The Virtual Space Weather Modeling Centre - Part 3

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Abstract

The ESA Virtual Space Weather Modelling Centre (VSWMC)project was defined as a long term project including different successive parts. Parts 1 and 2 were completed in the first 4-5 years and designed and developed a system that enables models and other components to be installed locally or geographically distributed and to be coupled and run remotely from the central system. A first, limited version went operational in May 2019 under the H-ESC umbrella on the ESA SSA SWE Portal. Part 3 is the next development step before all objectives of the VSWMC are achieved. The goal of the ESA project "Virtual Space Weather Modelling Centre - Part 3" (2019-2021) is to further develop the Virtual Space Weather Modelling Centre, building on the Part 2 prototype system and focusing on the interaction with the ESA SSA SWE system. The objective and scope of this new project include, apart from maintaining the current operational system, the efficient integration of new models and new model couplings, including daily automated end-to-end (Sun to Earth) simulations, the further development and wider use of the coupling toolkit and front-end GUI, making the operational system more robust and user-friendly. The VSWMC-Part 3 project started on 1 October 2019. The new models that are being integrated are Wind-predict (a global coronal model from CEA, France), the Coupled Thermosphere/Ionosphere Plasmasphere (CTIP) model, Multi-VP (another global coronal model form IRAP/CNRS, France), the BIRA Plasma sphere Model of electron density and temperatures inside and outside the plasmasphere coupled with the ionosphere (BPIM, Belgium), the SNRB (also named SNB3GEO) model for electron fluxes at geostationary orbit (covering the GOES 15 energy channels >800keV and >2MeV) and the SNGI geomagnetic indices Kp and Dst models (University of Sheffield, UK), the SPARX Solar Energetic Particles transport model (University of Central Lancashire, UK), Spenvis DICTAT tool for s/c internal charging analysis (BISA, Belgium), the Gorgon magnetosphere model (ICL, UK), and the Drag Temperature Model (DTM) and operations-focused whole atmosphere model MCM being developed in the H2020 project SWAMI. We will provide an overview of the state-of-the-art and demonstrate the system.

The ESA Virtual Space Weather Modelling Centre - Part 3

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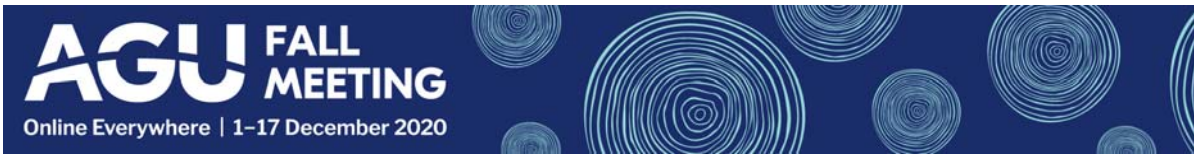
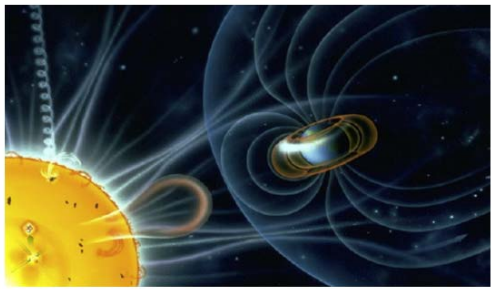


WHAT, WHY?

Motivation 1: need for reliable predictions

- Importance of **reliable predictions** of the space weather and its *effects on technological systems, human life and health*.
- Requires *a deeper insight in space weather physics*.
- Observations are much needed *but sometimes limited/difficult to interpret (projection effects,…) and* some things cannot be observed *(e.g. coronal magnetic field)*



Numerical simulation models can provide (additional) information that cannot be observed directly (magnetic field topology, density structure, local velocity, etc.)

Motivation 2: need for integrated Space Weather model frameworks

- **Space Weather needs to be predicted *reliably*** so that mitigation is possible to limit the damage
- ***Physics based models* are needed** as *empirical & semi-empirical models do not always work satisfactorily, but these are more complex to operate*

➢ Simple **(G)UI needed for easy of use** of (often very complicated) simulation models

➢ **A standard environment is** needed for

- *Model (and data) repository*
- *Optimal model simulations / verification / validation*
- *Enable coupling(s) of (sub-)models*

The Virtual SWE Modeling Centre

- An **open end-to-end** (Sun to Earth) space weather modeling system,
- enabling to **combine ("couple") various space weather models** in an integrated tool,
- with the models located **either locally or geographically distributed** (≠ CCMC),
- **Interactive** (≠ CCMC)

➢ **VSWMC combines <u>three roles</u>**:
- *A repository for models and data*
- *A facility offering a model coupling infrastructure*
- *Enables **interactive** (≠ CCMC) execution of coupled model simulations*

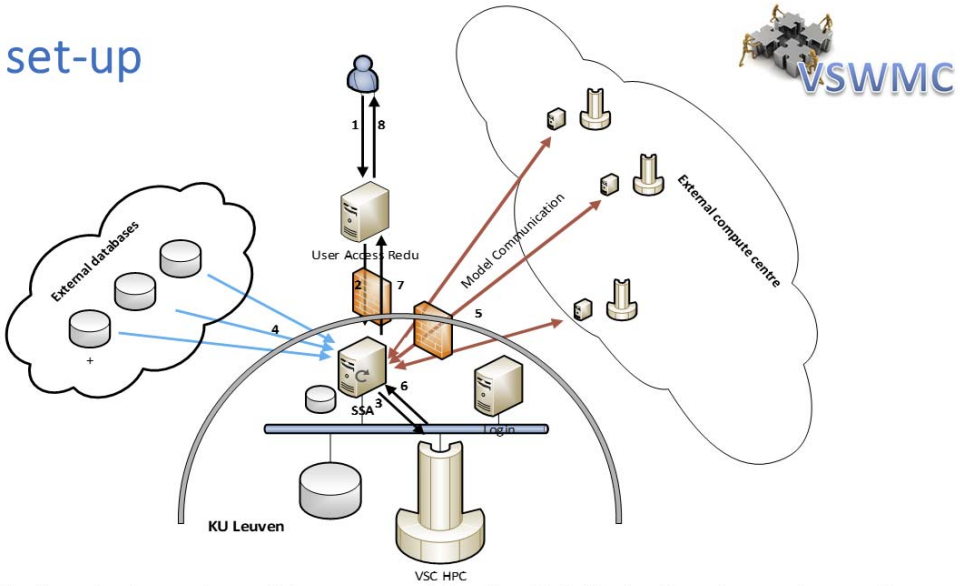
VSWMC Brief History

- **Phase 1** *(ESTEC/Contract No. 4000106155-VSWMC – Phase 1)*
  - Study **User and System Requirements** with 5–10 yr horizon
  - Development **proof of concept prototype** (limited # models)

- **Phase 2** *(P2-SWE-XIV - Virtual Space Weather Modelling Centre - Part 2)*
  - Integration of **new models** and **new model couplings**, including a first demonstration of an **end-to-end simulation capability** + models can be installed centrally or remotely
  - Further development of the **coupling toolkit** and **front-end GUI** (available through the ESA SSA/SWE portal (28/05/19)
  - Development of *APIs* & Improved access to input and output data Development of **integrated visualization tool** modules

HOW, WHEN?

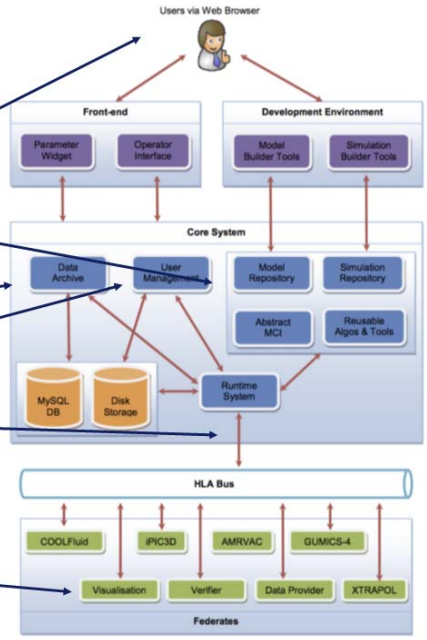
Basic set-up



Federated service with geographically distributed system elements

VSWMC structure

- Users interface via a web portal (in SSA SWE system)
- Developer environment with 4 service components
- Core system also contains data archive and user management component
- Only the runtime system interacts with HLA bus to coordinate simulations
- visualizations are implemented as 'federates'



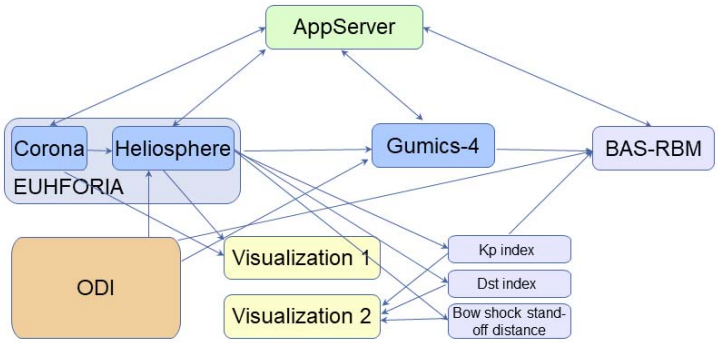
VSWMC-Part 2 integrated models

Model repository *contains the different models (operational/development system) installed (binary or source code, MCI, model metadata, input and visualization widgets). Shortlist:*

• ***XTRAPOL***	*solar model*	*(running in Paris)*
• ***AMRVAC***	*2.5D solar wind + CMEs*	*(running in Leuven)*
• ***GUMICS-4***	*magnetosphere*	*(")*
• ***Euhforia1***	*coronal model*	*(")*
• ***Euhforia2***	*inner heliosphere + CMEs*	*(")*
• ***CTIP/CMAT2***	*ionosphere*	*(under development)*
• ***BAS-RBM***	*radiation belt*	*(running at BAS)*
• ***COOLFluiD***	*magnetosphere*	*(running in VKI/Leuven)*
• ***Geo-effect models***:	*Kp, Dst and plasmapause stand-off distance*	*(running in Leuven)*
• ***ODI***	*takes data from the ODI database*	

First operational VSMWC

Framework node communication



https://sso.ssa.esa.int *(under Heliospheric -ESC product demonstration)*

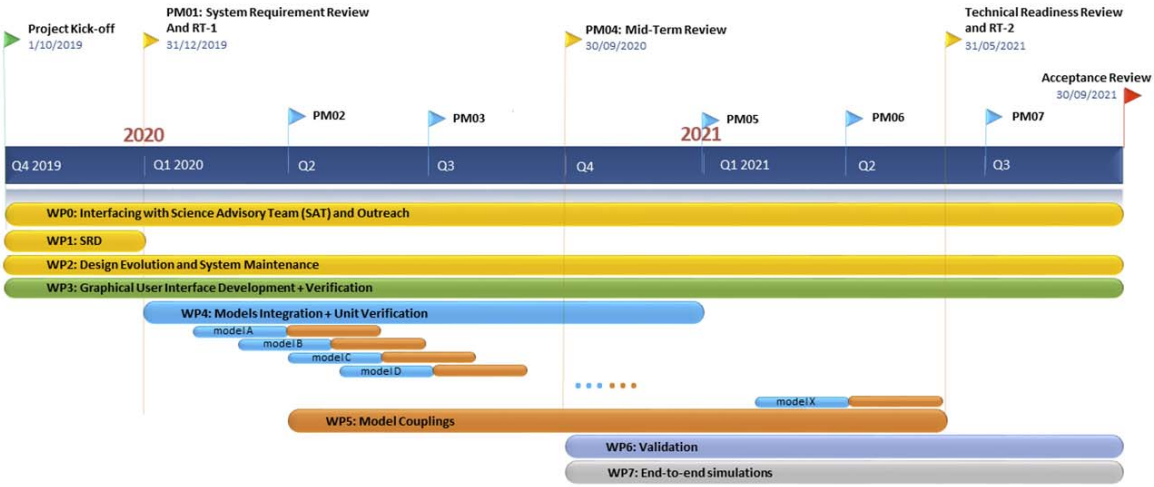
WHAT NOW…?

VSWMC-Part 3 Objectives

New developments for Part 3 focus on:

- *Maturing the VSWMC web interface accessible via the SSA portal;*
- *improvement of the model setup, parameter definition and visualisation GUI;*
- *interfacing of 11 new models on the system, development of new model couplings;*
- *extension of the end-to-end simulation capability;*
- *development of automatized verification and validation processes;*
- *development and **wider use of the coupling toolkit**;*
- *Making **more data available** on the system for new model inputs and validation of outputs.*

Gantt chart



Additional models installed/being installed

1.	Wind-Predict @KU Leuven	= alternative global corona model
2.	CTIP @KU Leuven	= Coupled Thermosphere Ionosphere Plasmasphere
3.	MULTI-VP @Toulouse	= alternative global corona model
4.	Plasma sphere Model (BPiM) @BIRA	= 3D dynamic model of the plasmasphere
5.	SNRB @ KU Leuven	= electron fluxes at geostationary orbit
6.	SNGI @ KU Leuven	= geomagnetic indices Kp and Dst
7.	SPARX @ University of Central Lancashire	= SEP time-flux profiles
8.	Spenvis DICTAT @ BIRA	= s/c internal charging analysis
9.	Gorgon @ Imperial College London	= alternative magnetosphere model
10.	MCM @ Leuvnen	= temp., density, and composition of the thermosphere
11.	DTM @ UK MetOffice	= temp., density, and composition of the thermosphere

Geographical distribution

AND THEN…?

Further plans – SEP model integration

- **SPARX model:**
  A modeling system for Solar Energetic Particle Radiation Space Weather forecasting (Marsh et al., 2015)
  - ➢ **To be included as part of the VSWMC-P3 project**

- **PARADISE model coupled to EUHFORIA:**
  Particle Radiation Asset Directed at Interplanetary Space Exploration (Wijsen 2020).
  - ➢ **To be included via another ESA ITT project ("EUHFORIA in PARADISE")**

SPARX model *(VSWMC-P3 plans)*

- based upon a relativistic full-orbit test particle code (originally developed to study particle acceleration during magnetic reconnection [Dalla and Browning, 2005])

- **Solving for each test particle**:

$$\frac{d\mathbf{p}}{dt} = q\left(\mathbf{E} + \frac{1}{c}\frac{\mathbf{p}}{m_0\gamma} \times \mathbf{B}\right)$$

using *unipolar Parker spiral for* ***E*** *and* ***B***

- **Triggering system:** manually (choosing location of given event) or automatically (triggered by real-time automated detection of a flare by the Flaremail tool)

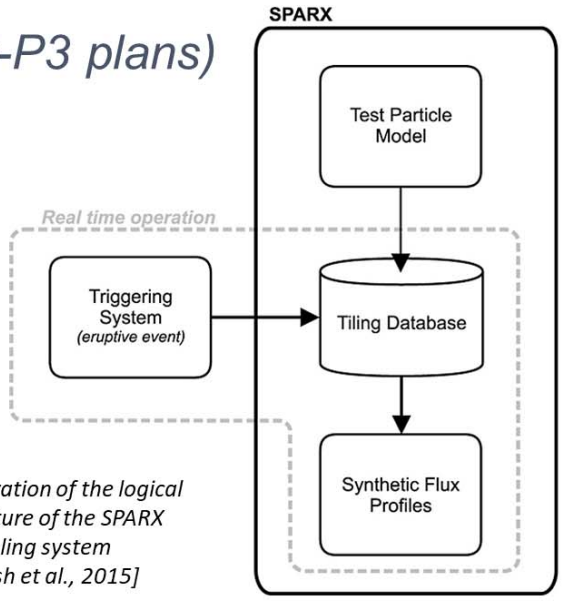


Illustration of the logical structure of the SPARX modeling system [Marsh et al., 2015]

PARADISE

'Particle radiation asset directed at interplanetary space exploration'

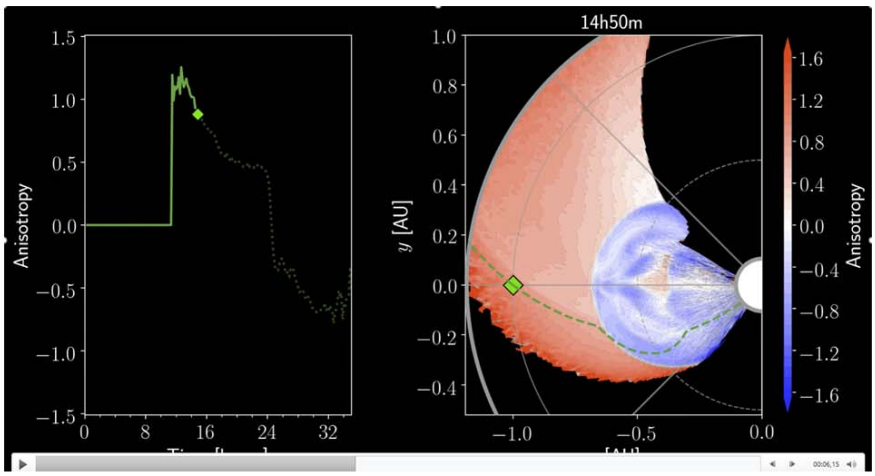
NEW model of energetic particles propagating through the solar wind

Time (omni-directional) intensity

$$I = \int_{-1}^{1} j(\mu) d\mu$$

and **anisotropy (A) profiles**

$$A = \frac{\int_{-1}^{1} \mu j(\mu) d\mu}{\int_{-1}^{1} j(\mu) d\mu}$$



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