The Solar Terrestrial ObseRvations and Modeling Service (STORMS)

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ABSTRACT:

We present an on-going effort to develop a public infrastructure to support research in heliophysics as well as space-weather forecasting. STORMS combines a wide range of observation and in situ measurements with heliospheric models to study and model the influence of solar activity on the near-Earth environment. Supporting operations of space missions, such as Solar Orbiter, is an important goal for this service. The Magnetic Connectivity Tool helps with deciding the pointing of remote-sensing instruments by exploiting real-time data and forecasts based on numerical simulations. It finds regions of the solar surface that may be connected with a spacecraft in a near future. It is operational since 2020 and is currently used for Solar Orbiter mission. Predicting solar wind properties is achieved by combining coronal and heliospheric models (Multi-VP, Pluto, 1D-MHD). Analysis of multi-point imaging to derive the 3-D structure of solar wind structures such as Coronal Mass Ejections (CMEs) and Corotating Interaction Regions (CIRs) is also performed (Shock Tool). Daily forecasts provides prediction to the scientific community and end users. As a community service, STORMS allows « run on request » simulations for users, helping them in studying a particular event. This is available through the VSWMC Virtual Space Weather Modelling Center and can be coupled with other models (EUHFORIA). Further STORMS services will integrate runs-on-demand of the new multi-species IRAP Solar Atmosphere Model (ISAM) and a full database of 3-D MHD simulations.

Figure 1: the welcome page of the STORMS website @ http://storms-service.irap.omp.eu/

1. ROLE OF THE STORMS service:

STORMS was created in 2014 and is a CNRS-labelled space-weather service with a team of 10 active researchers and engineers that aims to:

- develop new tools to connect databases that store in situ data (like the CDPP), planetary auroral imagery (such as APIS) and remote-sensing data centers (MEDOC),
- provide new catalogues of coronal and heliospheric structures (level 3 data products: catalogues of CIRs, 3-D shock reconstructions, CME trajectories),
- develop and deliver prototypes of novel space-weather forecasting tools useful to fundamental research in space weather, to end users and to spacecraft operators (e.g. Solar Orbiter).

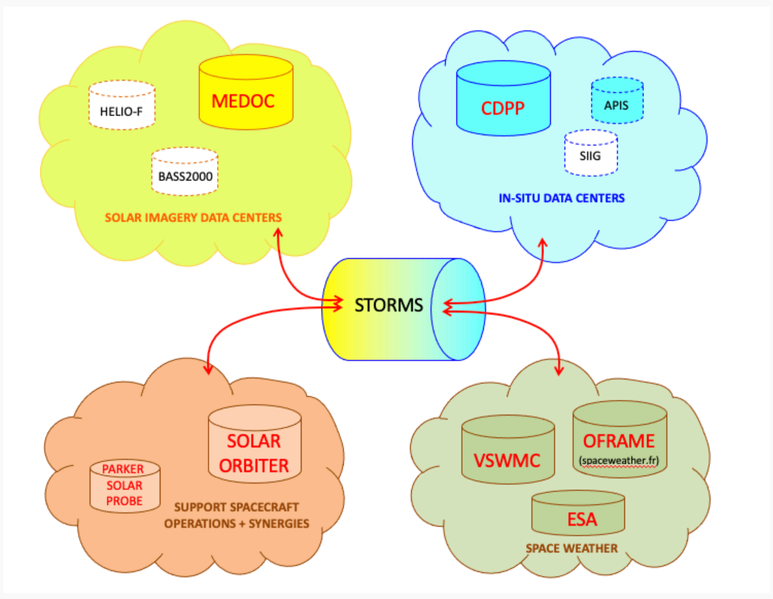

Figure 2: A schematic of the different roles of the STORMS service.

2. SPACE-WEATHER TOOLS @ STORMS

All these services are delivered through the main STORMS website (Figure 1). For each type of service there are several projects that correspond to on-going tool developments covering a diverse range of heliospheric phenomena (Solar Wind, CMEs, CIRs and SEPs). The space-weather related tools are listed below and acessibles via the webpage shown in Figure 3.

- **The Magnetic Connectivity Tool** computes magnetic connectivity between a spacecraft or a planet and solar surface for multiple observed data and multiple models (Rouillard et al. 2020a).
- **Heliocast** is a service that provides nowcast and forecast of the structure of the inner heliosphere based on 3D MHD modeling between 0.1 and 1 AU coupled to imagery-driven boundary conditions (Réville et al. 2022).
- **SWIFT 1-D Solar Wind Forecast** nowcasts and forecasts the properties of the solar wind at Earth based on the coronal solar wind model MULTI-VP (Pinto and Rouillard 2016).
- **The NowCasting CME Initiation Tool** is an automated calculation of the CME-initialization parameters tilt, poloidal and toroidal magnetic fields) derived in nowcasting mode by exploiting real-time observations by SDO AIA and HMI (Dalmasse et al. 2023).
- The **Flux Rope Propagation Tool:** provides a forecast of ICME properties at any point in the inner heliosphere. It computes the balance of forces acting on a magnetic flux rope erupting in the solar atmosphere and propagates the 3-D structure to provide the magnetic field and plasma components of an ICME measured by a spacecraft (Rouillard et al. 2020b)
- The **CME Shock Forecasting Tool** provides predictions of the properties of CME-driven shocks (e.g. Mach number) along magnetic field lines connected to different spacecraft. The tool exploits predictions of CME speeds given by the ASPECS project.

Figure 3: the list of space-weather related tools available through the STORMS website

3. STORMS' INFRASTRUCTURE

STORMS does not aim to be an operational space-weather center (which would require a team of forecasters) and is rather a testing facility for pre-operational space-weather tools:

- The STORMS tools and models run on the service's own infrastructure (Figure 4) funded over the years by the heliospheric program (SHM) at CNES.
- Its infrastructure is designed to put the hosted tools and models to the test by running them automatically 24/24 7/7.
- STORMS is interfaced through a number of other French and international space-weather facilities including the Virtual Space Weather Modelling Center (VSWMC) by executing MULTI-VP run-on-demands requested by the VSWMC and sending simulations output back to the VSWMC.
- Several STORMS tools are also being integrated in the Heliospheric Expert Center through the ESA SSA (S2P) portal, these include the Magnetic Connectivity Tool, the Shock Forecasting Tool and the SWIFT solar wind model.
- STORMS is also in charge of new developments inside the Propagation Tool (http://propagationtool.cdpp.eu/), a tool that links the French CDPP (http://cdpp.eu/) that stores space plasma physics data , APIS (https://apis.obspm.fr/) and MEDOC (https://idoc.ias.u-psud.fr/MEDOC) databases by connectiving remote-sensing and in situ data.

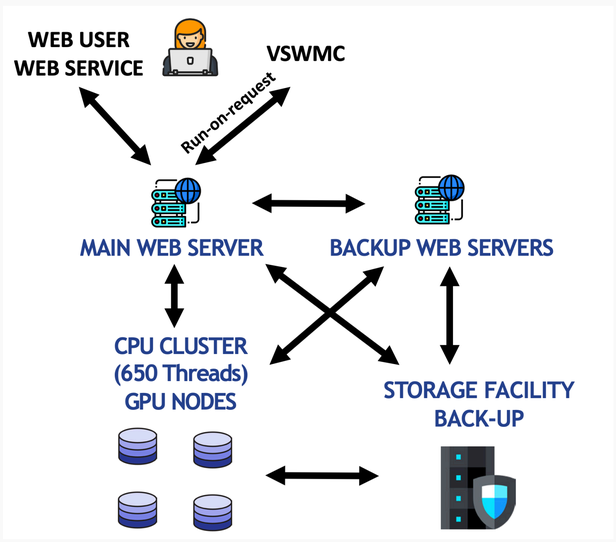

Figure 4: the general computational infrastructure of STORMS

4. SUPPORT TO SOLAR ORBITER OPERATIONS

STORMS provides on-going support to the Solar Orbiter mission by maintaining the Magnetic Connectivity Tool and participating in the mission's Pointing Decision Meetings.

- During each solar encounter, Solar Orbiter has three Remote-Sensing Windows during which the remote-sensing (RS) instruments can point to different targets. A major goal of the mission is to connect remote-sensing and in situ data which can only be achieved if the the RS instruments point to the correct source of the solar wind and/or energetic particles that will be later measured by the probe.
- The forecasting capabilities of the Magnetic Connectivity Tool were designed to support the coordinated campaigns of the Solar Orbiter mission.
- Figure 5 illustrates how STORMS and through its Magnetic Connectivity Tool (http://connect-tool.irap.omp.eu/) work with the Solar Orbiter Science Team and the spacecraft operators at ESA.
- Output of the Magnetic Connectivity Tool can be read easily in a number of different widely used tools including Jhelioviewer.

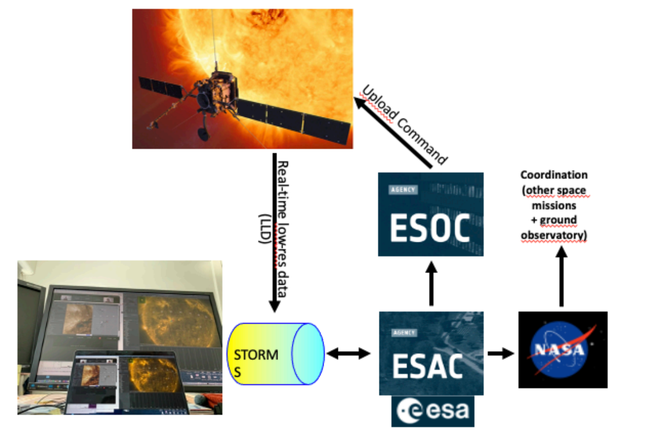

Figure 5: Role of STORMS in the operations of the Solar Orbiter mission.

Conclusions:

✓ STORMS is a space-weather facility that develops, deploys and tests novel pre-operational models and tools run 24/24 7/7 but it is not an operational space-weather center.

✓ STORMS tools are interfaced with a broad range of international space-weather related infrastructures and tools through a range of EU and ESA projects.

✓ There are on-going developments aimed at making the STORMS databases of advanced simulations interoperable in order to ease end-users' access to the facility's products.

References:

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