Space Weather Research to Operations:
Energetic Proton Forecasting for Artemis

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NATIONAL WEATHER SERVICE

NOAA SWPC support for NASA Crewed Missions

NOAA and NASA signed an Interagency Agreement on **Space Radiation Environment Support to NASA for the Conduct of all Human Spaceflight**.

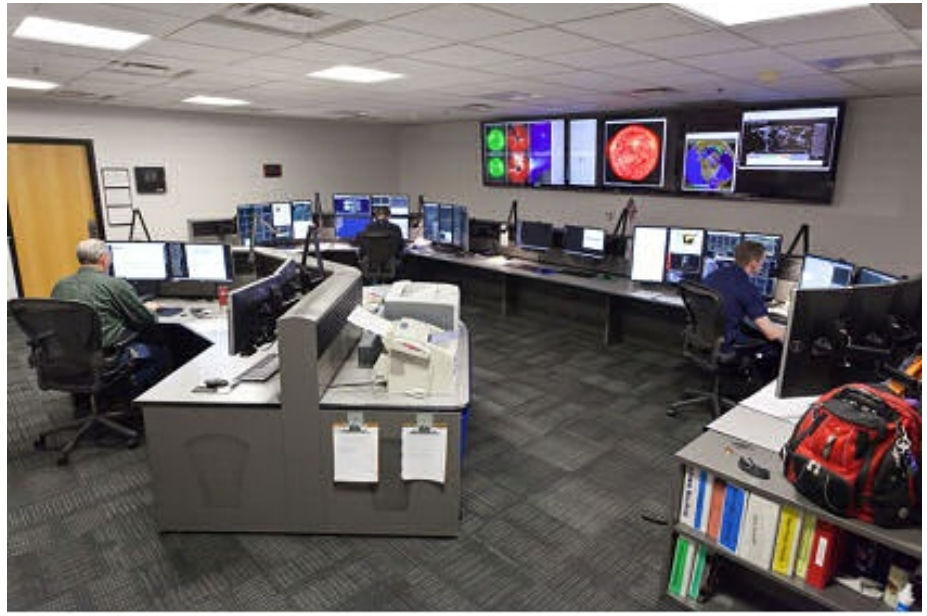
"SWPC will provide services including:

- observations,
- briefings,
- 24-hour forecasts, and
- Warnings and Alerts

for major

- solar flares,
- proton events, and
- geomagnetic storms

in support of ISS, Artemis Lunar Missions and Lunar Surface Operations, and future Mars missions."



Path to Operations

Basic/Applied Research (RL1/2)

Proof of Concept (RL3)

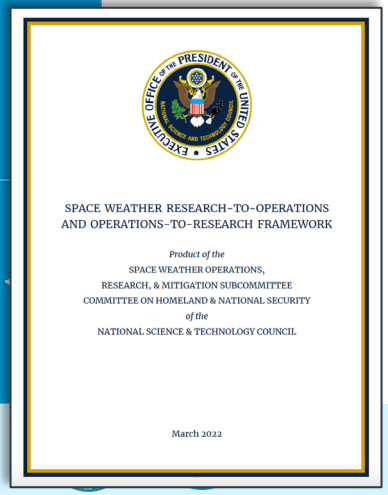
Developer Validation (RL4)

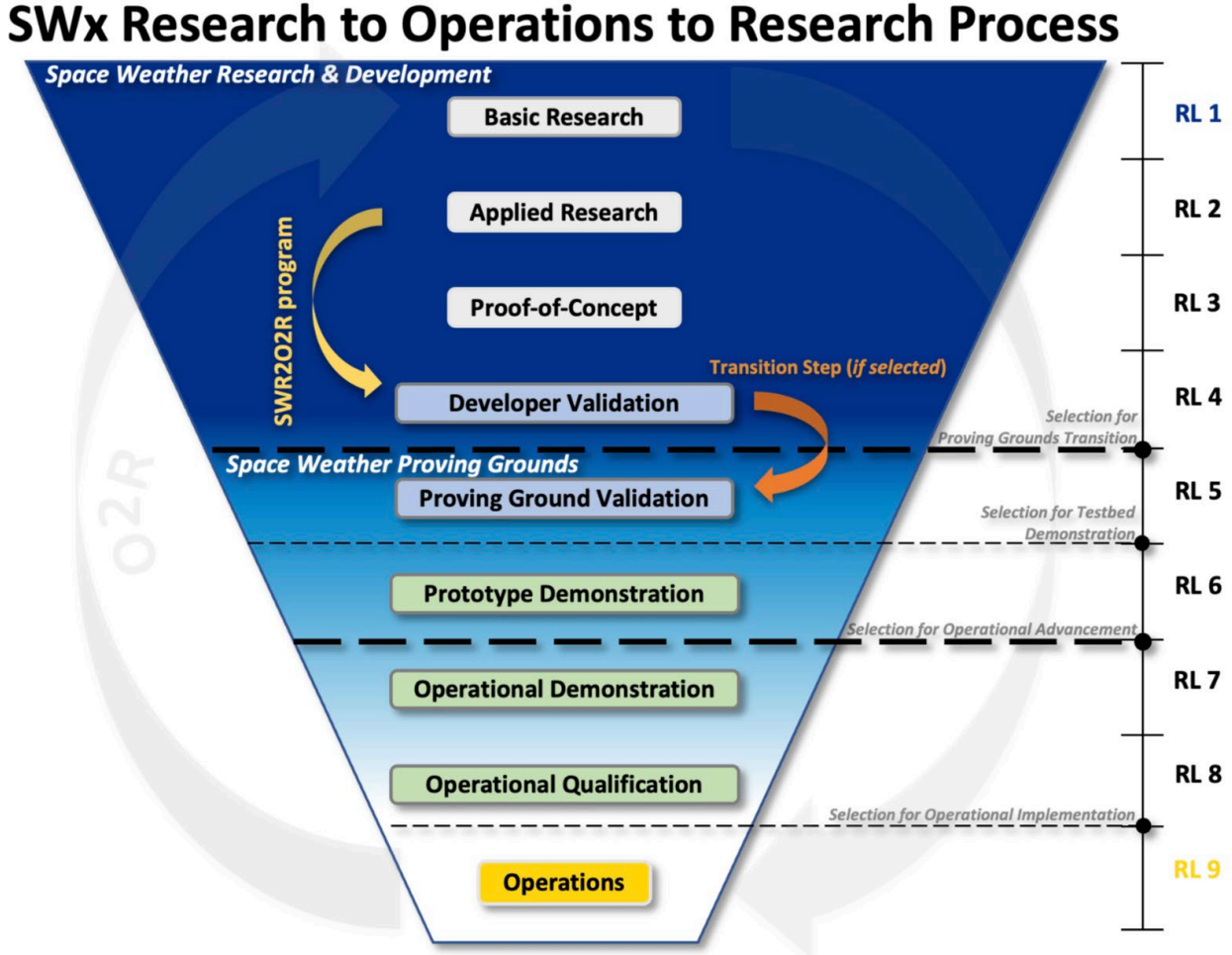
Proving Ground Validation (RL5)

Prototype Demonstration (RL6)

Operational Demonstration/Qualification (RL7-8)

Operations (RL9)





Space Weather Research-to-Operations and Operations-to-Research Framework
https://www.whitehouse.gov/wp-content/uploads/2022/03/03-2022-Space-Weather-R2O2R-Framework.pdf

UMASEP Model

University of **Má**laga **S**olar Particle **E**vent **P**redictor (M. Núñez, 2011)

Empirical model that relies on real-time GOES data (X-rays and proton flux)

Predicts event start and peak proton flux

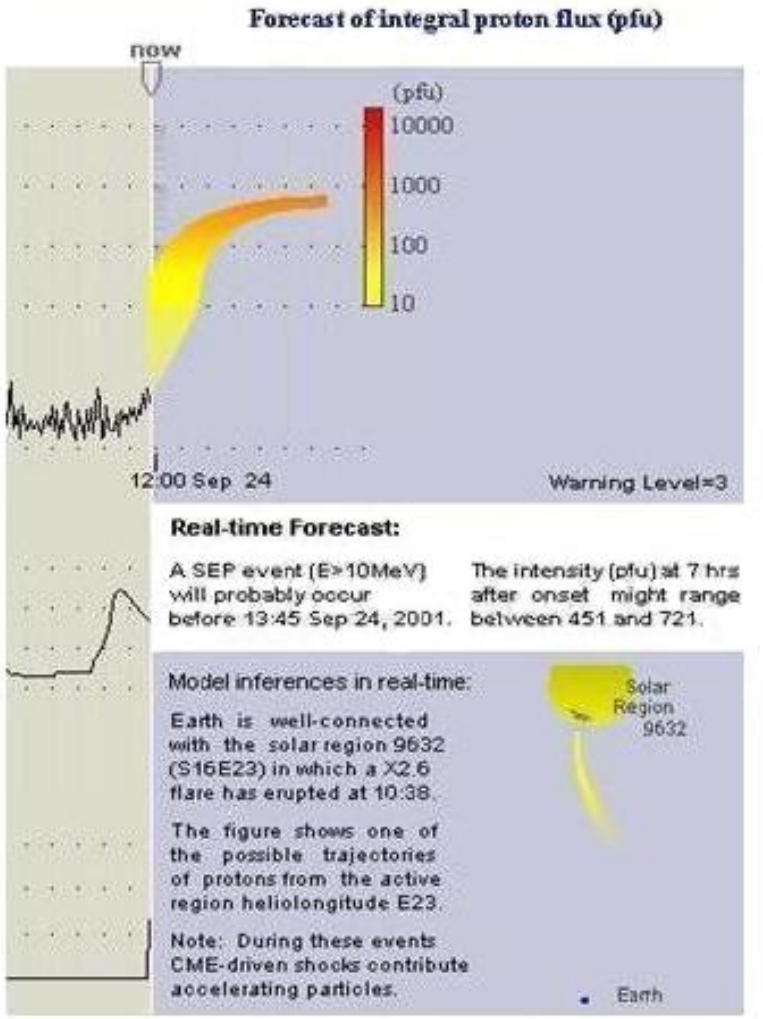
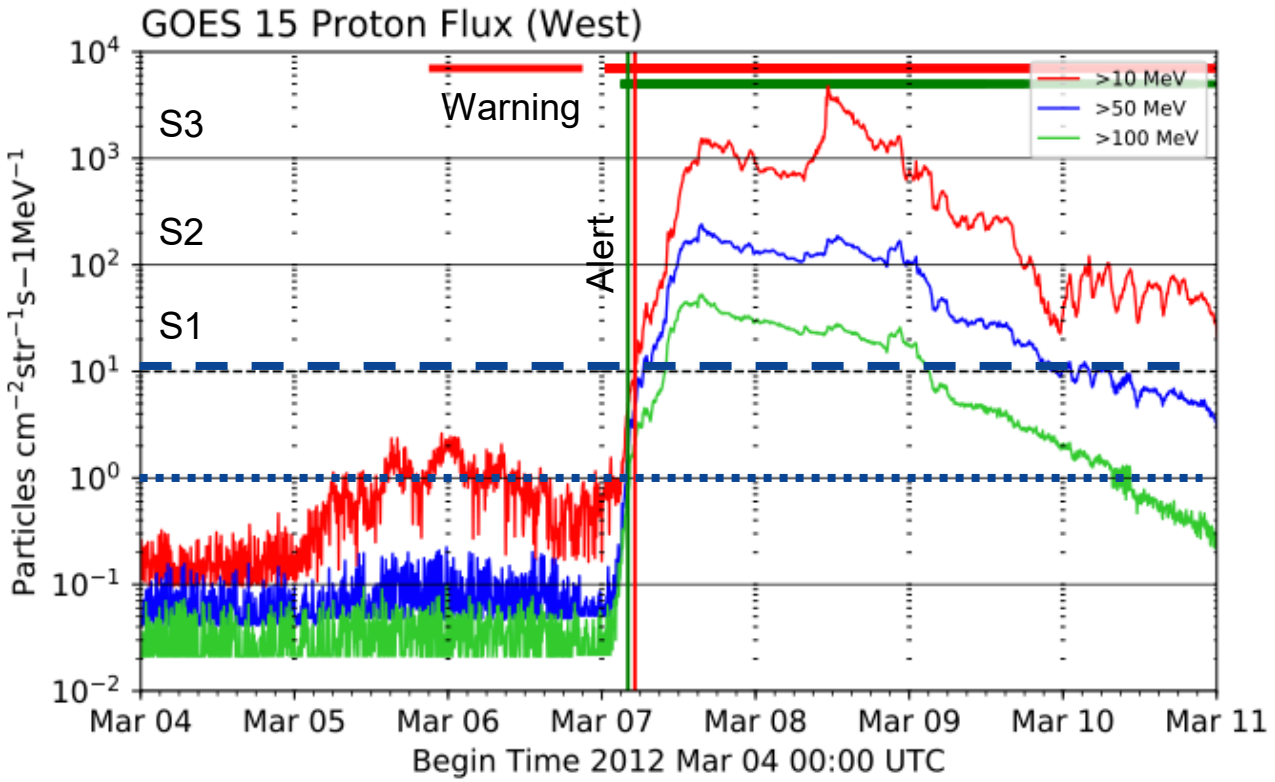


Fig 2. Prediction of a well-connected SEP event. It graphically shows the time interval whithin which the integral proton flux is expected to surpass 10 pfu and the intensity of the first hours of the expected event. UMASEP may also inform about the magnitud and the heliolongitude of the associated flare.

SWPC Proton Event Warning and Alerts

- Warning and Alert ≥ 10 MeV at 10 p.f.u.
- Warning and Alert for ≥ 100 MeV at 1 p.f.u.
- Alerts for S scale threshold crossing.

Currently guided by the PROTONS tool (Balch 99, 08)



Developer Validation (RL4)

Skill Metrics:

Probability of Detection (POD): $\frac{TP}{(TP+FN)}$

False Alarm Ratio (FAR): $\frac{FP}{(TP+FP)}$

Critical Success Index (CSI): $\frac{TP}{(TP+FP+FN)}$

True Positive/Hit (TP):
Event forecasted and occurred

False Negative/Miss (FN):
No event forecasted, event occurs

False Positive/False Alarm (FP):
Forecast issued, no event occurs

RL4 – SWPC* vs UMASEP: (± from SWPC Forecast Skill)

SC 23 – SC 25	POD	FAR	CSI	Lead Time (mins)
≥ 10 MeV	0.93 (+0.15)	0.17 (-0.08)	0.78 (+0.16)	100 (+37)
≥ 100 MeV	0.87 (+0.42)	0.31 (0.00)	0.63 (+0.25)	15 (-8)

*See Bain et al. (2021) for SWPC's proton forecast performance and skill

Proving Ground Validation (RL5)

Validation in operations-relevant environment e.g. NASA/CCMC – NOAA/SWPC Architecture for Collaborative Evaluation (ACE)

- Configured to be as similar to the NOAA operational systems as is reasonably possible.
- Validation to confirm RL4 results can be achieved in ops-like environment.
- Rigorous testing of model/application performance.

Prototype Demonstration (RL6)

Promising models will be selected to run in the Space Weather Prediction Testbed (SWPT)

RL6 – Demonstration of model/application in a testbed environment (includes all critical elements of the operational environment).

- functions as intended under real world operational constraints
- provides acceptable lead times
- meets established performance requirements

Demonstrated at a testbed experiment.

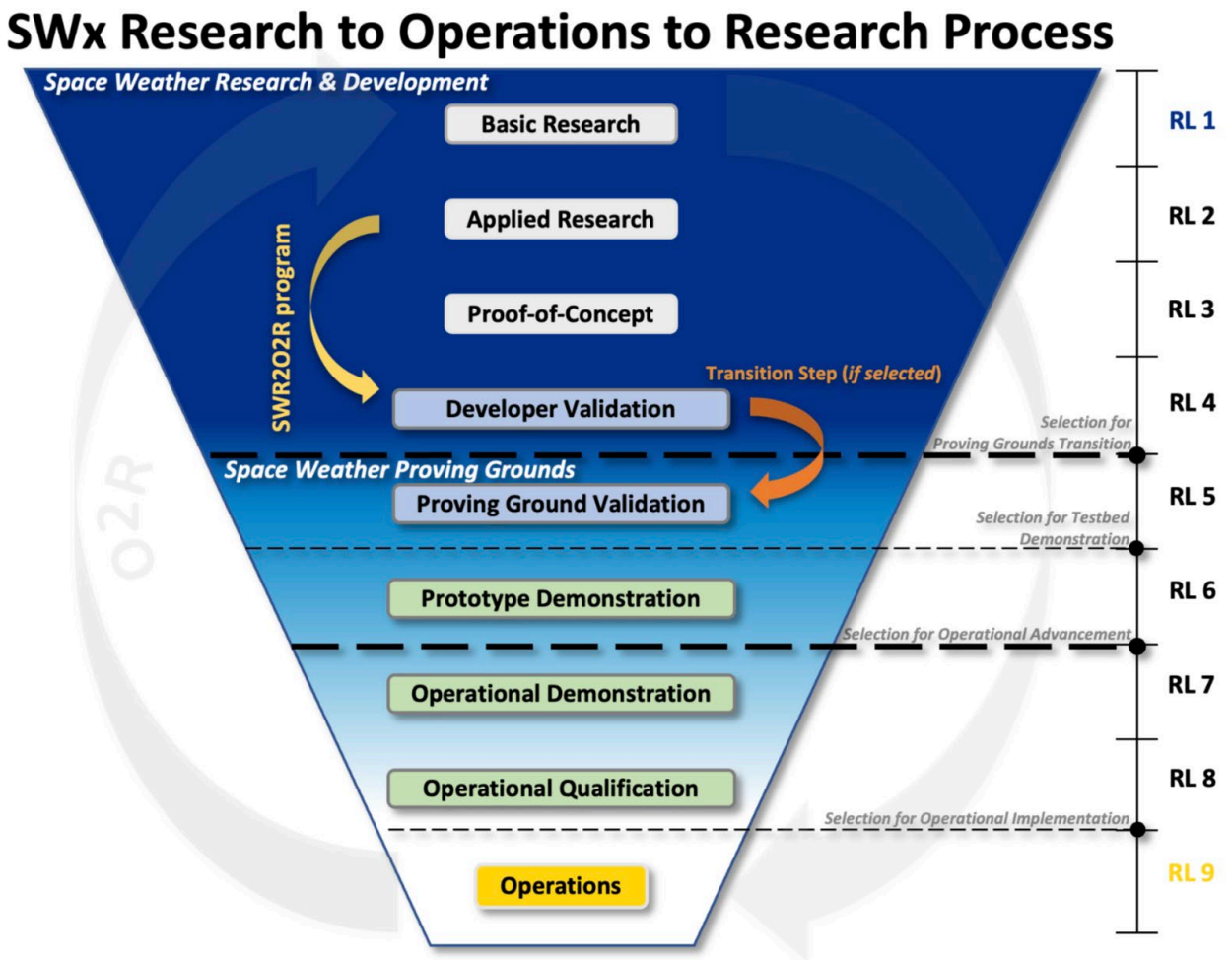
Operational Demonstration/Qualification (RL7-8)

RL7 - Demonstration of model/application in an operational environment

- demonstrated in near-real world environment
- subsystem components fully integrated
- effective error handling and monitoring
- uses available real-time data streams
- CONOPS fully implemented and successfully demonstrated.

RL 8 - Finalized model/application shown to operate as expected within the ops environment

- user training and documentation
- operator or user approval given



Challenges

Better communication of forecast/user requirements and currently implemented models/applications is needed.

Not all models/forecast products have a well documented baseline/skill for comparison.

R2O process requires careful validation and rigorous software engineering – time and effort shouldn't be underestimated.

Not every model/application will make it to operations.

If the model is not open source, intellectual property/licensing needs to be addressed.