clock. With the exception of galactic cosmic rays, processes that occur on our nearest star, the Sun, drive space weather and may result in events such as magnetic storms, and drastic enhancements of the energetic particles fluxes in the near Earth space that are hazardous to the operations of technological systems. The advanced accurate forecast of these hazards is essential for the mitigation of their effects. The major advance of the current space weather forecasting capabilities is the major target of PROGRESS.

2.1.1 Objectives

The overall aim of the project PROGRESS is to exploit the synergy of the complementary expertise available within the 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 of space weather hazards.

Particular objectives are:

- Develop a European numerical MHD based model that will enable the advanced forecast of solar wind parameters at L1 (WP2). This will give a direct simulation connection between observed photospheric drivers and solar wind parameters at L1.
- Use state of the art 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 the solar wind input conditions (WP3).
- Construct a new set of statistical wave models to describe the plasma wave environment of the inner magnetosphere that will accurately reflect the physics of the 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 (WP4).
- Incorporate forecasting capabilities into the physics based numerical model for low energy electrons IMPTAM that currently is able to provide a now-cast only (WP3, 5).
- 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 geostationary orbit SNB^{3}GEO, IMPTAM, the most advanced model for high energy electrons in the radiation belts – VERB, and state of the art data assimilation methodology (WP6).
- 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 (WP7).

2.1.2 Concept and approach

Currently, the smooth functioning of the European economy and welfare of European citizens depends upon services provided by spacecraft. Space weather hazards can influence the proper operation of this space infrastructure with detrimental effects for economic activity, emergency services, security of European countries, and even the routine activities involving ordinary Europeans such as depositing or withdrawing money from your bank, driving using a satnav, flying away on holiday, or simply forecasting tomorrows weather. The impact and cost of space weather on our modern economy can be illustrated by information published online by the National Oceanic Atmospheric Agency (http://www.swpc.noaa.gov/info/Satellites.html). During the period 1994-1999 a single major spacecraft insurance company estimated that over $500M in insurance claims were disbursed due to in-orbit failures related to space weather. Since that time the amount of space based hardware infrastructure has vastly increased, both in the number of operational satellites and the cost of each satellite. Since 2003 the number of operating satellites has increased from about 460 to more than 1000 today. Even a temporary disruption in the services of these commercial satellites incurs a high cost for their operators. As an example of the disruptive effects, consider the case of the communication satellites Anik-E1 and Anik-E2 launched by Canadian company TELESAT. On January 20th, 1994 the electronic unit controlling a momentum wheel failed on Anik-E1 as the result of a space weather induced electrostatic discharge (ESD), followed about 8 hours later by the failure of similar units on Anik-2E [Gubby and Evans, 2002]. During the following 7-hour period of disruption to the operations of Anik-E1 the Canadian press were unable to deliver news to 100 newspapers and 450 radio stations, and the telephone service to 40 isolated communities was interrupted. An hour after Anik-E1 recovered Anik-E2 went off-air. It took half a year and $50M to restore its operation. This cost does not include the loss in revenue resulting from the interruption of services across Canada.

ESD is one example of the effects that space weather hazards can have upon our satellite infrastructure. Surface ESD occurs when low energy electrons in the surrounding plasma deposit charge on the spacecraft surface. Eventually the gradient of the electrostatic potential exceeds the material breakdown potential causing an impulsive discharge of energy, which can result in either a Single Event Upset (SEU) or anomalies in electronic components [e.g. Lohmeyer and Cahoy, 2013]. It is currently accepted that electrons with an energy range from a few keV to a few tens of keV are the main cause of surface ESD. High-energy electrons, in contrast, are able to penetrate spacecraft shielding and deposit their charge directly into dielectric components or circuit boards, leading to internal ESD. By analysing satellite anomalies from data bases at NOAA, NASA, and US Air Force 55th Space Weather Squadron, Koons et al., [2000] determined that ESD is the main cause of spacecraft anomalies (54% of total anomalies). The second most frequent reason for spacecraft anomalies was SEU caused by South Atlantic Anomaly (6.7% of total anomalies), galactic cosmic rays (5%), solar energetic particles (3%). In 13.5% of these SEU anomalies the cause was not identified. In 5.3% of cases the anomaly was related to the degradation of solar arrays caused by solar particle events, total radiation dose, the South Atlantic Anomaly or material damage. According to the databases analysed by Koons et al., [2000] 11 missions were lost or terminated as the result of the space environment effects. Among these 11 cases 5 were caused by ESD. This cause exceeds even that of micrometeorite impacts (3 cases). More recent studies based on new data confirm the significant role of ESD in the occurrence of satellite anomalies [Choi et al., 2011,2012]. Whilst the prolonged exposure of satellites to enhanced fluxes of relativistic electrons leads to internal ESD, surface charging depends upon on a number the details of the electron distribution [Mazur, Obrien, 2013; Fennell et al., 2001]. Accurate models for the electron fluxes in the low and high-energy ranges will enable the provision of warnings of possible ESD hazards to operational spacecraft and may also assist in the analysis of historical anomalies.

The inner and outer radiation belts are regions in the magnetosphere that are saturated with energetic particles. Whilst the inner radiation belt of very high-energy protons and electrons is rather stable, the fluxes of energetic electrons in the outer radiation belt are very dynamic, capable of increasing by a few orders of magnitude on a time scale of a few hours. The radiation environment in the outer radiation belt is important for satellites with Medium Earth Orbits (MEO) that pass through its heart. While only a few per-cent of the currently operating spacecraft fleet use MEO orbits, these satellites provide extremely important services including navigation systems such as GPS, GLONASS and, importantly from the standpoint of European space infrastructure and security, Galileo. The geostationary orbit (GEO) is of no less importance with about 400 satellites operating as of the February 2014. GEO spacecraft provide communications, weather forecast and services for security and military requirements. While GEO lies on the periphery of the outer radiation belt this region is still home to high fluxes of relativistic MeV electrons that can prove hazardous to spacecraft hardware. In addition, night side sector of the GEO orbit is situated in the region where electrons with energy in the range from a few keV to a few hundred keV are accelerated during substorm activity as they propagate into the inner magnetosphere. The project PROGRESS aims to develop a set of accurate models and forecast tools to describe the spatio-temporal dynamics of electron population from low energies up to above 2 MeV.

The FP7 programme devoted significant resources to the development of forecast tools and physical models for the forecast of low and high energy electron populations in the inner magnetosphere. In particular, the SPACECAST project pioneered the consolidation of European modelling resources to create a forecast for the radiation environment within the inner magnetosphere. The real time, physics based forecast of high energy fluxes and the now-cast of low energy fluxes was developed and is still currently maintained (http://fp7-spacecast.eu). However, while the now-cast of low energy electron fluxes provided by the IMPTAM model are close to those observed, the 3 hour ahead forecast of the high energy fluxes by the ONERA and BAS models is not of the same quality. Validation of the forecasts may be performed by comparing the results directly with measurements from the GOES satellites at GEO. During 2013 the highest daily fluxes of electrons with energies > 2 MeV was measured on May 30-31. Three current data based models (NOAA, University of Colorado and the USFD model SNB^{3}GEO) provided quite accurate 24 hour-ahead warnings regarding the enhancement of fluxes of energetic electrons in this energy range. SNB^{3}GEO predicted the flux value to within 25% of the actual values measured by GOES 13. At the same time both the ONERA and BAS models under predicted the fluxes by 2 orders of magnitude (100 times). Currently the ONERA and BAS models provide only a 3 hour-ahead forecast. Since the time scale for the enhancement of the 2 MeV electron flux at GEO due to the solar wind drivers is about 2 days [Balikhin et al., 2013] a forecast with a lead-time significantly longer than 3 hours is feasible. While data based models (NOAA, University of Colorado and SNB^{3}GEO) provide an accurate forecast of the electron fluxes at GEO 24 hours in advance, their forecast cannot be easily expanded to cover the whole region of the radiation belts because a continuous set of measurements is required to develop this class of model. Such continuous measurements are currently available only at GEO. The disadvantages of the current European physics based models (BAS and ONERA) for high energy fluxes are due to unclear boundary conditions (often assumed to be constant), deficiencies in the statistical wave models implicitly used by these codes to develop the diffusion tensor coefficients, disregard of the mixed diffusion terms within these codes, and the assumption of a dipolar field for the calculation of the diffusion coefficients. PROGRESS aims to develop a forecast that overcomes these disadvantages. The SNB^{3}GEO NARMAX model for electron fluxes at GEO, which has shown its capability to provide reliable, online forecasts for the past two years, will be used to determine the boundary condition for the physics based models. PROGRESS will redevelop the statistical wave models to account for the dependence of the magnetospheric electron fluxes upon the solar wind parameters and for recent findings on the dynamics of inner magnetosphere waves obtained during the Cluster spacecraft mission Inner Magnetosphere Campaign.

The physics based models used by PROGRESS (IMPTAM and VERB) require geomagnetic indices such as Kp, AE, and Dst as input parameters. These values reflect the configuration of the terrestrial magnetic field and the level of geomagnetic substorm activity that is responsible for the seed populations of particles that may be accelerated to extremely high energies within the outer radiation belt. One of the aims of PROGRESS is, therefore, to re-evaluate and improve the current tools used to forecast geomagnetic indices. The location of the magnetopause is also a very important parameter for the evolution of electron fluxes within the outer radiation belt. Earthward displacement of the dayside magnetopause leads to "magnetopause shadowing" which is an extremely important mechanism for the loss of relativistic electrons. While it takes about 2 days for the MeV electron to react to the solar wind drivers, the low energy electrons respond on the same day [Balikhin et al., 2012, Boynton et al., 2013]. Therefore, the forecast of their fluxes will greatly benefit from knowing the solar wind parameters before a spacecraft situated at the L1 point measures them. PROGRESS will develop an MHD model (SWIFT) coupled with the model of the solar corona (AWSoM). This new suite of combined solar corona and inner heliosphere tools will provide an advanced forecast of the solar wind parameters at L1. There are three separate pillars of the PROGRESS forecast, namely

- The forecast of parameters at L1,
- The forecast of geomagnetic indices
- The forecast of radiation environment in the inner magnetosphere.

It must be emphasized that all three pillars have critical independent importance for the forecast of the space weather.

The complexity of the dynamics of geospace (and therefore space weather) is related to its constant evolution under the influence of the solar wind. This involves a chain comprising of an enormous number of coupled physical processes operating on spatial scales from meters to tens of thousands of kilometres [Balikhin et al., 2010]. Two complementary approaches to the understanding of such complex systems exist. The first one, which is as old as physics itself, is to advance our knowledge from first principles by building models of increasing complexity that reflect our understanding of each individual process and then, finally, to conjugate all these links into a comprehensive mathematical/numerical model that can be used to forecast the evolution of the dynamical system in a bottom-up approach. First principles based models have been developed for many aspects of space weather. However, our current knowledge of the physics involved does not allow the development of first principles based models that provide reliable and accurate forecasts. The second approach, which is often referred to as system science, is relatively young and advances our understanding about a particular system in the opposite direction, i.e. top-down, beginning with the overall system behaviour and working towards an understanding of the underlying physical processes and components. This second approach relies heavily on advanced data analysis methodologies developed in systems science from models based on Neural Networks and sophisticated optimisation techniques to Nonlinear AutoRegressive Moving Average models with eXogenous inputs models (NARMAX). The NARMAX models allow physical interpretation and provide insight into the physics of the dynamical processes involved. While system science models deliver an accurate and reliable forecast for some space weather parameters, this approach can only be applied to specific aspects of space weather for which a continuous set of measurements is available. For example SNB^{3}GEO, the USFD NARMAX model for the daily averaged fluxes of relativistic electrons at geostationary orbit, has been operating for the last two years, providing an accurate 24 hour ahead forecast (http://www.ssg.group.shef.ac.uk/USSW/2MeV_EF.html). However the expansion of this forecast to the entire region of the inner magnetosphere, for which only sparse satellite measurements are available, is not possible in the frame of the systems science approach. *The fusion between the first principles based numerical models, empirical models developed by systems science techniques and comprehensive validation these models using actual measurements is the cornerstone of the PROGRESS methodology*. This is the concept underpinning much of the activity within PROGRESS.

The PROGRESS consortium possess expertise in two high performing data based approaches to the forecast of complex dynamical systems: NARMAX and Neural Networks.

NARMAX (Nonlinear Autoregressive Moving Average Model with Exogenous inputs) modelling has been developed by USFD (participant 1) to analyse and forecast dynamical systems about which very little is known. Artificial Neural Networks (ANN) and similar kernel based approaches can be used to address the problem of prediction. However, the disadvantage of ANN is that to produce a reliable model a priori knowledge about the system, for example all the system inputs and lags, are required. If some inputs or lags are not known, these methods will attribute the response variations only to the set of inputs included in model. Therefore, such methods will provide reliable models only in the case when the "physics of the systems inputs is known". In addition, ANN often result in opaque models that are difficult to relate to the physics of the underlying system and are difficult to analyse [Billings and Chen, 1998]. In contrast, NARMAX is not only able to provide a reliable forecast for the evolution of complex systems with unknown physics, but also provides insights into the nature of the physical processes underlying the system dynamics. NARMAX is based on developing physically interpretable models that can be related to analytical models deduced from first principles. So if, for example, a system has a first order dynamic response with a cubic effect in the output then the model identified should have exactly this form. This is the basic philosophy behind the NARMAX model and what have now become known as 'NARMAX methods' developed by Billings, his Sheffield co-workers, and other USFD partner team members over several years. The only disadvantage of this method is that expertise in nonlinear system identification and estimation is required to fit the models but this is easily outweighed by the additional insight and properties of the system that are revealed. Application of NARMAX methodologies have led to major advances in such fields as the growth stem cells, animal vision, neuroscience and brain imaging [Billings, 2013].

The theory behind ANN originates from the 1940's of studies of the brain being a highly connected network with biological neurons. One rationale behind this is the brain's capability of modelling and learning complex non-linear systems. Simple mathematical models of the neurons were constructed but it was not until the 1970's that algorithms were proposed that could provide a learning mechanism (for an overview see e.g. Anderson and Rosenfeld, 1988). Studies of ANNs have two main branches: 1) understanding and modelling of the brain; 2) modelling of complex and non-linear systems. The latter is not about the biological counterpart but is a set mathematical tools that collectively may be called computational neural networks (CNN). Two basic categories of CNN exist: unsupervised (UCNN) and supervised (SCNN). The UCNNs find patterns in the underlying data based on some defined criteria, like Euclidian distances between pairs of input vectors. The SCNN finds an input-output mapping from given sets of input-output data pairs. In the context of input-output mapping models (SCNN) two basic types of CNNs exist, models with only exogenous inputs and models with both endogenous and exogenous inputs, where the latter can be interpreted as differential equations in their linear regime.

The basic approach of PROGRESS is:

i) To develop new empirical and physics based models, in particular of the solar wind propagation to L1.

ii) To exploit recent experimental findings and the vast amount of existing space missions data to further to improve state of the art physics based existing models for geospace environment (e.g. IMPTAM, VERB) and expand their capabilities.

iii) To develop new forecasting tools that will be based on fusion of first principle numerical models and empirical models (e.g. VERB-NARMAX, IMPTAM-NARMAX, IRF-CNN) that will possess advantages of the both types: forecast accuracy of data-based models and wide area of applicability of the physics based models.

These three concepts have been split into 6 scientific work packages (WP2-7).

2.1.2.1 WP2 Propagation of the Solar Wind from the Sun to L1:

Current simulation tools that connect the observed solar photospheric magnetic field to solar wind variables at L1, and beyond, either rely on semi-empirical models, e.g. the Wang-Sheeley-Arge model, or require large-scale computing resources. The first approach can be tuned to reasonable accuracy but lacks the predictive power of a first-principles based solution. The direct first-principle approach requires substantial computing power and is correspondingly slower thus limiting its appeal as a real-time predictive tool. PROGRESS will address these two issues by adopting a coupled model approach. From the photosphere out to ~ 20-30 Solar radii PROGRESS will use the recently developed AWSoM code [van der Holst et al. 2014]. This proven code combines large-scale MHD with modelled turbulence and thermal transport in a multi-temperature plasma. This captures the physics of the solar wind drive and coronal heating allowing for a self-consistent physical model. Since this code must capture the steep gradients near the solar surface this modelling requires at least 100 cores of a HPC cluster to simulate in real time. Once the solar wind has become super-sonic and super-Alfvenic much of the detailed physics included in AWSoM becomes less important. Therefore to avoid the substantial computing cost of running AWSoM in high resolution out to L1 a more efficient, but reduced physics, code will be used from 20-30 radii to L1.

The use of an ideal-MHD model from beyond the solar-wind sonic transition to L1 is common in space weather prediction, e.g. the ENLIL code [Odstrcil and Pizzo, 1999]. In PROGRESS this approach will be improved upon by allowing for different ion and electron temperatures. This two-temperature model will allow correct handling of CME shocks and improved modelling of electron thermal conduction. PROGRESS will therefore deliver a coupled model with the essential physics include near the Sun generating the solar wind data self-consistently to drive an MHD model for the solar wind transport to L1. The MHD model will be based on the extensively used Lare3d code [Arber et al. 2001], which while needing modification for solar wind studies, see Work Package details, is a well used and robust algorithm. The new solar wind version of Lare3d will be specifically customised for PROGRESS called SWIFT (Solar WInd Field Transport).

Partner 3 (UW) has a three-dimensional MHD code (Lare3d) that includes resistivity, thermal conduction, optically thin radiative losses and tensor shock viscosity. Once modified to spherical geometry this will be suitable for simulating the solar wind of the inner heliosphere. The code works by taking a fully three-dimension Lagrangian step followed by a geometry remap. This allows the code to easy include additional physics such as different ion and electron temperatures, ion shock heating and electron thermal transport.

Partner 5 (UM) has a three-dimensional Alfven Wave Solar atmosphere Model (AWSoM) that is suitable for simulating the upper chromosphere, transition region and corona. The coronal heating and solar wind acceleration are addressed with low-frequency Alfven wave turbulence. AWSoM uses a spherical grid in which the radial coordinate is highly stretched towards the Sun to numerically resolve the steep density gradients in the upper chromosphere and transition region. The only observational input is the ingestion of magnetograms as boundary conditions for the magnetic field. This model is part of the overarching Space Weather Modeling Framework (SWMF), a software tool to couple various space weather models into one new combined model [Toth et al. 2012]. Both the SWMF and AWSoM have been installed at the Community Coordinated Modeling Center, part of NASA Goddard Space Flight Center.

These models will form the basis of a brand new code to model the solar wind from the surface of the Sun to L1 and beyond.

2.1.2.2 WP3 Forecast of the evolution of geomagnetic indices:

Within the consortium there are a number of codes available that have been developed to model the evolution of various geomagnetic indices.

Models from partner 8 (IRF): In solar-terrestrial physics and space weather SCNNs have been applied in many domains and especially for the mapping from solar wind at L1 to various geomagnetic indices and other geomagnetic quantities: AE [Gleisner and Lundstedt, 2001], Dst [Lundstedt and Wintoft, 1994; Gleisner et al., 1996; Wu et al., 1998; Lundstedt et al., 2001], Kp [Boberg et al., 2000], local ground dB/dt [Wintoft 2005; Wintoft et al., 2005; Wintoft et al., 2014]. Models for Dst and Kp have been implemented for real-time operation driven by ACE solar wind data, and have been in operation since many years at IRF (http://src.irf.se/forecast/dst/, http://src.irf.se/forecast/kp/). In the recently finished EU/FP7 project EURISGIC data and forecasts tools were developed for local dB/dt and set up for real-time operation. The project is described at http://www.eurisgic.eu and the service is found at *http://src.irf.se/eurisgic*.

Models from partner 1 (USFD): Single and multiple input models to forecast Dst and Kp indices have been developed by USFD exploiting the NARMAX approach [e.g. Boaghe et al., 2001; Wei et al., 2004, 2006; Wing et al., 2005; Zhu et al., 2005; 2007]. These models are driven by real time solar wind IMF parameters measured at L1 with a time shift to account for the solar wind propagation from L1 to the Earth's magnetopause. These models are able to provide a forecast that requires knowledge of solar wind parameters and does not require measured values of the geomagnetic indices. With the present availability of solar wind measurements at the L1 point this translates to a one hour ahead forecast for the Dst index with respect to the current time and a few hours ahead with respect to the calculation of the "final" Dst value by the World Data Centre for Geomagnetism in Kyoto. Based on the success of forecast models, USFD team members H. Wei and R. J. Boynton were the only European researchers invited to join the Dst Challenge led by NASA CCMC and developed an advanced NARMAX Dst model in frame of this challenge [Rastätter et al. 2013].

Models from partner 6 (SRI NASU-NSAU): SRI NASU-NSAU possesses two models for the prediction of geomagnetic indices. The first, a recursive, robust bilinear dynamical model (RRBDM) [Yatsenko et al, 2008 and references therein] has minimal complexity and the same prediction limit as NARMAX. RRBDM provides forecasts of the Dst and Kp indices based on new robust algorithms and is driven by real time solar wind parameters measured at L1 with a time shift to account for the propagation of the solar wind to the terrestrial magnetopause and the real time Dst and Kp indices. The second, the Guaranteed NARMAX Model (GNM), [e.g. Semeniv and Yatsenko 2010 and references therein] also provides predictions of the Dst index. Its main advantage is that it delivers an increased prediction reliability in comparison to earlier SRI NASU-NSAU models.

A comparison of the strengths and weaknesses of these models will be used to decide when each of these models performs at its best and to create a new forecasting tool based on the fusion the results of all models.

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

Numerical codes that are currently used to model the evolution of high energy electrons within the radiation belts such as VERB involve solving a set of diffusion equations. These codes require tensors of the quasilinear diffusion coefficients to account for particle pitch angle and energy diffusion due to their interaction with various wave modes. The main types of waves that affect the energetic particles within the radiation belts are Chorus, hiss, Equatorial Magnetosonic Waves (EMW), Electromagnetic Ion Cyclotron waves (EMIC) and lightning whistlers.

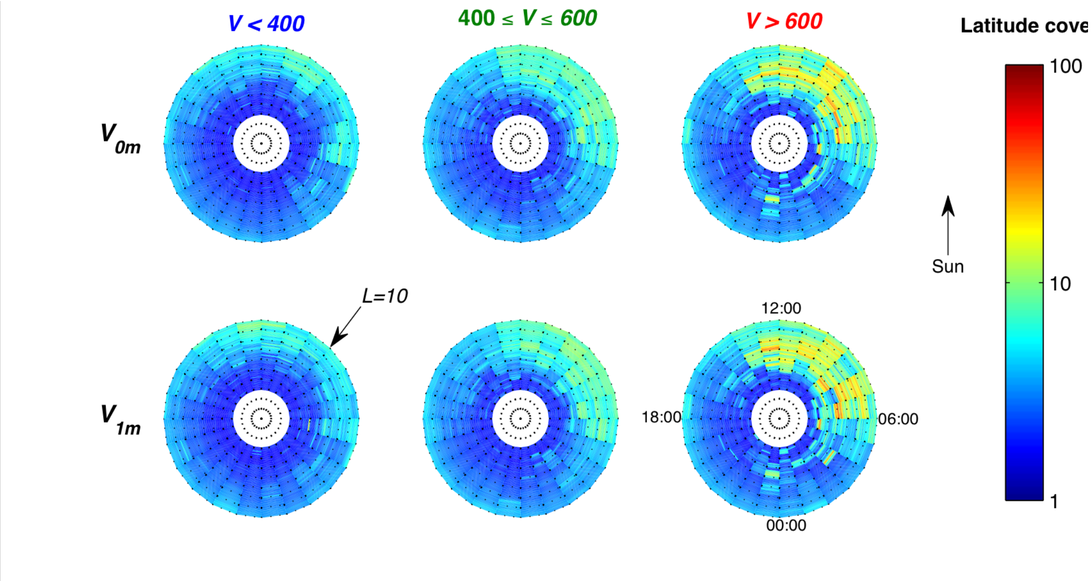

Figure 1: Distribution of wave intensity as a function of solar wind velocity and time

Diffusion coefficient tensors for Chorus, EMW and hiss are based on wave models that represent the statistically averaged wave power of a particular wave type organised according to local time, L-shell and the current value of geomagnetic index (Kp or AE). The Kp index reflects the average value of geomagnetic disturbances as measured on the ground whilst AE attempts to quantify the Auroral Electrojet. This classification of wave amplitudes, however, has several major drawbacks. Currently, these models assume that the state of the magnetosphere is memory-less and does not depend upon the short-term historical evolution of the magnetosphere, i.e. whether geomagnetic activity is constant, increasing, or decreasing. In a simple extreme example the wave amplitude for a case when Kp was zero for the previous 21 hours and is currently 9 will be added to the same cell of the wave model as that measured in the situation when Kp was 9 for the whole 24 hours period. Another weakness of the currently used wave models is related to the results of Reeves et al., [2003] who, after studying a number of strong geomagnetic storms, concluded that only 50% of storms resulted in enhancement of electron fluxes at GEO, whilst 25% caused a decrease and the final 25% had no substantial effect. Thus, whilst Kp and AE can be used to indicate the current level of geomagnetic

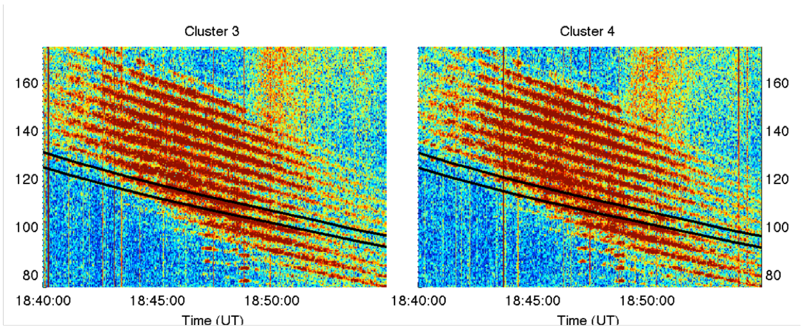

Figure 2: Observations of EMW by Cluster 3 and 4 during the Cluster Inner Magnetospheric Campaign.

activity they do not reflect the observed wave activity. If these models are used to simulate the evolution of energetic particle fluxes in the radiation belts they should be organized by the parameters that affect the evolution of these fluxes. Recent studies at USFD used the Error Reduction Ratio concept to identify the parameters that affect the evolution of the daily averaged electron fluxes in various energy ranges at GEO. The results showed that the solar wind velocity, density and, therefore, dynamical pressure are the most effective parameters that control the energetic electron fluxes [Balikhin et al., 2011; Boynton et al., 2013]. Recent results [Kim et al. 2013] have also shown that the solar wind parameters can provide a better indication of the occurrence of wave activity than geomagnetic indices. The strong dependence of the wave amplitude upon the solar wind parameters, based on Double Star measurements of upper band chorus, is shown in Figure 1. The six panels show the distribution of wave intensity as functions of L-shell and local time for different ranges of the solar wind velocity (columns) The top row shows the correlation between wave intensity and solar wind velocity measured on the same day, the lower row shows the correlation with the solar wind velocity measured on the previous day. The figure shows that the intensity distribution of the observed Chorus waves for different solar wind velocity regimes varies depending upon the time lag of the solar wind velocity measurements. PROGRESS will redevelop the current wave models for chorus, hiss and EMW to include the solar wind velocity and density as organisational parameters as well as geomagnetic indices (separate models for Kp and AE) based on data from Cluster, THEMIS, Akebono, Polar, and CRRES. The wave models that will be developed in frame of PROGRESS will account for previous states of the magnetosphere as well as its current state. This will be done by exploiting the nonlinear Structure Detection techniques that constitute the first stage of the NARMAX procedure and is based on the concept of Error Reduction Ratio developed by a member of the participant 1 team USFD [e.g. Billings et. al., 1989].

The necessity of another important modification of the EMW model has arisen from recent Cluster Inner Magnetosphere Campaign (July-October 2013) that targeted the study of various types of magnetospheric waves. The uniqueness of this data set lies in the very small inter-satellite separations (down to 4 km) employed. This situation is extremely favourable for probing waves and is beyond the capabilities of any other current or previous missions. The developers of the current EMW models assumed a Gaussian shaped wave spectrum. However, the Cluster measurements (Figure 2) show that the EMW spectrum consists of a number of discrete emissions at harmonics of proton gyro-frequency and, importantly, that the Chirikov resonance overlap criterion is not satisfied, indicating that the contribution of each harmonic to the quasilinear diffusion should be calculated separately to avoid erroneous results. PROGRESS will re-estimate the diffusion coefficients resulting from EMW models taking into account the discrete structure of the EMW emission.

2.1.2.4 WP5 Low energy electrons model improvements to develop forecasting products.

The approach of WP5 is based on the Inner Magnetosphere Particle Transport and Acceleration Model (IMPTAM) [Ganushkina, et al., 2005, 2012], available within the consortium through partner 2 (FMI). This code traces ions and electrons with arbitrary pitch angles from the plasma sheet to the inner L-shell regions with energies reaching up to hundreds of keV in time-dependent magnetic and electric fields. The tracing of a distribution of particles is conducted in the drift approximation under the conservation of the 1st and 2nd adiabatic invariants. Liouville's theorem is used to gain information of the entire distribution function. The IMPTAM version to nowcast low energy (< 200 keV) electrons in the inner magnetosphere [Ganushkina et al., 2013a, b] is currently operating online under the FP7 funded SPACECAST project (http://fp7-spacecast.eu).

The present model provides the low energy electron flux at all L-shells (L=2-8) and at all satellite orbits, when necessary. The IMPTAM model is driven by real time solar wind and IMF parameters measured at L1 with time shift to account for the solar wind propagation to the Earth's magnetopause, and by the real time Dst index. For electrons, the radial diffusion equation is solved, in addition to convection and drifts, and the effects of losses are incorporated due to convection outflow and pitch angle diffusion based on the electron lifetimes. The remarkable advantage of IMPTAM is that it takes into account the substorm-associated electromagnetic fields by launching an electromagnetic pulse at substorm onsets determined by AE index. The proper forecast of AE index is essential for accuracy of substorm representation in IMPTAM. The significance of IMPTAM within PROGRESS is related to the low energy electron fluxes that are critical to the processes involved in satellite surface charging phenomena. In addition, the low energy electron population constitutes the seed population for the high-energy MeV particles in the radiation belts

2.1.2.5 WP6 Forecast of the radiation belt environment.

The approach of WP6 is based on improvements to the current Versatile Electron Radiation Belt (VERB) code that is available in the consortium through partner 4 (Skoltech), [e.g. Subbotin et al., 2011, and references therein] and its fusion with the NARMAX SNB^{3}GEO model from USFD and also a fusion between VERB, SNB^{3}GEO and IMPTAM. VERB is a diffusion code that models radiation belt particle dynamics using the bounce-averaged Fokker-Planck equation [e.g. Schultz and Lanzerotti, 1974] with diffusion in radial distance, pitch angle and energy. One of the main advantages of the VERB code in comparison to the models available in Europe (e.g. BAS and ONERA models) is the inclusion of the mixed diffusion terms that are not accounted in European models. The VERB code uses tensor diffusion coefficients that are parameterised according to the location (L*, local time) and geomagnetic index (available options are Kp or AE). The significance of the VERB code within PROGRESS is related to the importance of high-energy electron fluxes to the spacecraft hardware damage. The NARMAX SNB^{3}GEO model is a Multi Input Single Output (MISO) NARMAX model that is developed to provide a forecast of the daily averaged electron flux at GEO for energy ranges >800 keV and >2MeV. NARMAX is a black box methodology and was trained on electron flux data from GOES13. The inputs to the model are the daily averaged L1 solar wind velocity and density, along with the fraction of time that the IMF is southward. SNB^{3}GEO has been operating online for the last two years, providing accurate 24 hour ahead forecasts of the daily averaged fluxes of relativistic electrons with energies in excess of 800 keV (http://www.ssg.group.shef.ac.uk/USSW/800keV_EF.html) and in excess of 2 MeV (http://www.ssg.group.shef.ac.uk/USSW/2MeV_EF.html) [Boynton et al, 2013]. Since the Sheffield SNB^{3}GEO model provides reliable forecast it has been solicited by the CCMC at GSFC NASA and currently operates from their web site as well as from Sheffield. Accurate forecast by SNB^{3}GEO will be exploited by WP6 to provide a boundary condition for VERB. The output of the IMPTAM model will be employed to provide low energy seed population for the VERB model.

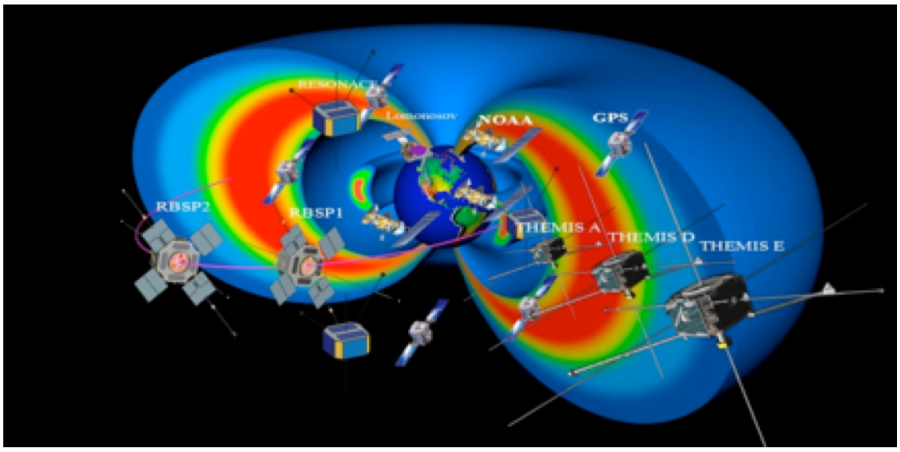

Figure 3: Earth's radiation belts with key satellite missions overlaid. Missions include: the THEMIS mission, NASA RBSP mission, UCLA-MSU mission Lomonosov, Russian RESONACE mission, and multiple GPS and NOAA and GOES spacecraft

Data assimilation is an algorithm that allows for an optimal combination of model results and sparse data from various sources contaminated by noise [e.g. *Kalman*, 1960; *Ghil*, 1997; *Ghil and Malanotte-Rizzoli*, 1991; *Shprits et al.,* 2007]. Satellite observations are often restricted to a limited range of radial distances and energies and have different observational errors. Data assimilation allows us to fill in the temporal and spatial gaps left by sparse in-situ measurements. It also allows for combining measurements from different spacecraft with different uncertainties according to the underlying errors of each of the instruments.

Members of the Skoltech participant team have used data assimilation with CRRES data and a simple one dimensional radial diffusion model to reconstruct the radiation belt electron PSD for a period of 50 days and found that radial diffusion, which produces monotonic profiles in PSD, cannot explain peaks in PSD that are clearly seen in the reanalysis [*Shprits et al.* 2007]. This result was consistent with earlier findings [*Green and Kivelson*, 2004*, Chen et al*., 2007] and consistent with a recent study of *Reeves et al.* [2013]. Similar results were obtained by *Koller et al*. [2007] for one storm in 2003.

Members of the Skolkovo participant team, in collaboration with colleagues at UCLA, performed data assimilation studies with a 1D radial diffusion code using data for a period of up to 1.5 years in 1990-1991 and for 160 days in 2003 [*Shprits et al.,* 2007; *Kondrashov et al*., 2007; *Ni et al.,* 2009a; 2009b; *Daae et al*., 2011; *Kondrashov et al*., 2011; *Shprits et al*., 2012; *Kondrashov et al*., 2012], and a LANL study of a storm in October 2003 [*Koller et al.,* 2007; *Reeves et al*., 2012], showed that data assimilation with a simple radial diffusion model can reconstruct radial profiles of the drift-averaged phase space density. We have performed validation and verification of the data assimilative code and also performed sensitivity simulations to the assumed boundary conditions and magnetic field models.

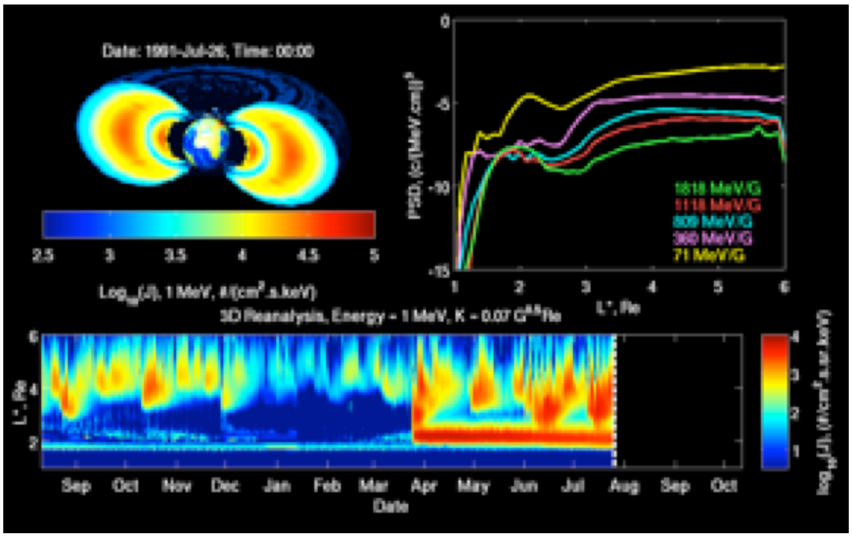

Figure 4: 3D reanalysis during 1990. The top 2 panels show a snapshot on the 13th Oct 1990. The left panel shows 1 MeV integrated flux to scale around the Earth, and right panel shows PSD versus L* at multiple values of the first invariant m. The bottom plot shows 1 MeV differential flux obtained from long-term 3D reanalysis in an L* versus time format. All plots are for a fixed K value of 0.07.

The results of the reanalysis revealed a number of key processes that determine the dynamic evolution of the radiation belts. Data assimilation showed evidence that there are peaks in phase space density associated with the local acceleration that occurs at around 5 R_E, right outside of the plasmasphere. The reanalysis results also showed evidence that dramatic depletions of the radiation belts occur when the magnetosphere is compressed, and particles escape to the interplanetary medium. Reanalysis have been recently made public as in an AGU publication as auxiliary material [e.g., *Shprits et al.,* 2012]. Our results are already used by a number of research groups around the world. To fully understand the complex nature of acceleration and loss, reanalysis should be done in terms of three dimensions (radial distance, pitch-angle, and energy), use a vast amount of observations including pitch-angle distributions and energy spectra. We need to be able to assimilate into the code all available information from different satellites (Figure 3). The computational requirements of the optimal Kalman filter become very large in the case of a multidimensional system. In a recent study *Shprits et al*. [2013] demonstrated computational efficiency of a split-operator method for data assimilation with the VERB 3D code In particular we will perform 1D data assimilation for each of the directions separately (radial diffusion, pitch-angle, energy). Special attention will be paid to estimating the errors of each of the measured and modelled quantities. Observational errors will be inferred from the inter-calibration of different satellites and from comparison of satellite measurements with reanalysis results for selected time intervals. Model errors will be estimated by a detailed analysis of the innovation vector. We will also verify the model and observational error estimates by the covariance matching method [*Fu et al.,* 1993]. Examples of 3D-data assimilation using five satellites during the CRRES era are shown in Figure 4.

Reanalysis of the radiation belts in 3D allows us to obtain a global picture of the radiation belts and the inner magnetosphere and to identify and quantify acceleration and loss mechanisms. A comparison of the reanalysis with the coupled code results with no data assimilation will indicate what processes are missing in the model and how accurately the code can predict the evolution of the radiation belt fluxes at various energies, pitch-angles, and radial distances. Such comparison will identify the conditions when these processes are most efficient and the spatial scales on which they operate.

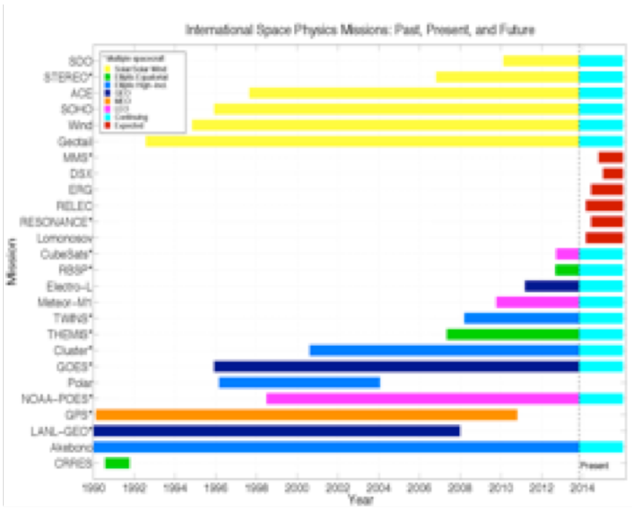

Figure 5: Available satellite data. Color-coded are various satellite orbits. Missions beyond 2011 are projected/continuing. Intervals with CRRES, Polar, THEMIS and RBSP data will be used for detailed validation of coupled codes and data assimilation, and cover all 4 phases of the solar cycle over a 25 year period

We will perform model runs from the start of the CRRES era to the current era (1990 – 2015). We plan to use the SSA method as was recently done by *Kondrashov et al.* [2010;] to fill gaps in solar wind data from 1990-1994, and utilize OMNI1-minute data thereafter. This period contains two full solar cycles with various satellites covering the solar maximum, declining phase, solar minimum and ascending phase periods. This interval included the very quiet conditions during 2007-2009 and time intervals that are well observed by a number of satellites during CIR and CME dominated storm time intervals. A list of the satellite data available during the interval is shown in Figure 5.

We will perform validation of the data assimilation by comparing the results of the reanalysis using different satellites. We will perform data assimilation for all available data for 1991 and compare the results using different sets of satellites.

2.1.2.6 WP7 Fusion of forecast tools

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. Thus, by combining the results of forecasts of the various geomagnetic indices it is possible to obtain a more complete picture of the way the magnetosphere is evolving due to changes in the solar wind. This picture is supplemented further by combining it with forecasts of the activity of the radiation belts and in particular the fluxes of electrons that inhabit this region. As a result, a more comprehensive overview of the effects of the interaction of space weather events will be produced, leading to a better scientific understanding of this interaction and vastly improved system for monitoring and warning of hazards to our susceptible space and ground-based infrastructure.

2.1.3 Ambition

The overall ambition of PROGRESS is to exploit the synergy between world leading experts in the fields of solar physics, magneto-hydrodynamics, magnetospheric physics, system science, and data assimilation to achieve radical advances in our capabilities of forecasting space weather. These advances will result from both a significant improvement in the forecast accuracy and a major increase in the forecast lead-time.

As was demonstrated in Section 1.3, Europe possesses a number of individual models that are used as stand alone systems to forecast particular features of space weather such as geomagnetic indices or the fluxes of energetic electrons within the radiation belts. These stand-alone models have been developed and their results validated, showing them to be mature technologies at a readiness level (TRL) of 4-5 (as defined in Annex G of the Horizon 2020 Space Work Program). Within project PROGRESS, we aim to take these models, and to build them into a prototype operational system (TRL 7) to demonstrate the advantages of using the models concurrently in order to achieve a bigger, more detailed picture of how space weather affects our planet. This ambition is supplemented by the drive to improve these existing models and their forecasting abilities, particularly in the development, validation and operation of the new solar wind model SWIFT. At the end of the project, Europe will possess a new, sophisticated tool to enable forecasts of the space weather environment. In addition, UW will be routinely running a local version of AWSoM, and USFD the new upgraded version of VERB, giving scientists within Europe access to these models.

This ambition will be achieved in the following six goals, each mapped to a separate work package:

2.1.3.1 WP2 – Propagation of the solar wind from the Sun to L1

In developing this new, coupled model approach PROGRESS will specifically address the following shortcomings of current state-of-art real-time space weather predictive packages. 1) Parameter tuned semi-empirical models will be replaced by first principles physics simulations to derive the solar wind properties from the photosphere out to 20-30 solar radii. 2) The solar wind transit from 20-30 radii outwards will be modelled with a customised MHD model including a two-temperature plasma and improved electron transport. These two advances will lead to increased fidelity in the L1 predictions in real-time from GONG magnetogram data. The PROGRESS MHD models will also be able to give predictions at the inner planets for comparison with Mercury MESSENGER and Venus Express, compare changes in the regions Sun to Mercury, Mercury to Venus and Venus to Earth, calculate SW parameters that drive accurate Dst, Kp, AE forecasts. This will transform the EU’s ability to predict space weather.

2.1.3.2 WP3 – Forecast of the evolution of geomagnetic indices

The forecasting of geomagnetic indices from upstream solar wind data has a long history and has evolved from linear filters for Dst [*Burton et al.*, 1975] to more complex non-linear and dynamic approaches [*Lundstedt and Wintoft*, 1994; *Yatsenko et al.*, 2008], but also to include other indices such as Kp [*Boberg et al.*, 2000; *Yatsenko et al.*, 2008], AE [*Gleisner and Lundstedt*, 2001], and local magnetic field disturbances [*Wintoft et al.*, 2014]. Today, several institutes provide real-time forecasts of Dst and Kp.

The aim within this project is to survey existing models, with special emphasis on the models available to this team, and perform verification to identify weaknesses and limitations, which will be used as inputs to improve the forecast models. Forecast verification is a mature subject within the meteorological research from which methodologies can be applied, especially for problems related to forecasting of extreme events. A subgroup within the COST ES0803 Action was devoted to this [*Wintoft et al.*, 2012].

For real time operation it is important to note that the ACE science level data, from which models usually are derived, are not identical to the ACE real time data. Of special importance are the plasma instrument outages that occur during proton events. These aspects must be considered during the verification. And it is not known how the coming DSCOVR will perform during these events. During the more severe events the plasma density and velocity are not known and models must be developed that rely on the magnetic fields only.

The standard approach to forecast indices from the solar wind is to map state-space vectors of solar wind quantities, like magnetic fields and plasma (either directly or parameterized) to the index, where the mapping function is found from the data. This is a powerful technique that has been applied to Kp, Dst, and AE [see references above]. The verification that will be carried out will help on how the models may be improved. Related to this are the onsets of major geomagnetic disturbances that are determined by the detailed solar wind evolution (minute resolution) which to a great degree is lost if temporal averaging are applied. Figure 6 illustrates an ICME with following geomagnetic response described by AE. However, moving towards high temporal resolution solar wind data raise another level of complexity as ballistic propagation from L1 to the magnetopause is not possible. Different approaches will be studied for shock identification [e.g. *Kartalev et al.*, 2002; *Clarke et al.*, 2005]. It should be noted that for extreme events the propagation time from L1 to the magnetopause is typically less than 30 minutes, and may reach down to only 10 minutes. From a practical point of view the L1-magnetopause modelling can be considered as now-casting, while the following substorm evolution may be forecast due to timescales of magnetospheric and

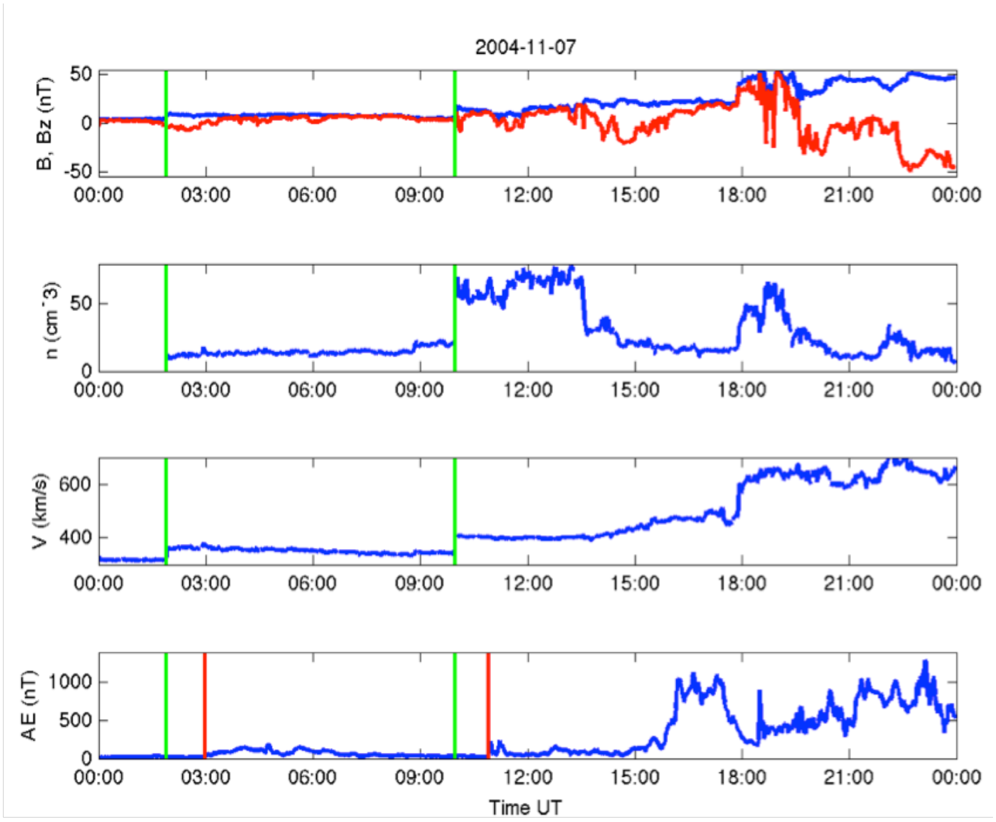

Figure 6: The solar wind magnetic field, density, and velocity for an ICME hitting the Earth on Nov. 7, 2004. The geomagnetic response in terms of the AE index is shown in the bottom panel. The green lines mark shocks in the solar wind and the red lines the sudden commencements. Later in the afternoon and evening the substorm activity sets in.

ionospheric dynamics.

The solar wind and geomagnetic response will also be explored using categorization and classification methods, which will provide information on e.g. shocks, sudden commencements, and sub-storms. This is a complex task but with a significant impact and the results can be used in the modelling mentioned above to improve Kp and Dst forecasts, and to develop the AE forecast models. This will also provide insights on how to capture the evolution of AE, like envelope or power spectrum, without having to know the detailed minute-to-minute variability.

The models, both updated and newly developed, connecting the L1 solar wind to the geomagnetic indices will provide forecasting from tens of minutes up to hours and may be driven by real time solar wind data. However, the models will also be used with inputs from forecast solar wind based on the Sun-L1 forecast models, thus providing forecasts of the indices 15 hours to days in advance.

We are planning to develop the following new methods, algorithms, and software for the identification of RRBDM models: 1) a novel robust recursive least-squares method with modified weights for the identification of bilinear model structure and unknown parameters; 2) a novel robust subspace identification of multivariate bilinear state space system based on separable least squares optimization; 2) robust algorithms for identification of RRBDM models using input-output data; 3) the software for the RRBDM model identification; 4) recommendation for improving of the existing services.

We propose the following new methods and algorithms for improving of the existing services using guaranteed NARMAX models (GNM): 1) a novel method for the identification of GNM model that based on the maximal and minimal Dst-index values forming an interval tube and a polynomial discrete input-output dynamical system; 2) a novel algorithm for the automatic selection of regressors for NARMAX models; 3) a novel algorithm for the automatic selection of the optimal model structure and unknown parameters by solving the corresponding mathematical programming problem using genetic algorithms.

2.1.3.3 WP4 – Improving current physics based models for the energetic electron fluxes in the magnetosphere.

Currently, all physics based models for energetic electron fluxes in radiation belts are based on the solution to the bounce-averaged Fokker-Planck equation and include terms for diffusion in radial distance, pitch angle and energy. The most advanced codes, such as VERB (Skoltech, Russia) or RAM (LANL, USA), incorporate mixed diffusion terms, factors that are lacking in current European models (BAS, ONERA). These diffusion codes require tensors of diffusion coefficients parameterised by location (L, local time) and the current level of geomagnetic activity, usually specified by the Kp or AE geomagnetic indices. These diffusion tensors are deduced, in turn, from statistical models of the observed wave amplitudes in the magnetosphere. Individual wave models have been developed for the key types of waves observed in the inner magnetosphere: chorus, hiss and equatorial magnetosonic waves [e.g. *Meredith et al.*, 2008, 2012] and have typically been parameterised by location and geomagnetic index, which then determines the parameterisation of the tensor diffusion coefficients. However, this parameterisation does not reflect recent findings regarding the evolution of the radiation belts. Parameterisation using the current value of geomagnetic index alone, neglects any knowledge we may have regarding the dynamics of the magnetosphere in general and the radiation belts in particular. It is known that the response of the radiation belts to magnetic storms driven by the high speed solar wind associated with co-rotating interaction regions differs from the response to storms of similar strength (and therefore similar variation of geomagnetic indices!) caused by coronal mass ejections [*Miyoshi and Kataoka*, 2005, 2008]. The current methodology used for these wave models is based on the implicit assumption that the spatial distribution and intensity of magnetospheric waves are the same in both cases mentioned above. This assumption, however, has not been proven by experimental studies. It is also doubtful that it will be proven in the future since waves are key to the processes of the electrons local acceleration or loss and the dynamics of energetic electrons differs in these two cases. PROGRESS will re-develop the wave models and corresponding diffusion tensors to account for this shortcoming in the current wave models by incorporating parameters of the solar wind within the classification scheme. According to recent studies, the solar wind velocity and density are the most effective parameters in the control of the energetic electron fluxes [*Boynton et al*., 2013]. PROGRESS will use these parameters to organize the wave models and sets of diffusion coefficients. The other drawback with the current methodology is the parameterisation of wave models using the current value of the geomagnetic index. This parameterisation assumes that the wave distribution is independent of the previous evolutionary state of the magnetosphere. Again, there is no experimental evidence to support this assumption. However, it is known that the dynamics of the high-energy particle fluxes is different during an interval corresponding to the main phase of a particular magnetic storm and an interval occurring in the recovery phase of a stronger storm even though these two intervals are characterized by the same value of geomagnetic index.

The software implementation of the algorithms for automatic identification of chorus, hiss and equatorial magnetosonic waves [*Bortnik et al*., 2011; *Mourenas et al*., 2013] is currently available within CNRS/LPC2E (partner 7), Skoltech (partner 4) and USFD (partner 1). However in the development of the new wave models PROGRESS must address the following problems 1) How to identify the time lag (time delay) between solar wind velocity/density changes and corresponding response of waves? and 2) Which time lags of the preceding values of geomagnetic indices should be used to account for the previous evolution of the magnetosphere. The existence of the first problem is evident from Figure 1 as the intensity of Chorus waves correlates with the maximum of the solar wind velocity both on the current and the previous day. To overcome these problems PROGRESS will exploit the Black Box System Structure detection methodology that is based on the Error Reduction Ratio and has been developed by USFD. This methodology has been successfully applied to the quest of the solar wind/magnetosphere coupling functions [*Boynton et al*., 2011, *Balikhin et al*., 2010] and to determine the time lags involved in the solar wind control of relativistic electron fluxes at GEO [*Boynton et al*., 2013, *Balikhin et al*., 2011]. Finally, the wave model for the equatorial magnetosonic waves will need to take into account the recent findings from the Cluster mission that the discrete nature of this emission should be not neglected in the contribution of these waves to the pitch angle and energy diffusion of magnetospheric electrons. The data from the Cluster Inner Magnetosphere campaign gives a clear indication of the harmonic structure of the Equatorial magnetosonic emission (see Figure 2). The data of this campaign proved that the previously used methodology that fitted Gaussian spectral shape in the calculation quasilinear diffusion coefficients [*Mourenas et al*., 2013] since the Chirikov criteria is not satisfied for all harmonics. WP4 will readjust methodology to calculate diffusion coefficients, using statistics gained by Cluster on the spectral widths of discrete harmonic line. As it is measurements from the spectral analyser data which are unable resolve the harmonic structure of these emission are used to develop wave models for equatorial magnetosonic waves, the new methodology will be developed. Instead of fitting Gaussian spectrum the discrete harmonic spectrum will be fitted. The number of and width of the harmonics will be identified using local magnetic field measurements, frequency range of the emission observed by spectral analyser, results of statistical study of the width of harmonics from Cluster Inner Magnetosphere campaign data.

Summarising, this new approach to the parameterisation of wave models and diffusion coefficients has never been performed before and requires the combination of expertise in the physics of the radiation belts and systems science that is available within the PROGRESS consortium. These novel diffusion tensors, developed by PROGRESS, will reflect the realistic conditions of wave particle interactions in the magnetosphere. The incorporation of the resulting diffusion tensors into the VERB code will significantly improve its modelling and forecasting capabilities. The development of these statistical models requires access to large amounts of satellite data. Between them, the PROGRESS partners have access to data from a large number of magnetospheric missions, including not only the freely available data from Cluster, THEMIS, and POLAR, but also from missions with limited access to data such as Akebono, CRRES and the Double Star mission for which the whole five year period of validated wave data is currently available only within the Sheffield partner.

2.1.3.4 WP5 – Low energy electron model and improvements to develop forecasting products.

The crucially important population in the inner magnetosphere, the low energy (< 200 keV) electrons, will be modelled with the Inner Magnetosphere Particle Transport and Acceleration (IMPTAM) model. The ability of the model to output realistic low energy electron fluxes depends on the several model constituents, one of the most important being the distribution at the model boundary. Electrons start to move from the plasma sheet towards the inner regions. It is vital to set time-dependent, solar wind driven boundary fluxes in the plasma sheet. There are no models like this currently available at present. We will construct an empirical model for the boundary conditions for the low energy (from a few to tens of keVs) electron fluxes at L=8-10 dependent on solar wind and IMF parameters using the available data from the satellites including Polar HYDRA DDEIS, Cluster PEACE, THEMIS ESA and Allen probes HOPE. Geostationary measurements at GOES MAGED, LANL MPA and SOPA (when available) will be used to verify the model when tracing the electrons with the developed boundary distribution at L=8-10. This will be a significant step forward, since the model output is highly determined by the accuracy of the boundary conditions.

Another important factor for proper modelling of low energy electrons is taking into account the loss processes determined by wave-particle interactions. A lot of effort has been put into studying wave-particle interactions when modelling high energy radiation belts. Low energy electrons have not been usually considered. The proper incorporation of wave-particle interactions is now possible due to the existence of the Full Diffusion Code (FDC) model (VERB) which provides the diffusion coefficients and can now calculate them in a non-dipole field. The matrix of diffusion coefficients as a function of L-shell, pitch-angle, and energy for various levels of geomagnetic activity will be computed by FDC. Using the diffusion coefficients, we will parameterize the loss and the computed lifetimes will be included in to the IMPTAM code.

IMPTAM will be extended from simply a nowcast model to a forecast tool. Since IMPTAM is driven by the real time solar wind and IMF parameters and Dst index, forecasting these input parameters will greatly advance the forecasting capabilities of IMPTAM. Substorm activity is a key player in the low energy electrons transport and acceleration. It is very difficult to incorporate the substorm activity effects even for nowcast modelling. IMPTAM considers the effects which substorm activity has upon the transport and acceleration of low energy electrons by launching an electromagnetic pulse at substorm onset times. To launch a pulse at a substorm onset with a magnitude scaled by a peak value of AE index, the substorm timing and AE peaks must be forecasted. With the development of the forecasting tools in PROGRESS for AE index in WP3, the substorm activity effects will be properly taken into account. A trial version of forecast model for low energy electrons will be put online. This is an innovative approach which has never been done before.

2.1.3.5 WP6 – Incorporation of data assimilation methodologies into current physics based models for the high-energy particle fluxes in the magnetosphere.

Data assimilation of the electron radiation belt observations is needed for the understanding and forecasting of physical processes in the radiation belts, prediction, and mitigation of space weather effects in the hazardous space environment. Over a period of less than 10 years, there has been a steady increase in Kalman filter applications to solve the assimilation problem of satellite observations. However, a fundamental problem in the application of the Kalman filter is the assumption about values of the noise statistics that describe the model errors arising from the imperfect description of the process dynamics. Additional difficulties appear in the assimilation of multiple-satellite observations characterized by large variety of unknown observation error statistics. The effectiveness of estimation and forecasting of radiation belts dynamics depends on how well the dominant physics is described by the model and the accuracy of the unknown noise statistics. However, accurate parameter estimation is a challenging problem when only sparse satellite observations are available coupled with the highly variability of radiation belts dynamics. This explains the wide application of the Kalman filter on the basis of empirical choice of noise statistics without sufficient justification that may significantly distort the assimilation output and provide false conclusions about the dynamics of the radiation belts.

Therefore, the development of consistent identification methods for physical model errors and satellite observation errors and the construction of an adaptive Kalman filter on the basis of parameter identification that optimizes the assimilation output is of prime importance for the estimation and prediction of radiation belt dynamics. Project PROGRESS aims to develop a set of identification methods for unknown noise statistics, such as the bias and covariance matrix of model errors, characterizing the uncertainty of radiation belts dynamics. These techniques will be further refined to estimate the observation errors statistics that are crucially important for optimal assimilation output, identifying the coefficients of proportionality that characterise the dependence of observation errors on satellite observations. Additional improvements and an increase in the accuracy of the assimilation of the electron radiation belt observations will result from the use of the backward optimal smoothing procedure applied to the forward Kalman filter estimates providing further refinement in our knowledge of the key physical mechanisms and leading to the operational forecasting of radiation belts.

One of the important weaknesses of the currently available European physics based forecast tools, including those that were developed in frame of the SPACECAST, is the absence of comprehensive dynamic models to define the boundary conditions. PROGRESS is going to overcome this weakness by exploiting the accuracy and reliability of data based models deduced for GEO. The availability of continuous and uniform (i.e. instruments with the same sensitivity range etc.) data is critical to the development of data based models. In the entire magnetosphere such data are available only at GEO. In other regions the measurements are sparse and not uniform since the observations are made by different satellites. Therefore there is no possibility to extend data based forecasting tools outside GEO. PROGRESS proposes to overcome this problem by incorporating data based forecast at GEO as a boundary condition for the physics based numerical models. The SNB^{3}GEO model for electron fluxes at GEO has proven reliability since online operations began in 2012. The accuracy of the USFD SNB^{3}GEO model was the reason why CCMC GSFC NASA requested and now operates this model from their web site. PROGRESS will couple the SNB^{3}GEO model with the VERB code. VERB is the only existing code that can accurately calculate diffusion coefficients in a non-dipole magnetic field, includes mixed term diffusion, and accounts for hiss, MLT dependent chorus, EMIC, and magnetosonic waves. Such codes are not currently available in Europe. The VERB-NARMAX coupled code will have advantage of accurate forecasts and the ability to model and forecast energetic electron fluxes in the whole entirety of the outer radiation belts. PROGRESS is planning to develop and run the code on the computing facilities of the Sheffield partner and make this code available in Europe after the completion of the project. The code similar to the VERB-NARMAX coupled code currently is not available either in Europe or outside.

2.1.3.6 WP7 – Coupling the solar wind forecast at L1 with the geomagnetic indices and radiation environment models.

In the final stages of the project the forecast of the solar wind at L1 will be conjugated with the forecast models developed for geomagnetic indices and radiation environment. The predicted solar wind parameters will be used as inputs to the geomagnetic indices forecasting tools, to increase the lead-time for the forecast of geomagnetic indices. Both the predicted solar wind parameters and the forecasted values of geomagnetic indices will be used as inputs to the IMPTAM and VERB-NARMAX coupled code. This will result in the forecast of electron fluxes in the inner magnetosphere with significantly increase lead-time in comparison to the present capabilities. Whilst it is useful to see an overview of the electron fluxes within the inner magnetosphere, it is important to use these forecasts to estimate the electron fluxes that occur along actual spacecraft orbits in order to estimate the probability that ESD may occur. PROGRESS will develop a tool to estimate the fluxes if electrons at different energies along an orbital track.

2.2 Impact

2.2.1 Expected impacts

According to the Horizon2020 work program call PROTEC-1-2014 projects are "… expected to **deliver new insights** into the detailed processes that generate space weather. This should contribute to **new services** able to predict, with a **significantly higher precision** than today, space weather events affecting the Earth and the near Earth space environment".

Project PROGRESS meets the expected impact through the analysis and modelling of data and processes within the geospace environment to develop of a set of tools to forecast the short term (up to a few days) evolution of this environment based on the observed changes of the Sun and solar wind. In particular:

PROGRESS will provide a set of '… ***new services*** …' that will deliver

- Forecast of the conditions in the solar wind as it propagates from the Sun towards L1 and the Earth from a new European MHD model of the solar wind. This will be achieved by the development the European SWIFT code and installation of the U. Michigan code AWSoM at Warwick. Currently, this code is unavailable in Europe.
- Forecasts of the evolution of the state of the magnetosphere as expressed by geomagnetic indices such as Dst, Kp, and AE.
- Significantly more accurate and reliable forecasts than those currently available from the models developed in framework of FP7. These forecasts of the radiation environment in the entire region of radiation belts will be achieved by the fusion of the most accurate European data derived tool SNB3GEO and the most advance physics based numerical code of radiation belts
- Forecasts of the electron fluxes along satellite orbits that pass through the inner magnetosphere.

PROGRESS will deliver forecasts with a '… ***significantly higher precision*** …' than those available today. This will be achieved by

- The use of data driven modelling techniques to forecast the geomagnetic indices and electron fluxes at GEO
- The use of data driven models to provide the boundary conditions for physical models such as VERB and IMPTAM.
- The re-engineering of statistical wave models to account for the short-term historical evolution of the magnetosphere as well as changes in the solar wind. These models are used to calculate the quasilinear tensors of diffusion coefficients that are used within numerical models.

The models developed within project PROGRESS will provide '… ***new insights*** …' into the physics of space weather processes. In particular

- The solar wind model will be used to trace and investigate the evolution of disturbances as they propagate from the Sun, passed Mercury, Venus, and on to the Earth.
- The use of the NARMAX modelling methodology naturally results in physically interpretable models describing the underlying processes occurring. These results

may be compared with physical models to highlight possible differences, which may then be investigated further thus improving the physical model.

- The relationship between changes in the solar wind and the response of the magnetosphere and the fluxes of energetic electrons in the radiation belts will be investigated to determine which solar wind parameters have the greatest influence on their evolution.

2.2.1.1 Science impact

PROGRESS will achieve scientific impact on four fronts. Firstly, PROGRESS will develop an MHD model to describe the evolution of the solar wind from the point at which it leaves the solar locality, typically from ~25Rs, and propagates to the Earth at 1AU and beyond. This code will include the propagation of CMEs and CIRs to provide an estimate of the time for their arrival at Earth, together with expected values for the solar wind plasma density, temperature, and velocity. These predicted values will be compared against measurements from Mercury MESSENGER, Venus Express, and ACE and its future replacement DSCOVR (planned launch date January 13, 2015).

Secondly, the evolution of state of the magnetosphere, as expressed in the form of geomagnetic indices, will be investigated based on the comparative results obtained from existing models as well as new ones determined using data driven modelling methods such as NARMAX and CNN. These data driven modelling techniques have been shown to provide models with a markedly higher accuracy than those based solely on physical principles. This aspect of PROGRESS will result in the best models to use for prediction of geomagnetic indices depending upon the state of the solar wind driver.

The third scientific aspect addressed by PROGRESS will be the forecasts of particle fluxes within the radiation belts. This will be achieved by coupling existing physics based models for the low (IMPTAM) and high (VERB) energy electron fluxes with the more accurate but spatially limited NARMAX models for the electron fluxes at GEO. This coupling of the models will enable forecasts to be made for the changes in the particle environment throughout the inner magnetosphere.

The fourth science aspect is the improvement of statistical wave models used within numerical codes to describe the interaction between the waves and electrons. Current numerical models use a set of diffusion tensors to describe the interaction between particles and waves. These tensors are, in turn, calculated using statistical models for the occurrence and amplitude of various wave types observed in the inner magnetosphere. These current models, however, neglect the effects of the time evolution of the magnetosphere and also the solar wind conditions that are driving the system. Both of these effects have been demonstrated to have significant impacts on the state of the magnetosphere and the particle environment of the radiation belts. Our new models will take these new factors into account, producing statistical models that more accurately reflect the wave-particle interaction process.

2.2.1.2 Commercial Impact

PROGRESS will also achieve significant impact from a commercial perspective. The models and prediction tools produced as a result of the above mentioned research will be amalgamated into one easy to use interface will cater to the requirements of both scientific and commercial users. This interface will provide users with an overall assessment of the current space weather conditions together with an accurate forecast for their short-term evolution. Satellite operators will be able to use the results of the data assimilation of past events to estimate the probabilities that a particular anomaly has been associated with space weather.

2.2.1.3 Challenges

Project PROGRESS brings together experts in the fields of numerical and data driven modelling and data analysis to combine their talents in pursuit of excellence in the forecasting of space weather events and their effects on the magnetosphere. The new knowledge gained as a result of these innovative activities will strengthen the level of science within Europe and it competitiveness on the world stage. The mix of scientists and stakeholders (via the SAB) will ensure that the resulting forecast tools within project PROGRESS will meet both scientific and commercial requirements, thereby increasing the competitiveness of in the global market place.

There are two technical challenges associated with the project. The first involves the propagation of the solar wind from the vicinity of the Sun to the L1 point and the accuracy of forecasts. In order to fulfil this task successfully the consortium includes experts in in the field of MHD modelling (University of Warwick) and is supplemented with further specialists from the University of Michigan who have extensive experience in the modelling of the solar wind and its interactions with planetary obstacles. Currently, there is no European model to compare our results against, only either actual measurements from Mercury MESSENGER, Venus Express, and ACE/DISCOVR or the online American model ENLIL.

The second technical challenge is to find a methodology to couple the physical models (IMPTAM and VERB) with the output of models based on data driven modelling. Preliminary studies in this area using NARMAX and VERB have already investigated some simple methods based on rescaling. Project PROGRESS will refine these methods based on comparisons of the output from the coupled model with measurements from missions such as Cluster, THEMIS, and Van Allen Probes to achieve realistic results.

A final challenge, related to the commercialisation of the results, centres around a system to express the forecasts such that they will be instantly comprehensible in the market place. This requires a set of standards by which to express the results in a way understood by industrialists and scientists alike. This aspect will be one of the items addressed in the meetings of the Stakeholder Advisory Board.

2.2.1.4 Advantages of a European Approach

As is evident from the number of participant, spread throughout Europe and also including important collaborators in USA and Russia, no single group has the expertise to complete this project alone. PROGRESS utilises expertise from around Europe to fulfil its aims, creating a collaboration between groups of differing interests to apply their knowledge in a concerted way to the study of Space Weather. However, in order to reduce the risk in one particular area of the project, the expertise required to complete the tasks resides at more than one of the participating institutions (this point is addressed further in Section 3.2 – risk mitigation).

Within ESA, space weather activities are coordinated by Space Situational Awareness (SAA) project, one segment of which is concerned with the impacts of Space Weather (SWE). The activities of SSA SWE focus on the monitoring of the Sun and conditions in the solar wind, magnetosphere, and ionosphere that can affect space based and groundbased infrastructure, concentrating on the development of services to suit the requirements of commercial and scientific operations. These targets are strongly aligned with those of PROGRESS, which will provide additional benefits to SSA activities.

2.2.2 Measures to maximise impact

2.2.2.1 Dissemination and exploitation of results

In his role as Work Package Leader for WP8 “Dissemination” the Coordinator of PROGRESS will monitor the dissemination activities in order to achieve maximum impact for the project. In particular he will

- Work to increase the awareness of the results and achievements of the project
- Be instrumental in the design and contents of the project web site.
- Promote the project through scientific and public presentations, press releases for the media, and articles in EC brochures and newsletters.

Project PROGRESS will result in a number of tools, models, and data products that will be of interest to other parties, both commercial and scientific, working in the field of space weather. The results from project PROGRESS, such as forecasts etc., will be made available to all users to all users via the project web site. This will allow interested parties to see our predictions in graphical form and download the numerical results. It is also envisaged to distribute the resulting models to external parties, provided it does not infringe on intellectual property rights, to implement within their own systems as is currently done at the CCMC at NASA/GSFC who run a copy of the USFD model to predict high energy electron fluxes.

The project will also generate new, more realistic set of statistical models to describe the role of waves in the process of particle acceleration and loss within the inner magnetosphere. These results, available from the web server, will be of interest to the numerical modelling community who use the currently available databases to determine various coefficients used within their models.

2.2.2.2 Communication activities

Dissemination of results involves the identification of target audiences, and tailoring our outputs to suit these groups. Within project PROGRESS we have identified three target audiences: scientists, stakeholders, and the general public. We recognise that it is important to broadcast our results at the right level to each of these groups.

Scientific dissemination

The main tools for dissemination to the scientific community include the production of papers describing the models, their results, and predictions in leading scientific journals in the field such as Journal of Geophysical Research (Space Physics), Geophysical Research Letters, Annales Geophysicae, Journal of Space Weather and Space Climate, Space Weather, Solar Physics, and Astrophysical Journal as appropriate, using the Open Access 'Gold' model. At the end of the project, we aim to produce a set of overview papers to be published together as a special section within an appropriate journal such as Space Science Reviews to summarise our results and outline further extensions to the studies. In addition, it is important to provide presentations at conferences such as European Geosciences Union, European Space Weather Week, US Space Weather Week, American Geophysical Union, COSPAR, and IAGA. We aim to propose suitable sessions at these conferences and also at scientific workshops, such as the Cluster-THEMIS series, to highlight our results and, if accepted, act as convener to organise and direct the focus. All scientific participants have requested funding provision (travel and subsistence) to enable these activities.

The European and American Space Weather Week meetings are of particular importance because they attract both scientific and commercial representatives. Therefore they provide an ideal opportunity for meetings and discussions between both communities, obtain feedback on the current situation of the project, to determine user requirements that will be used to shape some of the future activities within PROGRESS to ensure delivery of a system that can satisfy end users, and to recruit new parties to our Stakeholders Advisory Board.

As part of its scientific dissemination activities, PROGRESS will organise a Summer School during its final year and invite up to 25 students to learn about Space Weather, its effects on our technology, the methods used to forecast changes within the local geospace environment. The lectures will be based on the results obtained during project PROGRESS and be delivered by project participants in conjunction with other external experts from the science and commercial communities. A budget for this activity has been included within the costing of the project Coordinator (USFD).

In order to foster stronger ties between the participants within project PROGRESS the Coordinator institute has requested funds to allow young researchers working within the project to gain further experience by visiting other project institutions to enable them to increase their visibility within the scientific community and their network of contacts.

Stakeholder dissemination

An important part of project PROGRESS is the involvement of stakeholders who represent the commercial interests of space such as satellite and launch operators, satellite and aviation manufacturers, space agencies, and the space insurance sector. Dissemination of project results to these user groups will take place via meetings of the SAB, together with demonstrations of the resulting forecast tools at meetings such as the European and American Space Weather Weeks. At the same time it is invaluable to obtain their support and feedback on the work performed within PROGRESS to allow the convergence of commercial and scientific requirements for a set of useable tools whose results clearly meet the defined requirements. Wider commercial interest will be sought through engagement at meetings such as the European Space Weather Week, attended by scientists and stakeholders alike. This provides an ideal opportunity to publicise project PROGRESS to a wider commercial audience, obtain their direct feedback, recruit further members to the project SAB, and publicise the project website and the forecast tools and results available. The Coordinator institute has included provision of funds for stakeholders to attend meetings of the SAB.

To further increase dissemination among stakeholders we propose to submit high quality articles to the Commissions Research and Innovation website and the various EC/REA research publications and newsletters.

Dissemination to the general public

Opportunities for project PROGRESS to communicate with the public can result from the occurrence of natural events. Large space weather related events, such as the recent solar activity and aurora observable that occurred at the end of February 2014 made headlines around the world. Many news web sites carry pictures of the aurora observed around this period, inspiring the public to learn more about space. Thus it is important to engage the mass media such as the local, national, and international press to reach the widest dissemination of results. An example of this may be the summary of an article published in a high profile journal, e.g. Nature or Science. Such publications will be accompanied by a press release to bring these important findings to a greater audience. In order to maximise the potential, the Coordinator will make use of the Public Engagement Team here at USFD, who provide advice and organise a number of opportunities for USFD members to take their research to a wider audience.

As well as press releases, we hope to foster this aspect of outreach by providing a public access area on the project web site. This will explain, in layman's terms, the occurrence and problems that may be caused by space weather and how it could impact on the everyday lives of European citizens, our results in forecasting their effects together with examples of past-casts using historically significant events such as the one that caused the 'Quebec blackout' in 1989. Access to the website will be monitored to determine the key audiences using it and to help define the nature of new articles which will be added as the project evolves.

High quality articles will also be submitted to the Commissions Research and Innovation website and the various EC/REA research publications and newsletters (via the Project Officer) for wider dissemination of results to a space oriented audience.

2.2.2.3 Intellectual property rights

The rules concerning Intellectual Property Rights (IPR) will be addressed within the Consortium Agreement, a document signed by all participants before the start of the project. The protection and sharing of IPR will be overseen by the SSC and comply with the guidelines on IPF specified within the framework of Horizon 2020. The SSC will be the final arbiter on the dissemination of intellectual property, seeking to protect the owners/developers rights.

IPR is divided into two main areas. The first, background, covers intellectual property that is owned by the participants prior to the beginning of the project. Any background intellectual property rights will be respected by the project. The existence of all such items should be declared within the Consortium Agreement.

The second is foreground intellectual property rights. This covers intellectual property developed within PROGRESS and depends on the type of property, namely models, data, and data products.

Models – The models developed within PROGRESS will remain the property of the developers/owners. They will not be freely distributed outside the project. This ensures the control of future developments and usage of the models. However, after consultation within the SSC, models may be distributed to interested parties upon request subject to certain conditions being fulfilled.

Data – The policy towards the distribution of data used within project PROGRESS will reflect that of the source from which the data was obtained. Since PROGRESS is a scientific project and uses data without commercial gain it is envisaged that there should be no difficulties obtaining data, especially since most is publically accessible. PROGRESS will not redistribute any data sets that it receives from non-public sources.

Data products – Data products, resulting from the analysis carried out within project PROGRESS will be made publically accessible.

Within the project collaboration all data and models will be freely distributed for use within the project.

The project will also allow the participants to protect their results through a patent. Participants thinking of pursuing this form of protection for their property shall inform the SSC of their intention to apply.

2.3 Implementation

2.3.1 Work plan — Work packages, deliverables and milestones

2.3.1.1 Overview of work packages

The main research related work packages within the project are WP2, WP3, WP4, WP5, WP6 and WP7. They provide the framework for the modelling and data analysis tasks, resulting in expanding our understanding of the processes involved in the propagation of space weather disturbances from the Sun to the Earth and the changes they cause to the magnetospheric environment. The individual predictive models they generate will be combined within WP7 resulting in a practical tool to qualitatively access the level of risk to space assets. The other workpackages enable the dissemination of results to scientists, stakeholders, and the general public and feedback from scientists (WP8) and project management (WP1).

2.3.1.2 WP1 – Management

This WP encompasses the scientific, administrative, and financial management aspects of the project and ensure the necessary communications between the participants, the Scientific Steering Committee, the Stakeholder Advisory Board, and the Commission/REA.

2.3.1.3 WP2 – Propagation of the solar wind from the Sun to L1

The concept of WP2 is to provide forecasts of the solar wind parameters (e.g. density, electron and ion temperatures, velocity and magnetic field) at L1 based on magnetogram observations from GONG. It will result in the forecast of potential space weather hazards up to 2 or so days before they arrive at the Earth.

2.3.1.4 WP3 – Forecast of the evolution of geomagnetic indices

Geomagnetic indices are used to express the current state of the magnetosphere and quantify geomagnetic activity. Their evolution is a key indicator to the response of the magnetosphere to space weather disturbances and they are used as inputs to numerous models for assessing their impact. Hence the accurate forecast of their evolution is vital to provide timely warnings of potential hazards. WP3 will produce tools to provide such forecasts based on both measurements from ACE at L1 and/or the outputs of predictions from WP2.

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

Current numerical models for the forecast of the radiation belt environment use statistical models to describe the interaction of particles and waves. However, current models have several disadvantages. This WP intends to create new models that reflect the evolution of the magnetosphere mode accurately and therefore provide improved forecasts from numerically based models.

2.3.1.6 WP5 – Low energy electrons model improvements to develop forecasting products.

The goal of this WP is to develop the existing now-cast IMPTAM model into a forecasting tool. This will require the construction of an empirical solar wind and IMF driven model for low energy electrons in the plasma sheet using all available data, inclusion of proper diffusion coefficients provided by VERB radiation belts model, and incorporation of the developed in PROGRESS forecasting capabilities for solar wind and IMF parameters and Dst and AE indices.

2.3.1.7 WP6 – Forecast of the radiation belt environment.

This work package will combine the results from the two numerical codes IMPTAM (low energy particles) and VERB (high energy particles) with the data driven NARMAX model for the particle environment at GEO to provide forecasts of the particle environment within the whole of the inner magnetosphere region. The use of novel data assimilation tools will enable a further improvement of the forecasting and nowcasting capabilities.

2.3.1.8 WP7 – Fusion of forecast tools

The outputs of WP2, 3, and 6 involve the generation of models to forecast the state and particle environment of the inner magnetosphere. This goal of this WP is to link these individual models together under a single interface to provide stakeholders with a tool to provide an assessment of the local geospace environment with up to a couple of days advanced warding of potential space weather hazards.

2.3.1.9 WP8 – Dissemination activities

This WP focuses on the communication of results from the project to scientists, stakeholders, news agencies, and the general public. It will also be the primary means to receive peer feedback from scientists and commercial requirements and guidance from the stakeholders.

2.3.1.10 Timing of work packages

	Month	1-3	4-6	7-9	10-12	13-15	16-18	19-21	22-24	25-27	28-30	31-33	34-36
Work package 1 – Management													
	All tasks	▨	▨	▨	▨	D1.1	▨	▨	▨	D1.2	▨	▨	D1.3
	Milestones												
Work package 2 – Propagation of the Solar Wind from the Sun to L1													
	Task 2.1	▨	▨										
	Task 2.2	▨	▨	▨									
	Task 2.3			▨	D2.1								
	Task 2.4				▨	▨							
	Task 2.5					▨	▨	D2.2					
	Task 2.6							▨	▨	▨			
	Task 2.7									▨	▨	▨	▨
	Task 2.8											▨	D2.3
	Milestones							M2.1					
Work package 3 – Forecast of the evolution of geomagnetic indices													
	Task 3.1	D3.1											
	Task 3.2		D3.2										
	Task 3.3			D3.3									
	Task 3.4				▨	▨	▨	▨	D3.4				
	Task 3.5						▨	▨	▨	▨	D3.5		
	Task 3.6										▨	▨	D3.6
	Milestones						M3.1						
Work package 4 – Data assimilation													
	Task 4.1	D4.1											
	Task 4.2		D4.2										
	Task 4.3			D4.3									
	Task 4.4				▨	▨	▨	▨	D4.4				
	Milestones								M4.1				
Work package 5 – Development of IMPTAM													
	Task 5.1	▨	▨	▨	D5.1								
	Task 5.2					▨	▨	▨	D5.2				
	Task 5.3									▨	D5.3		
	Task 5.4									▨	▨	▨	D5.4
	Milestones								M5.1				
Work package 6 – Forecast of the radiation belt environment													
	Task 6.1	▨	D6.1										
	Task 6.2	▨	▨	▨	▨	▨	▨	▨	▨	D6.2			
	Task 6.3			▨	▨	▨	▨	▨	▨	▨	D6.3		
	Milestones		M6.1								M6.2		
Work package 7 – Fusion of forecasting tools													
	Task 7.1						▨	▨	▨	▨	D7.1		
	Task 7.2								▨	▨	▨	D7.2	
	Task 7.3									▨	D7.3		
	Task 7.4											▨	D7.4
Work package 8 - Dissemination													
	All tasks	D8.1	▨	▨	▨	▨	▨	▨	D8.2	▨	▨	▨	▨

2.3.1.11 Overview of work flow

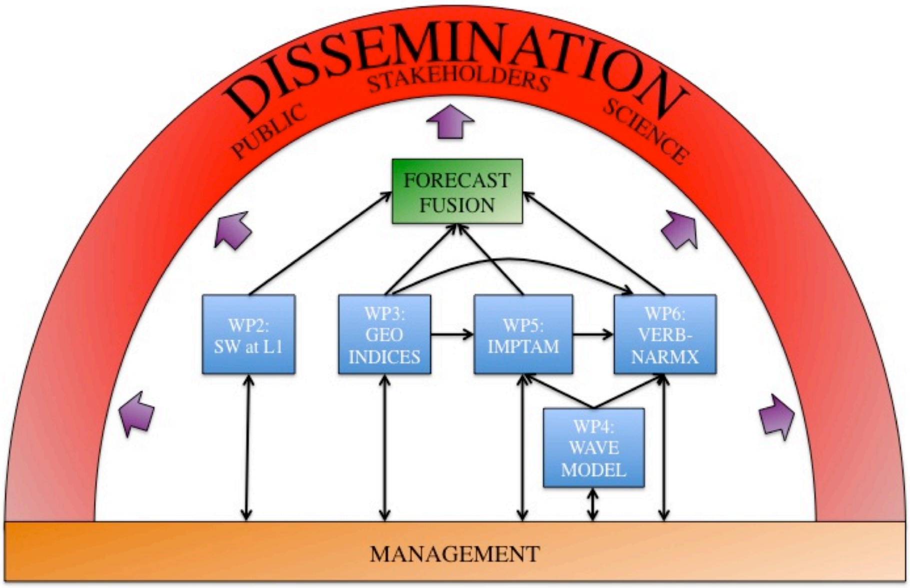

Figure 7: Workflow of project PROGRESS

Figure 7 shows a graphical overview of the workflow within project PROGRESS. Each of the scientific tasks in work packages (WP2-6) contains both a modelling and a forecasting component with the latter being the product resulting from the modelling tasks. Finally, the scientific task of WP 7 is to combine the various forecast tools in a single user interface to provide a complete picture of the current and future (2 day ahead) potential space weather hazards together with an estimate of their expected impact. Dissemination (WP8) of the results from both the modelling and forecast tool aspects of the project activities will enable the project to receive peer feedback from the scientific community (via conference presentations and journal publications) and the Stakeholder Advisory Board as to the direction of the project and the definition and fulfilment of any specific commercial requirements for a forecast system.

2.3.2 Management structure and procedures

The PROGRESS proposal is a new collaboration between 8 research groups in 7 countries, and also draws on currently established collaborations for the free exchange of data. In addition, a number of potential external stakeholders have been identified from across Europe whose input to the project will help to maximise the benefits for both science and industry. Thus the project will forge new links between academia, industry, and service providers.

2.3.2.1 Structure

Successful delivery of the project requires firm and clear guidelines in terms of responsibility, communication, and financial control as well as risk analysis and mitigation. The following five areas of management have been identified:

- Liaison with the Commission/REA

- Oversight, risk mitigation, and strategic management
- Scientific management and leadership
- Activity monitoring, and the coordination of deliveries and reporting
- Administrative and financial management

To successfully carry out these tasks, the PROGRESS project will establish a management structure consisting of:

- Project Coordinator (PC)
- Project Manager (PM)
- Work package leaders (WPL)
- Scientific Steering Committee (SSC)
- Stakeholder Advisory Board (SAB)

The role of the Project Coordinator (PC)

The PC of the project PROGRESS will be Professor R. von Fay-Siebenbergen. He will take overall responsibility for the project and its activities, including implementation and delivery. In particular, he will be responsible for

- Implementation of the consortium agreement
- Main point of liaison with the Commission/Research Executive Agency (REA)
- Representing the PROGRESS project externally
- Chairing meetings of the Scientific Steering Committee and Stakeholder Advisory Committee
- Monitoring the progress of the project in terms of deliverables and milestones
- Identifying risks to the schedule and, in conjunction with the Scientific Steering Committee, the negotiation and implementation mitigation solutions to the project work plan
- The PC will have the casting vote on decisions for which the SSC cannot reach a majority consensus.

The role of the Project Manager (PM)

The PM will, in conjunction with the PC, take the lead in the day to day running of the project, aided by clerical and financial support provided by the University of Sheffield. He will be responsible for

- Monitoring of the completion of tasks, achievement of milestones, and submission of deliverables.
- Organisation of Project, SSC, and SAB committee meetings
- Preparation of the annual, formal reports for the Commission/REA
- Monitor partner budgets

The PM will report to the PC.

The role of the Work Package Leaders (WPL)

Each work package will have a named leader and deputy. The WPL will be responsible for the scientific coordination of their assigned work package, including its deliverables, milestones, and dissemination of results, reporting their fulfilment to the PC and PM. The WPL will also highlight any discrepancies and risks to the project schedule, reporting any instances and possible mitigation solutions to the PC/PM who, with the aid of the SSC, will advise the WPL on the appropriate course of action to take to minimise the risk to the rest of the project. The identified WPLs and their deputies are listed in Table 1.

Table 1: List of work package leaders

WP	Leader (institute)	Deputy (institute)
1	R. von FaySiebenbergen (USFD)	N. Ganushkina (FMI)
2	T. Arber (UW)	B. van der Holst (UM)
3	P. Wintoft (IRF)	R. Boynton (USFD)
4	V. Krasnoselskikh (CNRS/LPC2E)	Y.Shprits (Skoltech)
5	N. Ganushkina (FMI)	R. Boynton (USFD)
6	M. Balikhin (USFD)	Y.Shprits (Skoltech)
7	S. Walker (USFD)	T. Arber (UW)
8	R. von FaySiebenbergen (USFD)	T. Arber (UW)

The role of the Scientific Steering Committee (SSC)

The SSC is the project's key management and scientific leadership committee. It is responsible for the overall direction of the project, assessing progress with respect to the schedule, identifying possible risks and proposing mitigation actions to minimise there effect on the rest of the project. Steering committee decisions will be made following open discussions. These will be based on the evidence available so that an informed decision may be reached ensuring transparency and traceability. The SSC is composed of:

- Project Coordinator (Chair)
- Project Manager
- Work Package Leaders
- At least one Stakeholder to provide an external view

The role of the Stakeholder Advisory Board (SAB)

The SAB, a body external to the project, will take a wider view of the project, advising the SSC and PC with respect to project direction and commercial interests. The main purpose of this body is to provide the commercial requirements that may be addressed by the project, resulting in a set of useful tools and standards. We feel that this mechanism is the most effective way to disseminate our results to the industrial sector and to obtain their feedback and guidance.

2.3.2.2 Procedures

Project Meetings

The PM will organise two Project Meetings per year during which the Project Teams will meet physically for a period of one to three days. One of these meetings will correspond to the Annual Review Meeting and will involve representatives of all project partners in addition to the Project Officer and External Project Evaluators. During each meeting the Workpackage Leaders (or their representative) will present the scientific and technological work carried out, comparing it against the project schedule and list of deliverables/milestones and also outline the future agenda for their workpackage.

SSC and SAB meetings

The PM will organise face to face meetings of the SSC (two per year) and SAB (one). These will, where possible, occur in conjunction with the Project Meetings or other scientific/industrial meeting such as European Space Weather Week (ESWW) to minimise their cost and maximise attendance. It would be envisaged to hold the SAB meeting first to inform the stakeholders of the current progress of the project, and then receive their feedback and advice that would then be discussed at the SSC.

Review meetings

It is expected that the Commission/REA will require yearly review meetings for the project with an external assessor. These meetings will take place shortly after the yearly reports are submitted. These meetings are attended by the PC, PM, and the Project Officer. Participation of the WPL may be required via phone/VoIP.

A provisional timetable for project meetings is shown in Table 2. Where possible meetings should run in tandem to reduce costs and travel time etc.

Table 2: Proposed meeting timetable

Meeting	Location	Date
PM1, SSC1	Sheffield, UK	T0
PM2, SSC2	Warwick, UK	T0+6 months
PM3, SSC3, SAB1	European Space Weather Week, Belgium	T0+12 months
RM1	Brussels, Belgium	T0+14 months
PM4, SSC4	CNRS/LPC2E, Orleans, France	T0+18 months
PM5, SSC5, SAB2	European Space Weather Week, Belgium	T0+24 months
RM2	Brussels, Belgium	T0+26
PM6, SSC6	Lund, Sweden	T0+30 months
PM7, SSC7, SAB3	European Space Weather Week, Belgium	T0+36 months
RM3	Brussels, Belgium	T0+38 months

Project Communications

The day to day communications within the project include:

- A project web site that will have links describing the research themes and of the project, material for training and dissemination activities, access to public reports generated by the project with a password protected area for reports private to the project, links to external resources, etc.
- List mailers will be setup and maintained by USFD for general e-mails to be circulated to the whole consortium, together with a separate list for e-mails related to the management of the project.
- Use of VoIP applications (e.g. Skype) for direct communications. This provides the easiest mechanism to resolve issues between the participants and keep the PC/PM informed.

Conflict resolution and decision making

The principles governing decision-making are evidence based decisions and transparency. This will be enshrined in a partnership agreement that clearly defines lines of responsibility and formal communication between partners, and the decision-making processes within the SSC. The main evidence base for decisions will be the performance data on progress against the scheduled deliverables, as well as technical briefings to the SSC meetings. Transparent decisions will be made through open discussion in the SSC, with agendas prior to meetings and the subsequent posting of meeting records with necessary background information, decisions and actions. These will be posted on the internal web pages of the project for all partners to consult and contribute. Major strategic decisions that affect the partnership and direction of research as a whole will be made by the SSC in consultation with the SAB. With clear evidence and open discussion, the main route to decisions will be through consensus building in these open meetings. If consensus cannot be reached, the final decision will be taken by the PC after he has consulted partners widely and been given as much information as possible. Partners will always be kept informed so they can feed in their views.

2.3.2.3 Reporting

The Project will produce three types of formal reports

Annual Progress Reports will be compiled every year in accordance with Commission/REA guidelines. These reports will summarise the achievements of the project by attaining the specified milestones and the production of the deliverables. It will also provide a work plan for the year ahead.

Financial reports Financial reports will be compiled on an annual basis in accordance with Commission/REA guidelines, and will be accompanied by an Auditor certificate for each Partner when necessary. The reports will indicate both the overall project expenditures and the expenditures of single partners.

Technical reports will be produced as the outputs for the workpackages. These will usually take the form of a report outlining the progress achieved as a result of working on the tasks listed in the individual work packages. Before submission to the Commission/REA, a member of the SSC will review the report to ensure their quality and accuracy. A standard template will be used to ensure all reports conform to a standard, well-structured layout. For those reports that are defined with a dissemination level as public the reports will be made available via the Project web site.

2.3.2.4 Financial management

USFD has managed and coordinated finances for grants in FP5, FP6 and FP7 and brings this experience to manage PROGRESS. The PC also has considerable experience in managing research grant budgets. A dedicated team in USFD financial services is experienced in Commission/REA project administration and formal reporting to funders, and will provide this service and advice to the PC.

2.3.2.5 Risk management

Risk management will be implemented as a three-stage plan within the Project. These steps are:

1. Identification of the main risk areas, assessment of their magnitude and their likely occurrence. These potential risks to the Project will be entered into a Risk Register from where they can be continually tracked.

2. Avoidance of the risk situation where ever possible.

3. If the risk cannot be avoided then contingency plans will be put into place to mitigate their effect to the rest of the Project. The main risks identified during the proposal phase are listed in the Table in Section 1.3.5 of Part A of the Description of Action.

To help minimise the risks, the proposed consortium possesses some degree of redundancy in the expertise required within the project as listed in Table 3 with the primary institute(s) marked in bold.

Table 3: Areas of expertise

Area of expertise	**Institute**
MHD modelling	**UW,** UM, USFD
Modelling of geomagnetic indices	**IRF**, USFD, SRI NASU-NSAU
Analysis of wave data	**CNRS/LPC2E**, USFD
Numerical models of the radiation belts	**FMI,** Skoltech
NARMAX modelling	**USFD**, SRI NASU-NSAU
Data assimilation	**Skoltech**, CNRS/LPC2E

During the project kick-off meeting The Coordinator and Team Leaders will identify and discuss the potential risks that could develop within the project. Once the main risks have been identified contingency plans will be designed to overcome these problems and keep the project back on track. Details of these risks and strategies to resolve them will be entered into the Project Risk Register. This evaluation of the potential risks and formulation and implementation of related contingency plans will continue throughout the Project to ensure the timely identification of problems and possible mitigation steps. In general, these processes will be carried out by the Work Package Leader responsible for that particular WP for which a problem has been identified. Hopefully a quick solution to the problem will be found and put in place to enable the work to continue unimpeded. The Steering Committee should be kept informed of these problems and their solution. If a local solution cannot be found, then the Steering Committee should be informed and a teleconference organised to discuss the problem, assess its impact and define a contingency plan that will minimise any disruption to the rest of the project. Table 1.3.5 (WT5 Critical Implementation risks and mitigation actions) in Part A of the DoA provides a preliminary outline of the currently perceived main risks and the mitigation steps required to correct them.

2.3.3 Consortium as a whole

Europe possesses a strong research community in the field of space science, with many outstanding individuals and research institutes. This, coupled to a large number of high quality space and ground based data sets, and current modelling expertise puts Europe in the forefront of space research. The proposal takes advantage of this strength to bring together a multidisciplinary team of researchers to answer the present call.

The project PROGRESS brings together top researchers in the fields of satellite data analysis (USFD, CNRS/LPC2E), numerical modelling (UW, FMI), systems science (USFD), neural networks (IRF), solar, and space physics (All) to harness their joint expertise to significantly improve Europe's potential to forecast the arrival of space weather disturbances and assess their probable effects on the magnetosphere. The fact that most areas of expertise are available at more than one institute provides joint studies to be performed and, at the same time, provides a level of redundancy should one of the partners have to leave the project, reducing the possibilities of single point failures. The nature of the challenge within this call is that no one institute could achieve the desired results single-handed. However, the collaborative efforts of all participants within project PROGRESS may be combined to yield a consortium that may tackle the problems associated with this call head on and make valuable scientific and commercial progress.

To further strengthen the profile of the consortium we have included experts from the USA and Russia. The project acknowledges the fact that the USA and Russia are two countries that are not listed in the Horizon 2020 list of Associated Countries. However, since this level of expertise is not available within Europe, we feel strongly that the inclusion of the following partners as official participants within PROGRESS significantly strengthens the level of expertise and knowledge available within the consortium. This inclusion also allows PROGRESS use of two models, AWSoM and VERB, that have no European equivalents.

Prof. M. Liemohn and Dr. B. van der Holst (University of Michigan) have extensive experience in the development of MHD codes for the solar wind and its interaction with planetary bodies. He is a member of the group that has developed the highly successful BATS-R-US code and can provide valuable expertise and guidance for the development of the model for solar wind propagation (WP2). UM has developed a model, AWSoM, that couples GONG magnetograms of the solar surface to coronal physics models. The output of this model is used to define the inner boundary conditions for SWIFT. Currently, Europe has no counterpart to the AWSoM.

Prof. Y. Shpritz (Skolkovo Institute of Science and Technology) is an expert on the physics of the radiation belts. He has been instrumental in the development of the numerical VERB code. VERB includes mixed diffusion terms that have been neglected in similar codes developed within Europe. The inclusion of Prof. Shpritz within the project provides access to this important tool, and enables further development of the code by incorporating data assimilation techniques as well as linking it with the USFD developed SNB^{3}GEO model to create a tool to accurately model the electron environment of the radiation belts. This tool will be able to produce reliable forecasts as well as prove an invaluable tool for investigating previous satellite anomalies.

2.3.3.1 Specific strengths

USFD are the world leading group in the development of data based models, their analysis, and interpretation. USFD has already used this methodology to develop online forecasting tools for both the Dst geomagnetic index and the flux of high-energy electrons at GEO. This later model has also been implemented on the NASA CCMC web site. USFD also has expertise in the analysis of satellite measurements plasma waves in the radiation belts

FMI provides expertise in the particles observed in the radiation belts and, in particular, the numerical modelling of low energy electron fluxes. FMI are the developers of the IMPTAM numerical simulation code, a nowcast model for low energy (E<200keV) electrons in the inner magnetosphere.

UW has internationally leading expertise in developing and using plasma simulation codes. This includes the Lare3d and Odin MHD codes but also extends to direct Vlasov solvers (Valis) and relativistic multi-scale kinetic plasma codes (EPOCH). Of these codes EPOCH and Odin were developed as part of a multi-institutional programme in collaboration with Warwick computer scientists. UW therefore has a proven record of developing World-leading simulations tools as part of a multi-institution collaboration, employing cutting edge techniques from both computational physics and computer science. In addition UW continues to support EPOCH and Lare3d for the international community.

Skoltech are internationally known for their research into the evolution of relativistic electron fluxes in the radiation belts and the development of the VERB diffusion code to model these processes.

UM are the world-leading group in the development of MHD simulation codes. They have immense experience in the development and coupling of MHD codes to model the solar atmosphere, the solar wind, the magnetosphere, and inner magnetosphere.

SRI NASU-NSAU provides expertise in the development and use of the dynamic-information and guaranteed approaches to space weather prediction using NARMAX and bilinear input-output models. SRI NASU-NSAU has already used these approaches to develop online forecasting tool for the Dst geomagnetic index and risk assessment of space radiation effect on satellite devices.

CNRS/LPC2E are world-leading researchers in the field of space plasma physics and the analysis of satellite based data sets and actively worked on the creation of the data base of wave measurements onboard Cluster, THEMIS, Polar, DE and Akebono satellites in the Earth magnetosphere with special attention to the vicinity of the radiation belts.

IRF performs basic and applied research in the Earth's upper atmosphere, the ionosphere, and planetary magnetospheres, and the Sun. IRF has been active in space weather since the 1990's and been involved in several international projects, both ESA and EU funded. Forecast models have been studied, developed, and implemented for various geomagnetic indices and ground geomagnetic field. IRF has well established relations with Swedish stakeholders, such as national electric grid and civil contingencies agency.

As well as the inclusion of UM and Skoltech within the consortium other collaborations will be undertaken within PROGRESS. These collaborations will be carried out at zero cost to the Commission/REA.

The activities to be performed by CNRS/LPC2E in the course of work package 4 will undertaken in the form on a collaboration between the work package leader, V Krasnoselskikh, and Dr. Oleksiy Agapitov from the Space Sciences Laboratory, The University of California, Berkeley, USA.

The activities to be performed by Skoltech in the course of work package 6 will undertaken in the form on a collaboration between the work package leader, Prof. Y. Shpritz, Dr. Dmitri. Kondrashov, and Dr. Adam Kellerman from the Institute of Geophysics and Planetary Physics, The University of California, Los Angeles, USA.

2.3.4 Capacity of participants and links to third parties

2.3.4.1 Participants

2.3.4.1.1 USFD - University of Sheffield

Web page: http://www.shef.ac.uk

Description

USFD is one of the largest UK universities with over 24,000 students from more than 124 countries. Six Queen's Anniversary prizes (the most distinguished UK educational award) awarded to USFD since 1998. USFD has been named UK University of the Year in the 2011 Times Higher Education Awards. USFD is proud to have 5 Nobel Prize winners associated with it. USFD has a long-standing tradition of collaborative research in the UK and overseas and has much experience managing large European research projects. Project PROGRESS brings together expertise in two research centres, Solar physics and Space Physics Research Centre and Centre for Signal Processing and Complex Systems.

Solar physics and Space Physics Research Centre

The Solar physics and Space Physics Research Centre comprises two research groups, the Solar Wave Theory Group (SWAT) in the Department of Applied Mathematics and the Space Systems Laboratory (SSL) in the Department of Automatic Control and Systems Engineering.

The principle aims of SWAT are to understand the key important physical processes governing the energy flow from the convective zone to the solar atmosphere and down to the Earth's upper atmosphere using analysis of observational data together with mathematical and computational models.

Space Systems Laboratory

The Space System Laboratory plays an active role in the development of hardware and software for ESA space missions. SSL is the PI group for the Cluster Digital Wave Processor (DWP), the central part of the Cluster Wave Experiment Consortium. Currently the group has Co-I involvement in the Cassini and VEX missions. The scientific interests of the group that are relevant to the project include dynamical processes in space and astrophysical plasmas, space weather, the dynamics of the radiation belts, nonlinear processes, plasma turbulence, and methods for spacecraft data analysis.

Centre for Signal Processing and Complex Systems

The aims of the Centre for Signal Processing and Complex Systems at the department of Automatic Control and Systems Engineering (ACSE) are twofold: First, to elaborate developments of nonlinear signal and information processing methods from a generic systems engineering perspective. Secondly, to extend and develop the systems engineering algorithms to address the specific problems associated with each of the multi-disciplinary topics in diverse fields such as signal processing, system identification, dynamical analysis, control and modelling to support emerging multi-disciplinary research themes in medicine, systems and synthetic biology, stem cell dynamics, neuro-imaging, bio-imaging, neural processing in Drosophila, reaction-diffusion systems, non-equilibrium growth processes, studies of solar terrestrial systems, mobile robots, volatility modelling and financial systems, climate dynamics, nonlinear materials design and many other complex systems.

Key publications relevant to the proposal:

Boynton, R. J., M. A. Balikhin, S. A. Billings, and O. A. Amariutei, Application of nonlinear autoregressive moving average exogenous input models to geospace: advances in understanding and space weather forecasts, Ann. Geo. 31, 1579-1589, 2013.

Boynton, R. J., M. A. Balikhin, S. A. Billings, G. D. Reeves, N. Ganushkina, M. Gedalin, O. A. Amariutei, J. E. Borovsky, and S. N. Walker, The analysis of electron fluxes at geosynchronous orbit employing a NARMAX approach, J. Geophys. Res. (Space Physics) 118, 1500-1513, 2013.

Boynton, R. J., S. A. Billings, O. A. Amariutei, and I. Moiseenko, The coupling between the solar wind and proton fluxes at GEO, Ann. Geo. 31, 1631-1636, 2013.

Boynton, R. J., M. A. Balikhin, S. A. Billings, A. S. Sharma, and O. A. Amariutei, Data derived narmax dst model, Ann. Geo. 29, 965-971, 2011.

Boynton, R. J., M. A. Balikhin, S. A. Billings, H. L. Wei, and N. Ganushkina, Using the NARMAX OLS_ERR algorithm to obtain the most influential coupling functions that affect the evolution of the magnetosphere, J. Geophys. Res. (Space Physics) 116, A05218, 2011.

Main tasks:

- Management/Coordination of the project (WP1).
- Oversee the dissemination and communication activities related to the project (WP8).
- Lead science WP 6, and 7
- Contribute to WP 3, 4, 5

The key participants in project PROGRESS at USFD are:

Prof. Robertus von Fay-Siebenburgen (Erdelyi) is a world renown authority on the solar atmosphere, the wave processes occurring within it, their propagation in the solar wind and its influence on the terrestrial magnetosphere. His main research interests include the theoretical study of linear and nonlinear processes for MHD wave heating and solar magneto-seismology in the solar atmosphere and the use of computational magnetohydrodynamics to investigate small-scale structures such as spicules, explosive events, blinkers, nano-flares, and solar tornadoes together with comparison of the results with the latest space (e.g. Hinode, DO, IRIS) and ground-based (SST, DST/NSO) observations. His most prestigious papers (3xNature; 2xScience, numerous in ApJ, 7xSSR, etc.) and extensive network of collaborators affirm his international standing. He is an invited CoI on the SDO mission, and invited international expert to ATST. RvFS has received a number of collaboration awards from Royal Society, British Council, ESA SP, IAU, IUPAP, and ISSI. RvFS was involved as a Co-I for three successful NASA SR&T collaborations with LMSAL and raised substantial funding for research (STFC, EPSRC, NATO, ESA, etc.). He has organized and chaired sessions at many conferences including SOHO, IAU, EGU, and AOGS. As a member of the White Rose Consortium, RvFS has participated in two successful Sheffield-led bids: (i) establishment of the White Rose Grid; (ii) establishment of a High Throughput Computing Grid System. In association with the UKMHD Consortium, he is a CoI in the upgrading of a UKMHD Grid System. He was Chairman of UK Solar Physics for seven years.

Prof von Fay-Siebenburgen is the Coordinator of project PROGRESS, and will lead WPs 1 (Management) and 7 (Dissemination).

Prof. Stephen Billings is the world leading expert in the field of nonlinear systems. His main expertise relates to aspects of signal processing and nonlinear and complex systems. Prof. Billings is one of the world's top 100 cited researchers in all engineering disciplines and is currently the fourth most cited engineer in the UK based on Web of Science. He has played a key role in the development of various methods for processing spacecraft wave data such as wave dispersion identification, determination of wave growth/damping rates and identification of nonlinear processes within plasma turbulence using frequency and time domain methods. These methods have been successfully applied to plasma turbulence observed in various regions: foreshock; shock front and the magnetosheath.

Prof. Billings is the pioneer of the NARMAX modelling methodology. He will provide advice on the use and interpretation of the NARMAX models resulting from WP 3, 4, and 6

Prof. Michael Balikhin is a world renown expert in the field of space plasma physics, plasma turbulence, satellite data analysis and nonlinear dynamical systems and is currently an editor for Journal of Geophysical Research-Space Physics, the most prestigious journal in the field of space physics. He has pioneered the use of advanced system dynamics methodologies within the field on space physics played a key role in the development of an online tool that provides reliable 24 hour ahead forecasts of relativistic electron fluxes at GEO (http://www.ssg.group.shef.ac.uk/USSW/2MeV_EF.html). In collaboration with UCLA, MB leads the development of the VERB-NARMAX-Coupling (VNC) code that combines the UCLA VERB model with the Sheffield NARMAX model to forecast the fluxes of high energy electrons throughout the whole region of the radiation belts.

Prof. Balikhin will lead WP 6 and provide scientific expertise to the modelling and interpretation for work packages 3, 4, and 7.

Dr. Simon Walker graduated with a PhD from USFD in 1991. After a short spell working at ESA/ESRIN, Frascati he returned to Sheffield, using Cluster data to investigate the structure and processes at the bow shock and wave activity in the magnetosheath. As part of the Sheffield led Cluster Inner Magnetosphere Campaign he is in the process of investigating the occurrence and properties of equatorial magnetosonic waves and their role in the acceleration and scattering of electrons. In addition, Dr. Walker is responsible for SSL data input to the Cluster Active Archive database. He is an author of over 60 papers in refereed journals.

Dr. Walker is the PROGRESS Project Manager. He is an expert satellite based data analysis and will provide technical and scientific input to WP 3 and 6 as well as leading WP 7. He has previously acted as coordinator for the FP7 funded project SEMEP.

Dr. Victor Fedun, graduated from physics department at Kiev National University (Ukraine) in 1994, PhD from Main Astronomical Observatory of the National Academy of Sciences of Ukraine He is the author/co-author of over 35 papers in space physics.

Dr. Fedun will provide support to WP 4.

Dr. R. Boynton completed his PhD at the end of 2011. Since then he has focused on the development of advanced methods for the analysis of space physics data. He has 13 publications in leading journals (e.g. JGR, GRL), 5 as 1st author and 9 related to RB physics and has delivered an invited presentation on radiation belt physics at the Cluster-THEMIS workshop 2012. RJB, together with Prof. Balikhin and Prof. Billings, has developed a set of online space weather forecasting models including the most accurate 24hour ahead forecast of >2MeV electrons at GEO. Based on the success of these models, RJB was invited to join the Dst Challenge led by NASA CCMC in which leading groups were tasked with the creation of a reliable tool to forecast the Dst index.

Dr. Boynton will provide advice on the application of NARMAX methods within WP 3 and 6.

2.3.4.1.2 FMI - Finnish Meteorological Institute

Web page: http://www.fmi.fi/

Description:

The Finnish Meteorological Institute (FMI, http://www.fmi.fi/) is a governmental research institute of about 690 employees providing the national weather service in Finland. Besides topics related to the neutral atmosphere, space research belongs to the statutory tasks of FMI, with about 50 employees. One of the challenges for the research of solar-terrestrial physics in FMI is to support the attempts to predict space weather. FMI has a crucial role especially in the establishment of European space weather activities. FMI is or has been a partner in about 25 FP6 projects, and is presently participating in about 15 FP7 projects. FMI has the coordinator status in two ERC projects and in one Marie Curie Grant Agreement. Besides these, FMI coordinates one and is a partner in two other EU LIFE+ 07 projects. FMI jointly with the Department of Physics of the University of Helsinki forms the Kumpula Space Centre to foster scientific collaboration in space sciences and Earth observation activities.

Key publications relevant to the proposal:

Ganushkina, N. Yu., T. I. Pulkkinen, T. Fritz (2005), Role of substorm-associated impulsive electric fields in the ring current development during storms, Ann. Geophys., 23, 579-591.

Ganushkina, N., T. I. Pulkkinen, M. Liemohn, and A. Milillo (2006), Evolution of the proton ring current energy distribution during April 21-25, 2001 storm, J. Geophys. Res., 111, A11S08, doi:10.1029/2006JA011609.

Ganushkina N. Yu., M. W. Liemohn, and T. I. Pulkkinen (2012), Storm-time ring current: model-dependent results, Ann. Geophys., 30, 177-202.

Ganushkina, N. Yu., O. A. Amariutei, Y. Y. Shprits, and M. W. Liemohn (2013), Transport of the plasma sheet electrons to the geostationary distances, J. Geophys. Res., 118, doi:10.1029/2012JA017923.

Ganushkina, N. Yu., M. W. Liemohn, O. A. Amariutei, and D. Pitchford (2014), Low energy electrons (5-50 keV) in the inner magnetosphere, J. Geophys. Res., 119, doi:10.1002/2013JA019304

Previous projects or activities, connected to the subject of this proposal;

The Inner Magnetosphere Particle Transport and Acceleration Model (IMPTAM) was developed at FMI and used successfully to model ions (including protons) and electrons in the inner Earthís magnetosphere. IMPTAM version to model low energy (< 200 keV) electrons in the inner magnetosphere [Ganushkina et al., 2013, 2014] was developed and now operates online under the SPACECAST project (http://fp7-spacecast.eu, projects ends on February 28, 2014).

Significant infrastructure and/or any major items of technical equipment, relevant to the proposed work

The team will utilise the resources provided by FMI, including computer and IT support. Administration can provide contractual and juridical support throughout the project.

Main tasks:

The main tasks that will be performed at FMI are:

(1) Develop an empirical solar wind and IMF driven model for low energy electrons in the plasma sheet;

(2) Adapt the IMPTAM to include proper diffusion coefficients provided by VERB radiation belts model;

(3) Provide the low energy seed population to VERB radiation belts model;

(4) Develop a trial version of forecast model for low energy electrons.

Key participants:

Dr Natalia Ganushkina will lead the work. She is a female Research Scientist at the Earth Observations Research Unit at FMI. She has more than 15 years of experience in space physics, with 66 scientific papers in peer-reviewed journals (h-index of 14), covering a wide range of topics on the Earth's magnetospheric physics. She is highly experienced and qualified in space environment modelling and has a wide experience in various types of inner magnetosphere models and data analysis. She has developed the IMPTAM model, which will be used in the proposed project. She was a National Representative from Finland in the Management Committee of the recently accomplished COST ES0803 Action 'Developing space weather products and services in Europe'. She was a member of AGU (American Geophysical Union) Publications Committee during 2010-2012. She is currently a Secretary on Magnetospheric Physics in Division of Solar-Terrestrial Sciences of European Geosciences Union.

A post doc researcher will be hired to conduct the actual work required for the project under the supervision of Dr. Natalia Ganushkina.

2.3.4.1.3 UW - University of Warwick

Web page: http://www.warwick.ac.uk/

Description:

Number of Employees: 4912, Number of Students: 23420, Number of Researchers: 702, Number of Academics: 687.

Date of Creation: 1965, Annual Turnover 2012/13: £459.6m

The University of Warwick is one of the UK's leading universities with an acknowledged reputation for excellence in research and teaching, for innovation, and for links with business and industry. Founded in 1965 with an initial intake of 450 undergraduates, Warwick now has in excess of 22,000 students and is ranked comfortably in the top 10 of all UK university league tables.

Warwick is one of the top ten universities targeted by the Times Top 100 Graduate Employers. Warwick is renowned for excellence and innovation within research and in the 2008 Research Assessment Exercise, was ranked seventh overall in the UK, with 65% of the University's research rated as 3* (internationally excellent) or 4* (world leading). Warwick's mission is to become a world leader in research and teaching.

The Physics Department

The Physics Department at Warwick currently has some 60 research active academic staff, a similar number of Research Assistants, and strong technical and administrative support. This represents a rapid expansion and a doubling in size over the past ten years. Postgraduate students form an important part of the research community, with a population of over 150 in 2012. Research in the Warwick Physics Department was rated as internationally prominent in the 2008 Research Assessment Exercise.

Centre for Fusion, Space and Astrophysics (CFSA)

Within UW Physics Arber and Bennet are also members of CFSA is one of the largest interdisciplinary plasma physics centres in Europe. Its mission is to address key physics questions that arise from the grand challenges of fusion energy and the solar-terrestrial environment, and that require deep expertise in plasma physics to solve. The twin-track approach of contributing to fundamental physics and mission-led programmes ensures CFSA's activity is relevant to diverse funding sources: EPSRC and STFC; Euratom and ESA; and aligns with the UK's strategic energy and environmental needs. The group has a strong international reputation that is sustained through close partnerships with large facilities and their communities.

Centre for Computational Sciences (CSC)

Arber is also a core member of The Centre for Scientific Computing which employ state-of-the-art high performance computing tools to nurture internationally competitive research groups within Warwick

This is achieved by maintaining and enhancing an inter-disciplinary research environment which develops and shares computational expertise for the resolution of significant research goals.

In addition CSC manages a strategy for making a range of high performance computing environments available at Warwick so that research groups are well-placed to use larger national and international facilities.

Key publications relevant to the proposal:

T D Arber, A W Longbottom, C L Gerrard and A M Milne, A Staggered Grid, Lagrangian-Eulerian Remap Code for 3-D MHD Simulations, J. Computational Physics 171, 151-181, 2001

J A Merrifield, T D Arber, S C Chapman and R O Dendy, The scaling properties of two-dimensional compressible magnetohydrodynamic turbulence, Physics of Plasmas 13, 012305, 2006

G J J Botha, T D Arber and Abhishek K Srivastava, Observational Signatures of the Coronal Kink Instability with Thermal Conduction, Astrophysical Journal 745, 53-61, 2012

T D Arber, G J J Botha and C S Brady, Effect of Solar Chromospheric Neutrals on Equilibrium Field Structures, Astrophysical Journal 705, 1183-1188, 2009.

Previous projects relevant to the proposal:

2008-2012 STFC funded project 'Fundamental Plasma Physics of the Solar Corona'. This grant funded one PDRA under Prof. Arber's supervision to study solar coronal MHD, chromospheric physics and flux emergence.

2009 STFC funded 'Parallel computing resource for the UKMHD community' grant to cover MHD research and computing.

2011-2013 EPSRC funded project 'A radiation hydrodynamic ALE code'. This funded three PDRA, one each in Warwick, Oxford and Imperial College, to develop ALE codes for laboratory and space physics applications.

2014-2017 STFC funded Consolidated grant at Warwick. This grant funded one PDRA under Prof. Arber's supervision to study chromospheric heat via Alfvenic turbulence, chromospheric reconnection and coronal MHD.

Main tasks:

- Development of SWIFT code.
- Oversee the integration of SWIFT and AWSoM codes in WP2.
- WP2 integration to whole PROGRESS forecast model in WP7.
- Dissemination of results and methods in WP8.

The key participants in project PROGRESS at UW are:

Professor Tony Arber is a world-renowned expert in computational plasma physics. His research interests span kinetic plasmas, QED-plasma, MHD and fluid models all applied to either laboratory plasma devices or to space physics. Within space physics he has concentrated on MHD modelling of the solar chromosphere and corona and was the lead developer of the Lare3d MHD shock capturing code that is used extensively by the solar community. Other major code initiatives include the EPOCH code, a relativistic kinetic plasma model, which is now used worldwide by over 300 users. The development of Lare3d and EPOCH have demonstrated Arber's international standing in developing community codes developed across multiple sites. A skill of direct relevance to the PROGRESS project. Arber is the Chair of the UK's Collaborative Computational Project in Plasmas (CCPP) that coordinates UK efforts in plasma software development and training as well as being Chair of the UK Plasma Physics High End Computing Consortium (Plasma HEC) which manages the UK's allocation of national supercomputing time for plasma physics and coordinates efforts to optimise codes for such architectures. He is also a CoI on the UK MHD Consortium grant which hosts one of its HPC clusters at Warwick University's Centre for Scientific Computing. Arber's work has resulted in substantial research grants from the UK research councils SFTC, EPSRC as well as ESA and industrial sponsorship. He has organised conferences on computational plasma physics and chaired many sessions and international conferences. Professor Arber will lead WP2 on MHD code development, coordinating input from UM and UW, and is involved in the final integration of the PROGRES tool-chain (WP7) and dissemination (WP8)

Dr Keith Bennett is an expert in large-scale software development for plasma physics. Following his PhD in solar MHD from St. Andrews (2000) was the Scientific Computing Officer in St Andrews responsible for all scientific computing support and as lead developer of Lare3d. From 2005 he worked in industry as a scientific programming consultant for Fluid Gravity Engineering ltd. Much of this work involved fluid simulations and advanced visualisation. Since 2010 he has been at Warwick as the lead developer of the EPOCH project. This is a multi-institute, multi-national collaborative software development project to write a relativistic, including QED, kinetic plasma physics code. This project ends in March 2014 with the final code used by ~300 international researchers. From April 2014 he will move on to become the lead developer of the Odin MHD ALE code. He therefore has the ideal academic background, industrial experience and has been lead developer of Lare3d and Odin. He is the ideal candidate to develop SWIFT.

2.3.4.1.4 Skoltech - Skolkovo Institute of Science and Technology

Web page: http://www.skoltech.ru/

Description:

The Skolkovo Institute of Science and Technology (Skoltech) is a private graduate research university in Skolkovo, Russia, a suburb of Moscow. Established in 2011 in collaboration with MIT, Skoltech educates global leaders in innovation, advance scientific knowledge, and fosters new technologies to address critical issues facing Russia and the world. Applying international research and educational models, the university integrates the best Russian scientific traditions with twenty-first century entrepreneurship and innovation. Skoltech initially has five primary education and research programs, corresponding to priority areas as defined by Russia: these are Programs in Information Science and Technology, Energy Science and Technology, Biomedical Science and Technology, Space Science and Technology, and civilian Nuclear Science and Technology. Fifteen Centers for Research, Education and Innovation (CREIs) are associated with Skoltech, each residing under one or more of the programs.

Space Research and Technology Center is aiming to develop innovative space sensors, payloads and onboard systems to conduct new observations and measurements from Earth orbit, thus supporting observation and navigation on Earth and nearby bodies

Further, the center will also investigate technologies supporting human preparation for longer-term exploration, particularly in regards to radiation and microgravity environments, and human displays and controls to lessen human workload when supervising robotic systems in space or on planetary surfaces. In addition, researcher of the center will explore technologies in the area of geodesy and earth Observations, such as high-quality maps in real-time, Planetary Geodesy Global Navigation Satellite Systems; Deep Space Navigation Optical Navigation and Tracking.

Key publications relevant to the proposal:

Shprits, Y. Y., D. Subbotin, A. Drozdov, M. E. Usanova, A. Kellerman, K. Orlova, D. N. Baker, D. L. Turner & K.-C. Kim (2013), Unusual stable trapping of the ultrarelativistic electrons in the Van Allen radiation belts, Nature Physics, doi:10.1038/nphys2760

Shprits, Y. Y. and R. M. Thorne (2004), Time dependent radial diffusion modeling of relativistic electrons with realistic loss rates, Geophys. Res. Lett., 31, L08805, doi:10.1029/2004GL019591.

Horne, R. B., R. M. Thorne, Y. Y. Shprits, N. Meredith , S. Glauert , A. Smith , S. Kanekal , D. Baker , M. Engebretson , J. Posch , M. Spasojevic , U. Inan , J. Pickett , P. Decreau (2005), A critical test of electron acceleration in the Van Allen radiation belts, Nature, 437, 8 doi:10.1038/nature03939.

Shprits, Y. Y., D. A. Subbotin, N. P. Meredith, S. R. Elkington (2008), Review of modeling of losses and sources of relativistic electrons in the outer radiation belts: II. Local acceleration and loss, J. Atmos. Sol. Terr. Phys., 70, 14, 1694-1713, doi:10.1016/j.jastp.2008.06.014.

Shprits, Y., D. Kondrashov, Y. Chen, R. Thorne, M. Ghil, R. Friedel, and G. Reeves (2007), Reanalysis of relativistic radiation belt electron fluxes using CRRES satellite data, a radial diffusion model, and a Kalman filter, J. Geophys. Res., 112, A12216, doi:10.1029/2007JA012579.

Main tasks:

Skolkovo Institute of Science and Technology will be responsible for coupling the Versatile Electron Radiation Belt (VERB) 3D code with NARMAX and will implement the state of the art data assimilation tools (work package 6).

Key participants:

Prof. Yuri Shprits has a joint appointment at Skoltech and UCLA. UCLA and Skoltech will be closely collaborating on this project. Yuri Shprits is the author of over 80 publications related to the radiation belt modelling. Currently, the modelling methodology developed by Yuri Shprits and his groups is used by a number of groups around the world. He was also one of the first to apply data assimilation for the radiation belts. Skoltech and UCLA have a unique experience of using data assimilation. Members of the Skoltech team have recently demonstrated [Podladchikova et al., 2014 a, b] how to evaluate model related errors and measurement errors in an objective way. Yuri has served as PI on 15 projects funded by NASA, NSF, AFRL, and UCOP. He is the recipient of 2012 Presidential Early Career Award for Scientists and Engineers, Washington DC and 2011 Arne Richter Award for Outstanding Young Scientists, Union award of the European Geosciences Union, Vienna, Austria.

Dr.Tatiana Podladchikova is a postdoctoral fellow at Skolkovo Institute of Science and Technology, Russain Federation. Dr. Tatiana Podladchikova is an expert in the developing of data assimilation tools, an adaptive Kalman filter and parameter identification. Her research experience is related to the developing of space weather forecasting techniques for mitigation hazards of space accidents and their consequences. She developed and implemented real-time space weather forecasting services of the sunspot number prediction (http://sidc.be/products/kalfil/) and geomagnetic storm forecasting several hours ahead (http://spaceweather.ru).

2.3.4.1.5 UM – University of Michigan

Web page: http://www.umich.edu/

Description:

The University of Michigan is a public research university located in Michigan, United States. UM has more than 43,000 enrolled students from more than 100 countries. Both *Dr. Bart van der Holst* and *Prof. Michael W. Liemohn* are faculty members of the Department of Atmospheric, Oceanic, and Space Sciences at UM and members of the Center for Space Environment Modeling (CSEM). CSEM is an interdisciplinary research organization of the College of Engineering at UM. CSEM is comprised of a tightly integrated group of faculty, students and staff from the Departments of Aerospace Engineering, Atmospheric, Oceanic and Space Sciences, and Electrical Engineering and Computer Science. The overall goal of CSEM is to develop high-performance, first-principles based computational models to describe and predict hazardous conditions in the near-earth space environment extending from the sun to the ionosphere, called space weather.

Key publications relevant to the proposal:

Van der Holst, B., I.V. Sokolov, X. Meng, M. Jin, W.B. Manchester IV, G. Toth, and T.I. Gombosi, Alfvén wave solar model (AWSoM): coronal heating, Ap.J. 782, 81, 2014.

Manchester IV, W.B., B. van der Holst, and B. Lavraud, Flux rope evolution in ICMEs: The 2005 May 13 event, Plasma Phys. Control. Fusion 56, 064006, 2014.

Toth, G., B. van der Holst, I.V. Sokolov, D.L. De Zeeuw, T.I. Gombosi, F. Fang, W.B. Manchester IV, X. Meng, D. Najib, K.G. Powell, Q.F. Stout, A. Glocer, Y.-J. Ma, and M. Opher, Adaptive Numerical Algorithms in Space Weather Modeling, J. Comp. Phys. 231, 870-903, 2012.

Sokolov, I.V., B. van der Holst, R. Oran, C. Downs, I.I. Roussev, M. Jin, W.B. Manchester IV, R.M. Evans, and T.I. Gombosi, Magnetohydrodynamic waves and coronal heating: unifying empirical and MHD turbulence models, Ap.J. 764, 23, 2013.

Van der Holst, B., W.B. Manchester IV, R.A. Frazin, A.M. Vasquez, G. Toth, and T.I. Gombosi, A data-driven, two-temperature solar wind model with Alfvén waves, Ap.J. 725, 1373-1383, 2010.

Main tasks:

The University of Michigan plays a key role in WP2, the development of a model for the solar wind.

Key participants:

Dr. Bart van der Holst (Co-I, University of Michigan) and *Prof. Michael W. Liemohn* (Co-I, University of Michigan) are two of the leading developers of the Space Weather Modeling Framework (SWMF) numerical software tool. They will both assist an unnamed Post-Doc of the University of Michigan to make the solar corona model (AWSoM) of the SWMF time-accurate using hourly updated magnetograms. They will also assist this Post-Doc in coupling the solar corona model (AWSoM) of the SWMF to the new to be developed inner heliosphere model (SWIFT) at University of Warwick.

2.3.4.1.6 SRI NASU-NSAU

Web page: http://www.ikd.kiev.ua/

Description:

Space Research Institute of the National Academy of Sciences of Ukraine and National Space Agency of Ukraine has been active in investigating the need within Ukraine for increased space weather activities. Our activities included: analysis of space weather impact on spacecraft, communication system, climate change, networks; development of dynamic-information approach to space weather prediction using NARMAX and bilinear input-output models; development of risk assessment methods for space radiation effect estimation on satellite devices; development of algorithms and software for geomagnetic indices prediction based on dynamic-information approach. Project PROGRESS brings together expertise in two research department, Space Plasma and Remote Sensing and Advanced Instrumentation.

Key publications relevant to the proposal:

Agapitov O., Cheremnykh S. MHD Waves in the Plasma System with Dipole Magnetic Field Configuration, Advances in Astronomy and Space Physics 2, 103-106, 2011.

Cheremnykh O., Yatsenko V., Semeniv O., Shatokhina Iu. Nonlinear Dynamical Model for Space Weather Prediction. Ukr. J. Phys 53(5), 502-504, 2008.

V. Yatsenko, N. Boyko, S. Rebennack, P. Pardalos, Space Weather Influence on Power Systems: Prediction, Risk Analysis, and Modeling.-Energy Systems, Pub Springer, 1, 197-207, 2010.

Pardalos, P. and Yatsenko. Optimization and control of bilinear systems: theory, algorithms, applications, Pub. Springer, Dordrecht–Boston–London, p370, 2008.

O. Semeniv and V. Yatsenko, Identification of Dynamical Models for Dst-Index Forecasting. Control Problems and Informatics 16(1), 51–56, 2010.

Main tasks:

SRI NASU-NSAU will participate in WP3 and WP8.

Key participants:

Prof. Vitaliy Yatsenko is Head of Department ”Remote Sensing and Advanced Instrumentation” at the Space Research Institute of the Ukrainian Academy of Sciences and the Space Agency of Ukraine. He is the world leading expert in the field of nonlinear control systems. His main expertise relates to aspects of signal processing, control systems, identification, optimization and space weather prediction. He is author of more than 270 scientific articles and developed several well known software packages. He will provide input to WP 3 and 8.

Prof. Oleg Cheremnykh is Head of Department “Space Plasma” at the Space Research Institute of the Ukrainian Academy of Sciences and the Space Agency of Ukraine. Engaged in plasma physics from 1978. He is the author of 171 scientific publications. He will developed physical-based dynamic models of space weather prediction.

Dr. Oleh Semeniv is senior researcher at the Space Research Institute of the Ukrainian Academy of Sciences and the Space Agency of Ukraine. His investigation deals with modeling and space weather prediction. He is the author of 21 scientific publications. In the framework of the Project he will develop software related to space weather prediction.

Maksym Makarychev is PhD student at the Space Research Institute of the Ukrainian Academy of Sciences and the Space Agency of Ukraine. His investigation deals with nonlinear analysis of time series and reconstruction of dynamic models using satellite data. He is the author of 6 scientific publications. He will develop software related to space weather prediction.

2.3.4.1.7 CNRS: Centre National de la Recherche Scientifique

Web page: http://www.lpce.cnrs-orleans.fr/

Description:

The Centre National de la Recherche Scientifique is a government funded research organization under the administrative authority of the French Ministry of Research. CNRS research laboratories, spread all over France and often partnered with universities, carry out research in all fields of science. Those focusing on the studies in space plasma, planetary environment, solar physics, astrophysics and geophysics are coordinated by one of the Institutes of the CNRS, the "Institut National des Sciences de l'Univers" (INSU).

The Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E) is a Joint Research Unit (JRU) operated by the French Centre National de la Recherche Scientifique (CNRS) and the University of Orleans (UO). The Centre National de la Recherche Scientifique (CNRS) is the legal entity acting on behalf of LPC2E.

The research done in LPC2E is related to the study and modelling of physical processes occurring in the neutral environment (atmosphere) or ionized environment (ionosphere, magnetosphere, solar wind) of the Earth and other planets. This research is carried out in the frame of national, European, and international programmes. The different activities of LPC2E are: the physic of the space plasmas, the physico-chemistry of the planetary environments, the physico-chemistry of the atmosphere, astrophysics.

The group at CNRS/LPC2E has a great experience in analysis of satellite data of wave experiments onboard satellites. The group was one of the first to develop and apply tools for the determination of k-vectors making use of multi-satellite data. This technique was applied to analyze the data of Cluster project. It was one of the first groups to develop and apply the technique for the identification of non-linear processes in space plasmas, in particular bi-coherence and tri-coherence methods that allow one to establish the presence of wave-wave interactions. This technique was applied to the data of AMPTE project and on the basis of this development the special package SWAN was developed by LPC2E and delivered to scientific community of Cluster project. Recently our group has actively worked on creation of the database of wave measurements onboard Cluster, THEMIS, Polar, DE and Akebono satellites in the Earth magnetosphere with special attention to the vicinity of the radiation belts. The data base realized by Orleans group represent statistical distribution of wave observations that includes the probability of observations, amplitudeof electric and magnetic field distributions upon several parameters such as the L-shell, MLT, and geomagnetic indices. The database includes also the distribution of wave vectors upon latitudes that is crucially important for the calculation of the diffusion coefficients that determine the time of life of energetic particles. The group will lead activities of package 4 where similar database should be created but it should include the dependencies of wave characteristics upon solar wind parameters.

Key publications relevant to the proposal:

1. Artemyev, A. V., Mourenas, D., Agapitov, O. V., and Krasnoselskikh, V. V.: Parametric validations of analytical lifetime estimates for radiation belt electron diffusion by whistler waves, Ann. Geophys., 31, 599-624, DOI:10.5194/angeo-31-599-2013, 2013.

2. Mourenas, D.; Artemyev, A. V.; Agapitov, O. V.; Krasnoselskikh, V., Analytical estimates of electron quasi-linear diffusion by fast magnetosonic waves, Journal of Geophysical Research: Space Physics, Volume 118, Issue 6, pp. 3096-3112, DOI 10.1002/jgra.50349, 2013 ;

3. Arpad Kis, O. Agapitov, V. Krasnoselskikh, Yu. Khotyaintsev, Gyrosurfing Acceleration of Ions in Front of Earth's Quasi-parallel Bow Shock , Ap.J., **771** 4, 2013;

4. Krasnoselskikh, V.; Balikhin, M.; Walker, S. N.; Schwartz, S.; Sundkvist, D.; Lobzin, V.; Gedalin, M.; Bale, S. D.; Mozer, F.; Soucek, J.; Hobara, Y.; Comisel, H., The Dynamic

Quasiperpendicular Shock: Cluster Discoveries, Space Sci. Rev., DOI 10.1007/s11214-013-9972-y, 2013;

5. Agapitov, O., A. Artemyev, V. Krasnoselskikh, Y. V. Khotyaintsev, D. Mourenas, H. Breuillard, M. Balikhin, and G. Rolland *(*2013*),* Statistics of whistler-mode waves in the outer radiation belt: Cluster STAFF-SA measurements*,* J. Geophys. Res. Space Physics*,* 118*,* 3407–3420*,*DOI :10.1002/jgra.50312 ;

Main tasks:

The group will lead activities of package 4. The analysis of the CLUSTER, Helios, WIND and STEREO satellite data sets will be performed at LPC2E by the participants named below. The main tasks of LPC2E within the PROGRESS project are the participation in creation of the data base of wave characteristics in the inner magnetosphere of the Earth and around radiation belts and evaluation of the diffusion coefficients due to wave-particle interaction, that is one of the critical parameters that determine particle losses.

Key participants:

The group consists of one permanent scientist, Dr. Krasnosselskikh V., one Post Doc, one engineer and Ph. D. student Andrii Voshchepynets.

Dr. Vladimir Krasnosselskikh (leader) is a research scientist responsible for the search coil instrument in the Solar Orbiter project that will study the turbulence characteristics and the wave activity in the solar wind. Dr. Krasnosselskikh was born in Russia, in 1952. After receiving his 3rd cycle thesis at the Moscow Physical Technological Institute in Moscow under the supervision of Academician Galeev in 1978, he began working at Space Research Institute in Moscow. In the beginning of 1991 he moved to France and joined LPCE/INSU/CNRS. His recent research activities are related to the studies of statistical characteristics of waves in the radiation belts and their role in particle acceleration and angular diffusion in the inner magnetosphere. He works as the theoretician and he performs the analysis of wave activity in the magnetosphere. He is author/ co-author of about 120 papers published in refereed journals.

2.3.4.1.8 IRF – Swedish Institute for Space Physics

Web page: http://www.irf.se/

Description:

The Swedish Institute of Space Physics is a governmental research institute with about 100 employees. The research activities concern studies of phenomena in the Earth's upper atmosphere, ionosphere, and planetary magnetospheres. Ground-based measurements of ionospheric parameters, geomagnetic field, optical aurora, and radio wave propagation, as well as in situ measurements with satellites are being performed. The group in Lund (IRF-Lund, http://lund.irf.se/) was formed in 1996 as a part of IRF's Solar Terrestrial Physics Research Programme. IRF-Lund studies the solar driver of space weather, the solar activity, and also the link between solar activity and climate changes. IRF-Lund runs the Swedish Space Weather Center (http://src.irf.se/) and is also a Regional Warning Center (RWC-Sweden, http://www.lund.irf.se/rwc/) within the International Space Environment Service (ISES).

Key publications relevant to the proposal:

Wintoft, P., M. Wik and A. Viljanen, Empirical solar wind driven model for real time forecasting of local ground magnetic field variation, To be submitted to Journal of Space Weather and Space Climate, 2014.

Watermann, J., P. **Wintoft**, B. Sanahuja, E. Saiz, S. Poedts, M. Palmroth, A. Milillo, F. A. Metallinou, C. Jacobs, N. Ganushkina, I. Daglis, C. Cid, Y. Cerrato, G. Balasis, A. Aylward and A. Aran, 2009. Models of Solar Wind Structures and Their Interaction with the Earth's Space Environment. Space Science Reviews.

Wintoft, P., 2005. Study of the solar wind coupling to the time difference horizontal geomagnetic field. Ann. Geophys., 23, 1949–1957, doi:10.5194/angeo-23-1949-2005.

Wintoft, P., 2011. The variability of solar EUV: A multiscale comparison between sunspot number, 10.7 cm flux, LASP MgII index, and SOHO/SEM EUV flux, Journal of Atmospheric and Solar-Terrestrial Physics, 73, 1708–1714.

Wintoft, P., M. Wik, H. Lundstedt and L. Eliasson, 2005. Predictions of local ground geomagnetic field fluctuations during the 7-10 November 2004 events studied with solar wind driven models. Ann. Geophys., 23, 3095–3101, doi:10.5194/angeo-23-3095-2005.

Main tasks:

Leader of WP3 *Forecast of the evolution of geomagnetic indices*: improvement and new development of models based on data driven modelling to forecast geomagnetic indices *Kp*, *Dst*, and *AE*; classification of relevant solar wind and geomagnetic structures (shocks, sudden impulses, sub-storms); verification of existing and future models.

Key participants:

Dr. Peter Wintoft (M)

- Scientist at IRF-Lund

- Scientific expertise: wavelet analysis, neural networks, forecast verification, space weather analysis and forecasting

- Development of AI Methods in Spacecraft Anomaly Predictions, (SAAPS), ESA funded project, http://www.lund.irf.se/saaps/, 1999–2001, Lead by IRF.

- Real-time forecast service for geomagnetically induced currents, ESA Space Weather Applications Pilot Project, http://www.lund.irf.se/gicpilot/, 2003–2006, Lead by IRF.

- Virtual observatory for space weather data and models (VISPANET), ESA funded project, 2009–2011, IRF subcontractor.

- Developing Space Weather Products and Services in Europe, COST Action ES0803, http://www.costes0803.noa.gr, 2008–2012, Leader of subgroup on "Performance of available research and operational models".

- Solar storms and space weather, MSB funded project, http://www.lund.irf.se/msb/, 2012–2014. Lead by IRF.

- EURISGIC (European Risk from Geomagnetically Induced Currents, 2011-2014), funded by EU/FP7; coordinator: FMI

2.3.4.2 Third parties involved in the project (including use of third party resources)

There is no subcontracting of work in the Project.

For this Project, the University of Orléans is linked to CNRS as third party. The Laboratoire de Physique et Chimie de l'Environnement et de l'Espace (LPC2E) is a Joint Research Unit (UMR n° 7328). The LPC2E is under the control of the CNRS and the University of Orléans. All staff associated with project PROGRESS for the partner CNRS will work in LPC2E. As LPC2E is a Joint Research Unit, the LPC2E staff may belong either to the CNRS or to the University of Orléans. The financial and administrative issues concerning CNRS and the third parties will be managed by CNRS as a whole. For this reason the clause 14.1 is to be inserted in the Grant Agreement.

A description of the partner LPC2E may be found in section 2.3.4.1.6. The costs associated with the participant CNRS, the third party (UO), and the JRU (LPC2E) are to enable LPC2E to fulfill the tasks assigned to them within the workpackages of the Project. A small provision of 6363 Eur for Personnel Costs has been allocated to UO. This financial split is reflected in the Annex 2 Budget table.

2.3.5 Resources to be committed

2.3.5.1 Cost justifications.

USFD

	Cost (€)	Justification
Travel	76534	1. Project, Steering Committee, and Stakeholder meetings (travel €300, subsistence €156, 4 nights, 4 people * 7 meetings) €21991 2. Funds for stakeholders to attend meetings (travel €360 (€840 from US), subsistence €156, 2 nights, 6 people * 3 meetings) €14851 3. EC/REA review meetings (travel €300, subsistence €156, 2 nights, 3 people * 3 meetings) €5462 4. Scientific conferences 3* Fall AGU, 3* EGU, COSPAR, 3 * ESWW, 2*US SWW, GEM €15951 5. Post doc travel fund for post doc researchers to travel between participant groups €18279
Equipment	0	
Other goods and services	25,692 14,200 2,017	Costs of running summer school and Sheffield in year 3 Publication fees, consumables Audit fee
Total	118,443	

FMI

	Cost (€)	Justification
Travel	19,600	Project meetings 8,000 Eur, EC/REA review meetings 3150Eur Scientific conferences (AGU, EGU, COSPAR, European

		Space Weather Week) 8450 Eur
Equipment	0	
Other goods and services	4,900	Publication charges 3,000 Eur Conference abstract and registration fees (AGU, EGU, ESWW)
Total	24,500	

UW

	Cost (€)	Justification
Travel	26,300	1. Project meetings in Sheffield (€162 travel, €270 accommodation, €108 subsistence for two days per meeting) x7 = €3,780 2. One week research visit to UM for Arber and Bennett (€1,300 flight, €8,400 hotel, €560 subsistence) x2 = €20,520 3. Scientific conferences EGU (€250 travel, €150 hotel, €100 subsistence, 3 nights) x2 = €2,000
Equipment	7,000	High end workstation, 8 core, 64GB RAM for software development
Other goods and services	53,845	Access charges to UW HPC services at €0.04725 per CPU hour for 12 months use of 130 cores
Total	87,145	

Skoltech

	Cost (€)	Justification
Travel	7,000	Project meetings 7* (250Eur flight + 3 nights subsistence 250Eur) for one person
Equipment	0	
Other goods and services	2,000	Computer (1500Eur) Publication fees (500Eur)
Total	9,000	

UM

	Cost (€)	Justification
Travel	8,267	Project meetings 1 person* 6 meetings travel 6604 Eur, subsistence 1663Eur
Equipment	0	
Other goods and services	9,067	AOSS Network computing services 4,279 Eur Books/Publications 4788 Eur
Total	17,334	

SRI NASU-NSAU

	Cost (€)	Justification
Travel	11,974	1. Project meetings - 300Eur travel + 200Eur subsistence per night, 2 nights per meeting, 7 meetings 2. Scientific conferences e.g. AGU, EGU, COSPAR
Equipment	0	
Other goods and services	0	
Total	11,974	

CNRS/LPC2E

	Cost (€)	Justification
Travel	14,000	1. Project meetings 7 meetings * 3 nights, subsistence 300Eur per night, 300Eur flight = 8400 Eur 2. Scientific conferences (AGU, EGU, COSPAR, Space Weather Week 5600Eur
Equipment	0	
Other goods and services	4,000	Publication fees 4000 Eur
Total	18,000	

IRF

	Cost (€)	Justification
Travel	10,400	Project meetings €300 flight, €200 accommodation, €200 subsistence, 6 meetings, two persons €8400 + organization of meeting in Lund
Equipment	4,000	Work station for database and running models
Other goods and services	0	
Total	14,400	

2.3.6 Ethics and Security

2.3.6.1 Ethics

The EC/REA advice of ethical issues has been noted. No ethical issues, as listed within the ethical issues table within the proposal administrative forms, arise from project PROGRESS. In particular we confirm that there are no activities that require informed consent, no data protection issues regarding the collection and storage of personal data, no use of animals, animal tissues, or embryonic stem cells.

2.3.6.2 Security

There are no activities or results that raise security issues.

There is no EU-classified information arising from project PROGRESS.

Appendix 1 References

Agapitov, O., V., Artemyev, A Krasnoselskikh, Y. V. Khotyaintsev, and G. Rolland, A statistical study of the propagation characteristics of whistler waves observed by Cluster, Geophys. Res. Lett., 382, L20103, doi:10.1029/2011GL049597, 2011.

Agapitov, O., V. Krasnoselskikh, Y. V. Khotyaintsev, and G. Rolland, Correction to "A statistical study of the propagation characteristics of whistler waves observed by Cluster", Geophys. Res. Lett., 39, L24102, doi:10.1029/2012GL054320, 2012.

Agapitov, O., A. Artemyev, V. Krasnoselskikh, Y. V. Khotyaintsev, D. Mourenas, H. Breuillard, M. Balikhin, and G. Rolland, Statistics of whistler-mode waves in the outer radiation belt: Cluster STAFF-SA measurements, J. Geophys. Res. Space Physics, 118, 3407–3420, doi:10.1002/jgra.50312, 2013.

Arber, T. D., A. W. Longbottom, C. L. Gerrard, and A. M. Milne, A Staggered Grid, Lagrangian-Eulerian Remap Code for 3-D MHD Simulations, J. Comp. Phys. 171, 151-181, doi:10.1006/jcph.2001.6780, 2001.

Balikhin, M. A., R. J. Boynton, S. A. Billings, M. Gedalin, N. Ganushkina, D. Coca, and H. Wei, Data based quest for solar wind-magnetosphere coupling function, Geophys. Res. Lett. 37, L24107, 2010

Balikhin, M. A., R. J. Boynton, S. N. Walker, J. E. Borovsky, S. A. Billings, and H. L. Wei, Using the NARMAX approach to model the evolution of energetic electrons fluxes at geostationary orbit, Geophys. Res. Lett. 38, L18105, 2011

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Appendix 2 List of Acronyms

ACE	Advanced Composition Explorer
AE	Auroral Electrojet geomagnetic index
AGU	American Geophysical Union
ANN	Artificial Neural Network
AWSoM	Alfven Wave Solar atmosphere Model
BAS	British Antarctic Survey
BATS-R-US	US MHD simulation code
CCMC	Community Coordinated Modelling Center
CIR	Corotating Interaction Region
CME	Coronal Mass Ejection
CNN	Computational Neural Network
CNRS	Centre National de la Recherche Scientifique
COSPAR	Committee on Space research International Association of
CRRES	Combined Release and Radiation Effects Satellite
DSCOVR	Deep Space Climate Observatory
Dst	Disturbance Storm Time geomagnetic index
EC	European Commission
EGU	European Geosciences Union
EMIC	ElectroMagnetic Ion Cyclotron
EMW	Equatorial Magnetosonic Waves
ENLIL	Solar wind model named after the Sumerian god of winds and storms
ERR	Error Reduction Ratio (part of the NARMAX methodology)
ESA	European Space Agency
ESD	ElectroStatic Discharge
ESWW	European Space Weather Week
FDC	Full Diffusion Code
FMI	Finnish Meteorological Institute
GEO	Geosynchronous Earth Orbit
GLONASS	Globalnaya navigatsionnaya sputnikovaya sistema (Russian satellite based navigational system)
GNSS	Global Navigation Satellite System
GOES	Geostatinary Operatinal Environment Satellite
GOES MAGED	Magnetspheric Electrn Detector onboard the GOES series of satellites

GONG	Global Oscillation Network Group
GPS	Global Positioning System
HOPE	Helium Oxygen Proton Electron plasma particle detector on Van Allen probes
HPC	High Performance Computer
HYDRA DDEIS	Duo-Decker Electron Ion Spectrometer
IAGA	International Association of Geomagnetism and Aeronomy
IMF	Interplanetary Magnetic Field
IMPTAM	Inner Magnetospheric Particle Transport and Acceleration Model
IPR	Intellectual Property Rights
IRF	Swedish Institute for Space Physics (Institut for Rymdfysik)
JRU	Joint Research Unitgalileo
Kp	Planetary K geomagnetic index
L1	LeGrange point 1
LANL MPA	Los Almos National Laboratory Magnetospheric Plasma Detector (particle instrument)
LANL SOPA	Los Almos National Laboratory Synchronous Orbit Particle Analyser (particle instrument)
LPC2E	Laboratoire de Physique et Chimie de l'Environnement et de l'Espace
MEO	Medium Earth Orbit
MESSENGER	MErcury Surface, Space Environment, Geochemistry and Ranging
MHD	MagnetoHydroDynamic
NARMAX	Nonlinear Autoregressive Moving Average Model with eXogenous inputs
NASA	National Aeronautical and Space Agency
NOAA	National Ocianic and Atmospheric Administration
ONERA	French Aerospace Laboratory
PC	Project Coordinator
PEACE	Plasma Electron and Current Experiment (instrument onboard Cluster satellites)
PM	Project Manager
PROGRESS	Prediction Of Geospace Radiation Environment and Solar wind ParameterS
PSD	Phase Space Density
REA	Research Executive Agency (European Commission)
RRBDM	Recursive, Robust, Bilinear Dynamical Model
SAB	Stakeholder Advisory Board
SCNN	Supervised Computational Neural Network
SEU	Single Event Upset
Skoltech	Skolkovo Institute of Science and Technology
SNB^{3}GEO	Sheffield NARMAX model for electron fluxes at Geostationary orbit

SRI NASU-NSAU	Space Research Institute of the National Academy of Sciences of Ukraine and the National Space Agency of Ukraine
SSA	Space Situational Awareness
SSC	Scientific Steering Committee
SWIFT	Solar Wind Flux Transfer model
SWMF	Solar Wind Modelling Framework
THEMIS	Time History of Events and Macroscale Interactions during Substorms
TRL	Technology Readiness Level
UCNN	Unsupervised Computational Neural Network
UM	University of Michigan
USFD	University of Sheffield
UW	University of Warwick
VERB	Versatile Electron Radiation Belt particle model
VoIP	Voice over Internet Protocol
WPL	Work Package Leader