Model Validation and R2O at CCMC

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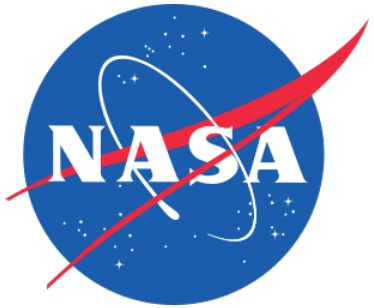
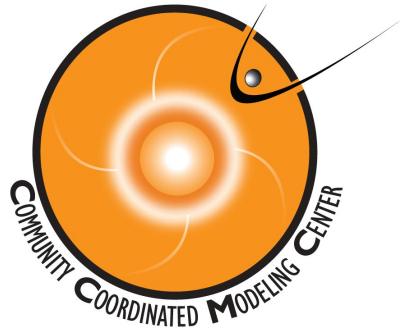
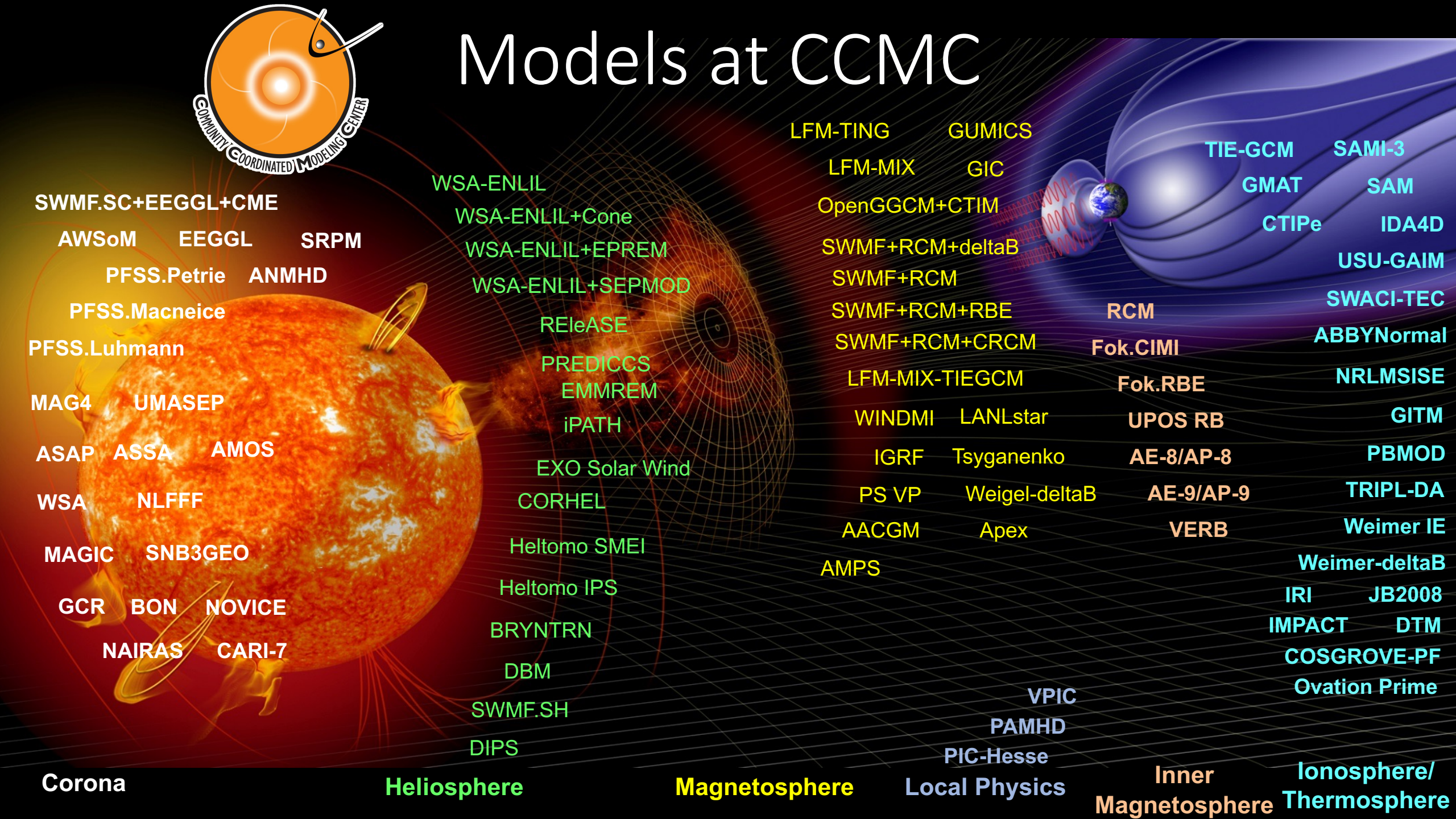
Space Weather Operations and Research Infrastructure Workshop
(National Academies Space Studies Board)





Models at CCMC



SWMF.SC+EEGGL+CME
AWSoM
EEGGL
SRPM
PFSS.Petrie
ANMHD
PFSS.Macneice
PFSS.Luhmann
MAG4
UMASEP
ASAP
ASSA
AMOS
WSA
NLFFF
MAGIC
SNB3GEO
GCR
BON
NOVICE
NAIRAS
CARI-7

WSA-ENLIL
WSA-ENLIL+Cone
WSA-ENLIL+EPREM
WSA-ENLIL+SEPMOD
REIeASE
PREDICCS
EMMREM
iPATH
EXO Solar Wind
CORHEL
Heltomo SMEI
Heltomo IPS
BRYNTRN
DBM
SWMF.SH
DIPS

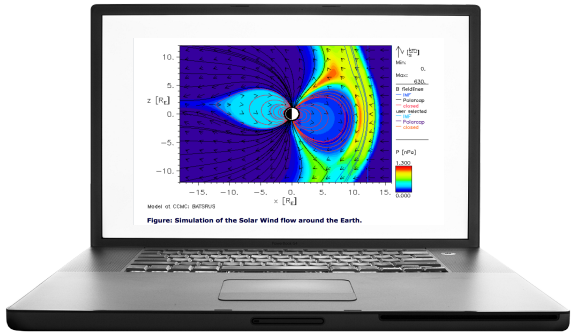
LFM-TING
GUMICS
LFM-MIX
GIC
OpenGGCM+CTIM
SWMF+RCM+deltaB
SWMF+RCM
SWMF+RCM+RBE
SWMF+RCM+CRCM
LFM-MIX-TIEGCM
WINDMI
LANLstar
IGRF
Tsyganenko
PS VP
Weigel-deltaB
AACGM
Apex
AMPS

TIE-GCM
SAMI-3
GMAT
SAM
CTIPe
IDA4D
USU-GAIM
SWACI-TEC
RCM
ABBYNormal
Fok.CIMI
NRLMSISE
Fok.RBE
GITM
UPOS RB
PBMOD
AE-8/AP-8
TRIPL-DA
AE-9/AP-9
Weimer IE
VERB
Weimer-deltaB
IRI
JB2008
IMPACT
DTM
COSGROVE-PF
Ovation Prime

VPIC
PAMHD
PIC-Hesse

Corona
Heliosphere
Magnetosphere
Local Physics
Inner Magnetosphere
Ionosphere/ Thermosphere

CCMC Simulation Services: Runs-on-Request

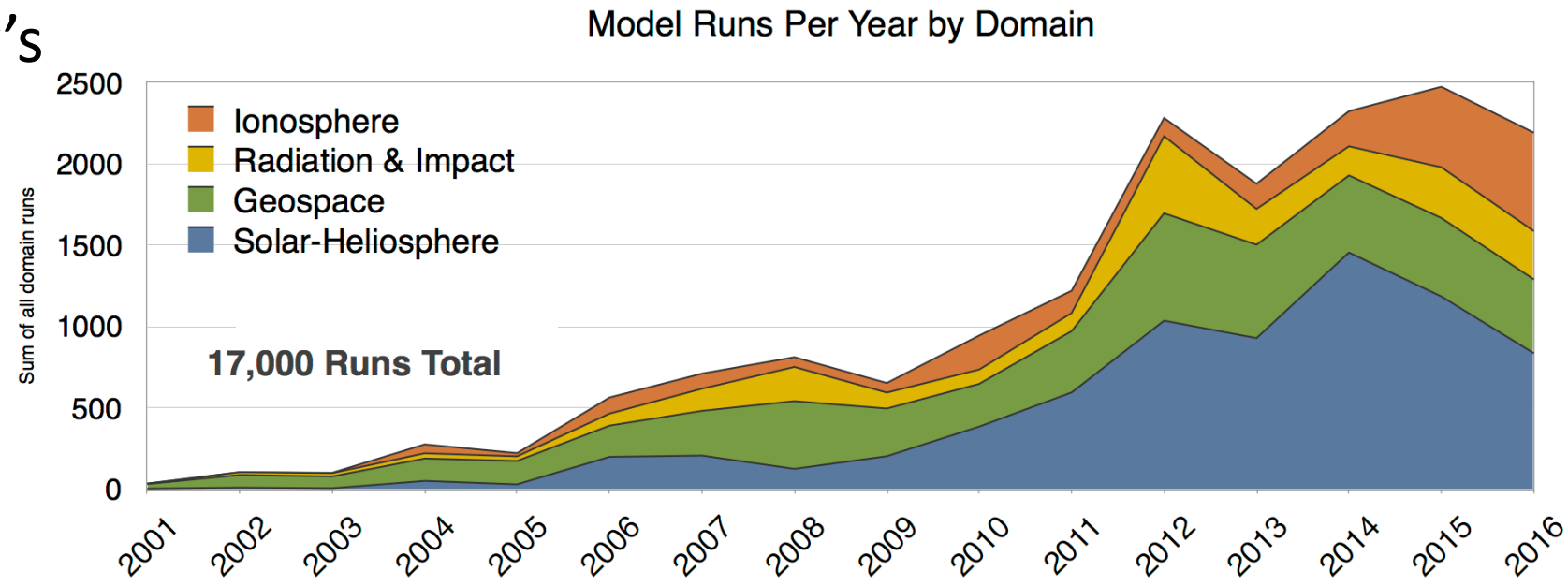


REQUESTS

RESULTS

Super Computing Clusters	**Searchable Simulation Archive (>20,000 runs)**
ccmc.gsfc.nasa.gov	
Peta-Bytes of Data Storage	**Online Visualization & Downloads**

- Advances the community's scientific research
- Mission science/planning support
- Model validation in a research setting
- Model delivery point



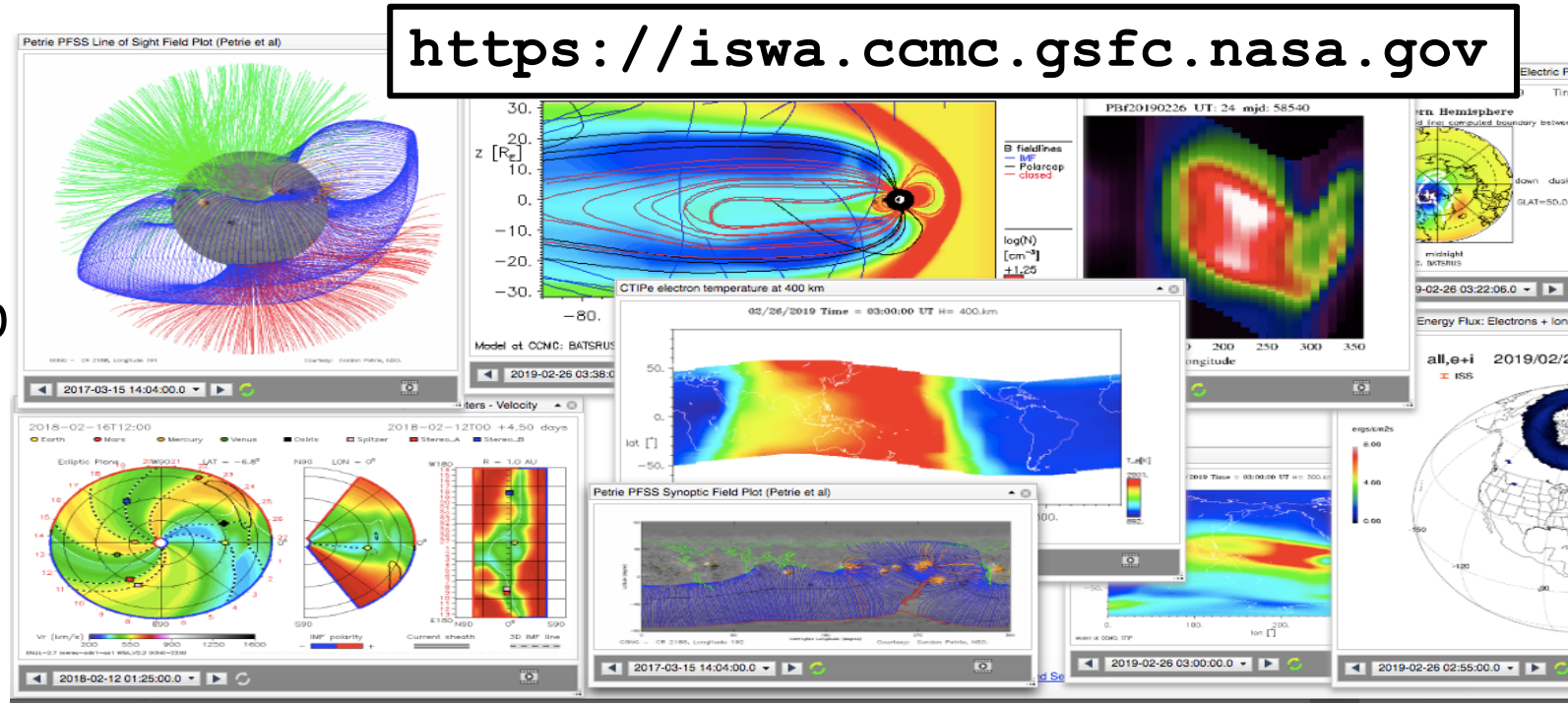
CCMC Simulation Services: Continuous Runs

- CCMC hosts ~100 models, 20 of which are also running in real time, including experimental model chains
- CCMC approach to finding model forecasting value: highlight the forecast possibilities while keeping in mind the model limitations. Experiment.
- Real time model outputs are available via iSWA displays and streaming

Goals include:

- Validation in a real time setting
- Demonstration of operational potential and facilitate entry to R2O pipeline
- Mission science campaign support
- Feedback for the model developer on long term model performance

https://iswa.ccmc.gsfc.nasa.gov



Validation at CCMC: Evaluating Model Performance

- Benchmarks current model performance. Traces progress over time.
- Validation to improve scientific understanding
  - Science-based metrics
  - CCMC leadership in community challenges/campaigns at GEM, CEDAR, SHINE, ISWAT
- Validation to determine R2O transition suitability
  - Operationally relevant metrics to test forecast value
  - CCMC validation collaborations with SWPC (ENLIL, SWMF, WSA, ADAPT)

Modes:

- Historical validation
- Real-time forecast validation (CCMC community scoreboards)
- Simulated (as-if) real-time forecast validation

Coordinated Community Effort:
International Forum on Space Weather Capabilities Assessment

SOLAR
CCMC facilitator(s): P. Macneice

- Solar Flare Prediction (Leads: S. Murray, M. Georgoulis, S. Bloomfield, K.D. Leka
  Scoreboard Leads: S. Murray, M.L Mays) SSA-0,SSA-6
- Coronal & Solar Wind Structure
  Coronal & SW Structure; Ambient SW; Coronal Hole Boundaries
  (Leads: P. Macneice, L. Jian) SSA-?
- 3D CME kinematics and topology (Leads: B.Thompson, C.Moestl, D.Barnes)
- Solar Indices and Irradiance (Leads: J. Klenzing, C. Henney, K. Muglach) SSA-0

GEOSPACE: Geomagnetic Environment
CCMC facilitator(s): L.Rastaetter

- Ground Magnetic Perturbations: dBdt, delta-B, GICs, FACs
  (Leads: D. Welling, H. Opgenoorth, C. Ngwira) SSA-1
- Geomagnetic Indices (Leads: M. Liemohn) SSA-1
- Magnetopause location and geosync. orbit crossing
  (Leads: Y. Collado-Vega, S. Merkin) SSA-1

HELIOSPHERE
CCMC facilitator(s): M.L. Mays, A. Taktakishvili, P. Macneice

- CME Arrival Time (Leads: C. Verbeke, M.L. Mays, A. Taktakishvili) SSA-1
- IMF Bz at L1 (Leads: N. Savani, P. Riley) SSA-1
- SEPs (Leads: I.G. Richardson. P. Quinn, M. Marsh, M.L. Mays
  Scoreboard Leads: M. Dierckxsens, M. Marsh) SSA-3,SSA-6

GEOSPACE: Auroral Region
CCMC facilitator(s): M.Kuznetsova

- Auroral precipitation and high latitude i
  (Leads: R. Robinson, Y. Zhang, B. Kosar)

Forum working teams focused on different **evaluation topics**.

Cross-team interactions.

RADIATION and PLASMA EFFECTS Scope of work
CCMC facilitator(s): Y. Zheng, M. Kuznetsova

- Surface Charging *few eV - keV electrons, plasma density*
  (Leads: J. Minow, D. Pitchford, N. Ganushkina) SSA-6
- Internal Charging *keV–MeV electrons*
  (Leads: P. O'Brien, Y. Shprits) SSA-6
- Single Event Effects *MeV–GeV-TeV protons, ions*
  (Leads: M. Xapsos, J. Mazur, P. Jiggens) SSA-3,SSA-6
- Total Ionizing Dose *keV–MeV electrons, keV–GeV protons,ions*
  (Leads: I. Jun, T. Guild, M. Xapsos) SSA-6
- Radiation effects for aviation (Leads: K. Tobiska, M. Meier) SSA-6

IONOSPHERE
CCMC facilitator(s): J. Shim, M. Kuznetsova

- Neutral Density and Orbit Determination at LEO
  (Leads: S. Solomon, T. Fuller-Rowell, S. Bruinsma, E. Sutton) SSA-2
- Global & Regional TEC (Leads: L. Scherliess, R. Calfas) SSA-4
- Ionosphere Plasma Density: NmF2/foF2, hmF2, TEC
  (Leads: I. Tsagouri, M. Angling, J. Shim) SSA-5
- Ionosphere Scintillation (Leads: E. Yizengaw) SSA-5

The COSPAR ISWAT initiative is a global hub for collaborations addressing challenges across the field of space weather.

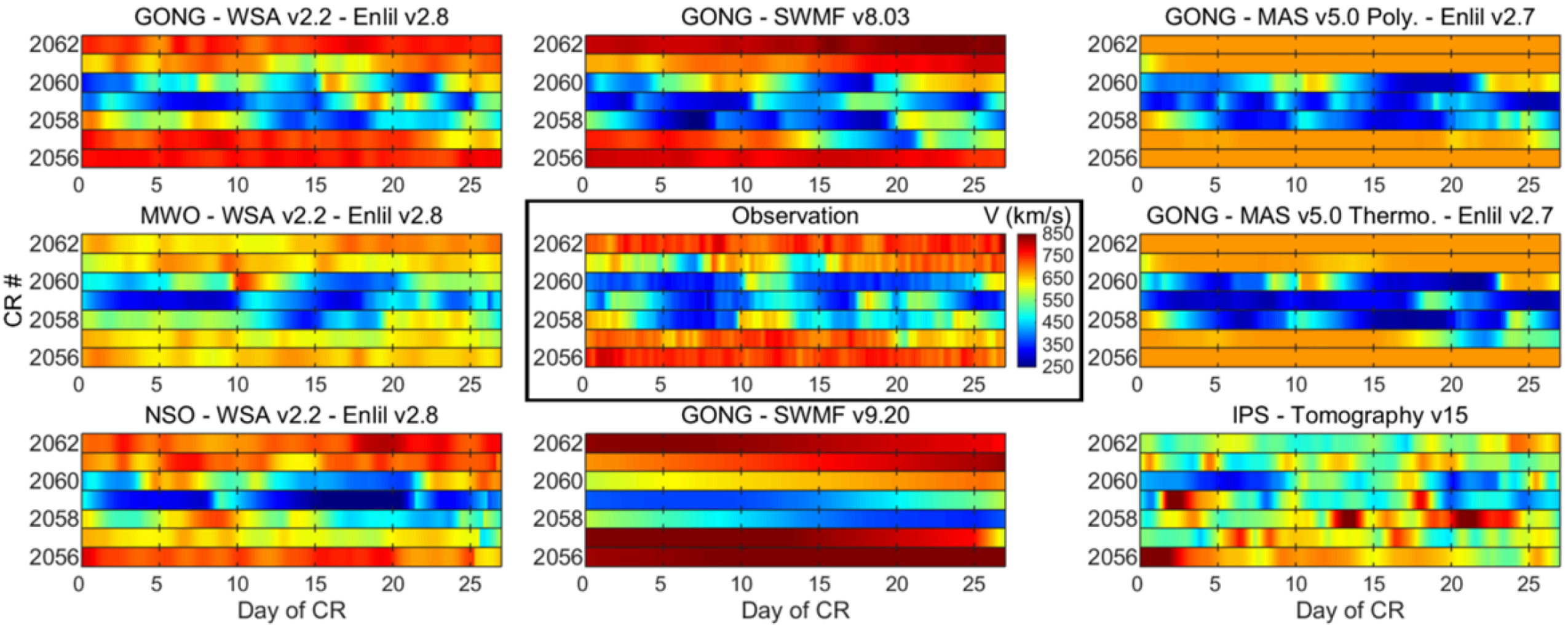
S: Space weather origins at the Sun	H: Heliosphere variability	G: Coupled geospace system	Impacts
S1: Long-term solar variability	H1: Heliospheric magnetic field and solar wind	G1: Geomagnetic environment	Climate
S2: Ambient solar magnetic field, heating and spectral irradiance	H2: CME structure, evolution and propagation through heliosphere	G2a: Atmosphere variability	Electric power systems/GICs
S3: Solar eruptions	H3: Radiation environment in heliosphere	G2b: Ionosphere variability	Satellite/debris drag
	H4: Space weather at other planets/planetary bodies	G3: Near-Earth radiation and plasma environment	Navigation/ Communications
			(Aero)space assets functions
			Human Exploration

Overarching Activities:
Assessment Information Architecture Data Utilization Education/Outreach

Each Cluster has at least one team on predictive capabilities assessment with CCMC involvement

Example: Validation Study using CCMC Runs-on-Request

Jian et al. (2015) *Space Weather:* solar wind speed at Ulysses

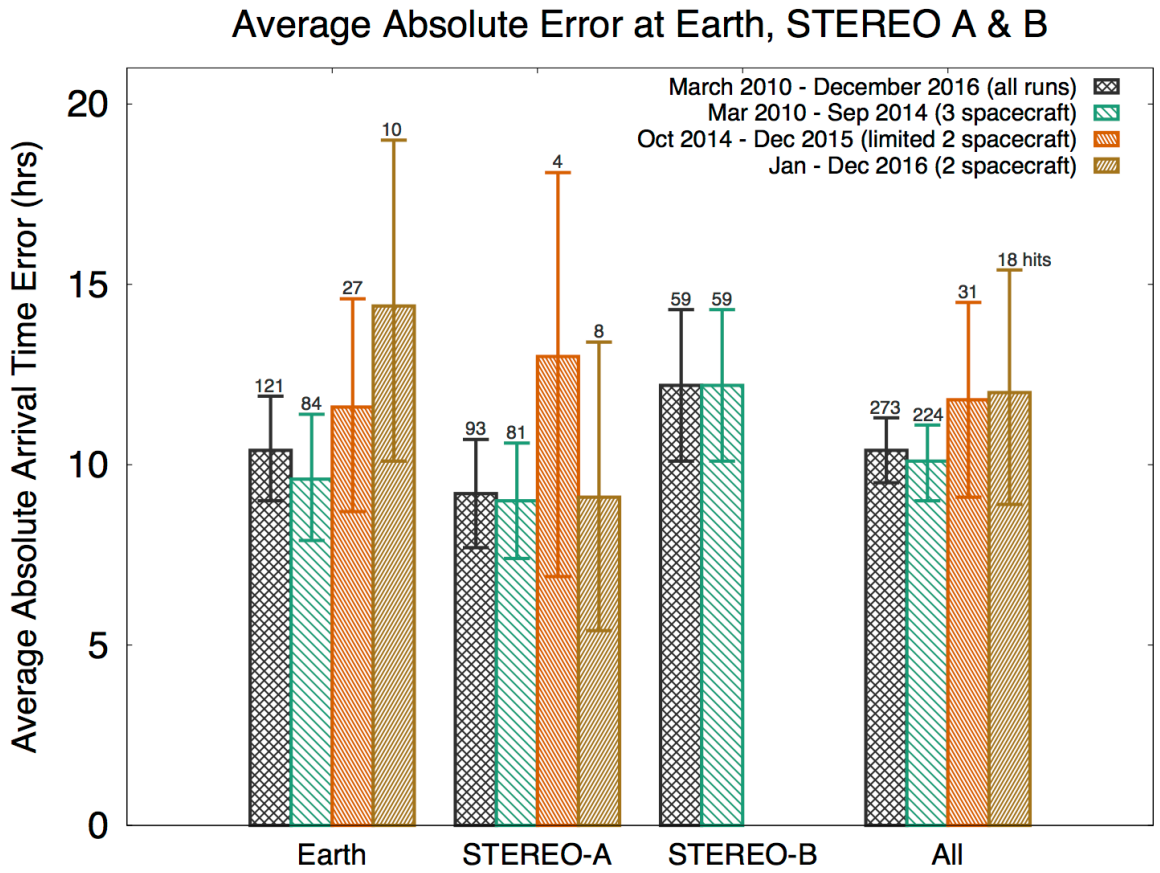


Examples: Validation Studies of CME Arrival Time Error using:

CCMC Real-Time Runs

Wold et al. (2018) *JSWSC*, for WSA-ENLIL+Cone:

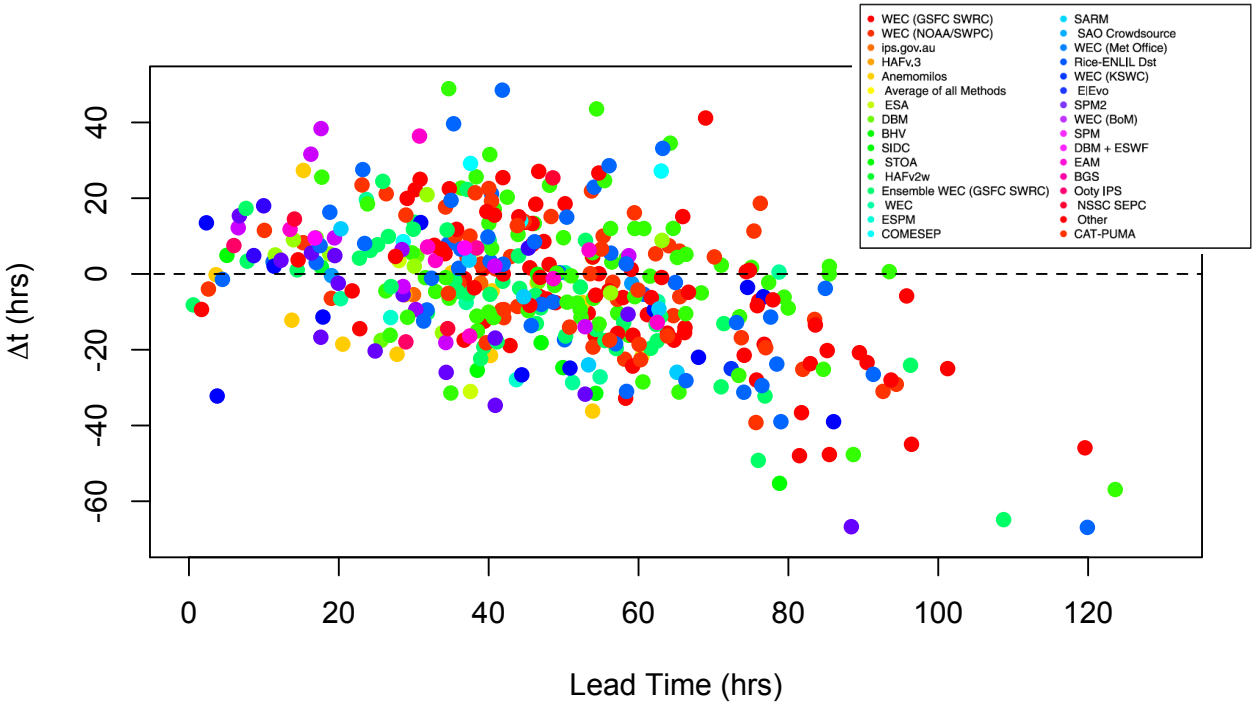
- 10.4 ± 0.9 hours error
- 1.7 hour error increase with single coronagraph



CCMC Scoreboards

Riley et al. (2018) *Space Weather*:

- First comprehensive analysis of CME scoreboard data
- 13 hours error (scoreboard average)
- ±20 hours standard deviation



Validation: CCMC community scoreboards

https://ccmc.gsfc.nasa.gov/challenges/

Leads: **Trinity College Dublin** (S. Murray), **ROB** (J. Andries)

Leads: **NASA SRAG**, **CCMC** (L. Mays), **BIRA-IASB** (M. Dierckxsens), **GSFC** (I. Richardson)

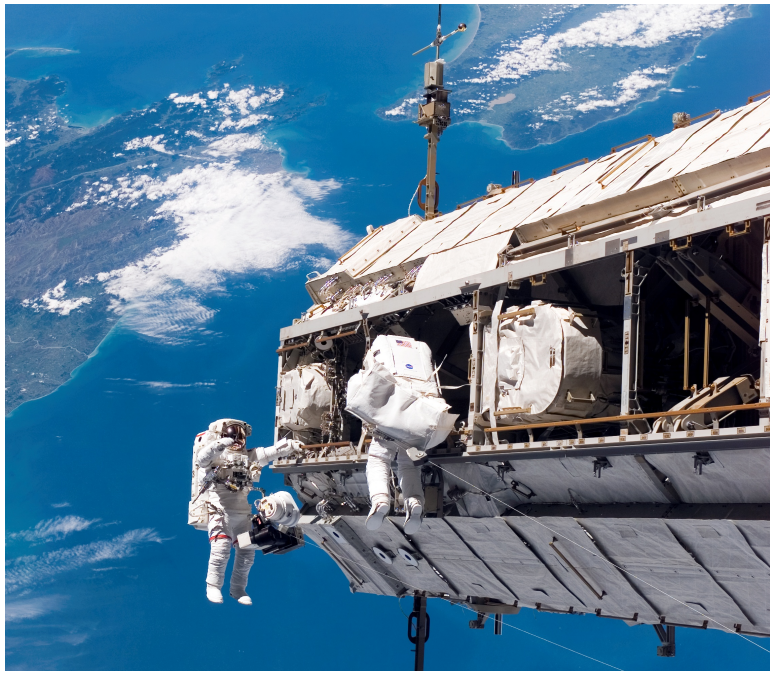
Leads: **CCMC** (L. Mays), **UK Met Office**

Leads: **PredSci** (P. Riley), **University of Reading** (M. Owens)

- Scoreboards collect forecasts from the community before event is observed
- Allows a consistent **real-time** comparison of various operational and research forecasts.

CCMC R2O Collaboration with NASA Johnson Space Center: Astronaut Safety

- In 2018 CCMC started a multi year project (ISEP) with NASA Space Radiation Analysis Group to **transition 7 research Solar Energetic Particle models to operations**: including MAG4, UMASEP, RELeASE, SEPSTER, SEPMOD, STAT, iPATH
- These **models were chosen by SRAG** based on their operational requirements including
  - Can it run in real-time?
  - Is the input data available in near real-time?
  - Some degree of documented performance
- Models transitioned, and **SEP Scoreboard displays** built by CCMC will be used operationally by SRAG for human missions beyond LEO starting in 2022.



SEP Scoreboard

-1 week | -1 day | -1 hour | 2017-09-10 19:00 | +1 hour | +1 day | +1 week | Today | Refresh Plots

Proton Intensity Forecasts:

2017-09-10 19:00 UT

	> 10 MeV	> 100 MeV
GOES	890.0	40.9
SEPSTER	3590.0	35.9
STAT	920.5	143.64
UMASEP	Not Clear	Not Clear

pfu: 10^6, 10^5, 10^4, 10^3, 10^2, 10^1, 10^0, 10^{-1}, 10^{-2}

pfu: 300, 200, 100, 50, 10, 1, 10^{-1}, 10^{-2}, 10^{-3}

not clear | clear | no data

Proton All Clear Forecasts:

2017-09-10
19:00 UT

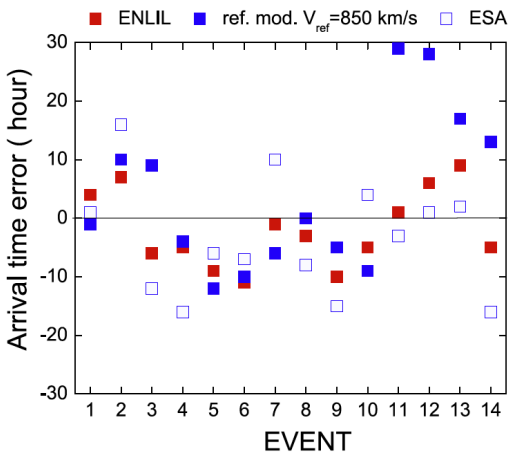
All Clear

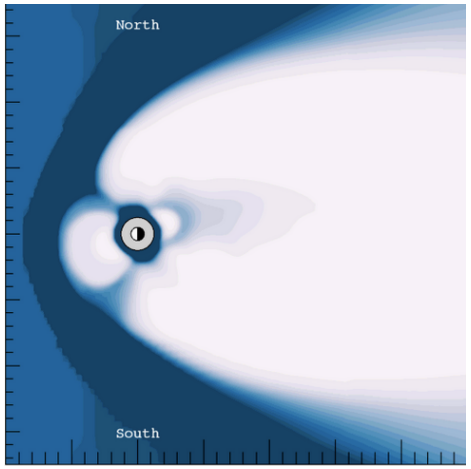
CCMC & NOAA SWPC Collaborations

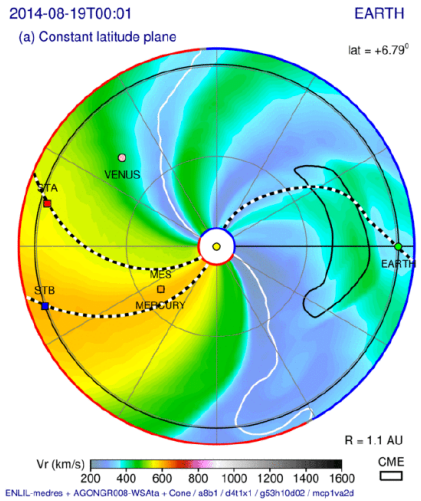
- 20-year partnership since CCMC establishment.

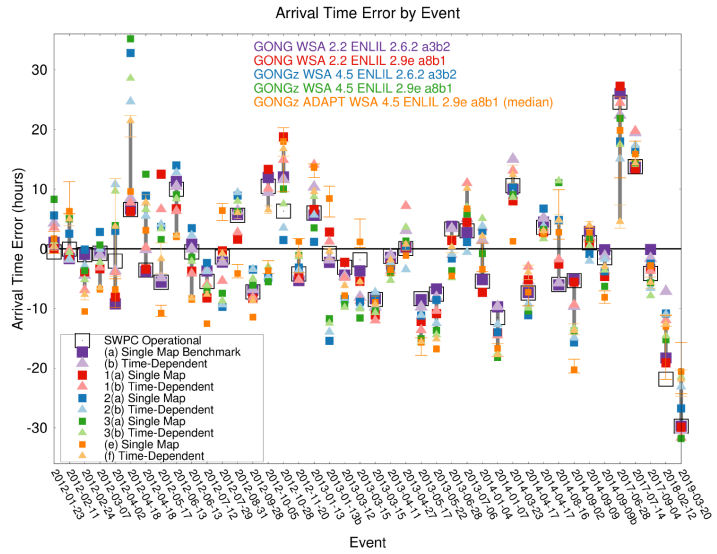
Major successes:

- Demonstrated potential of Enlil for operational forecasting (2006 - 2009)
- Geospace model transition to operations at NOAA/SWPC (2013 - 2015)
- NASA-NOAA space weather MOU on space weather modeling capabilities: MOU Annex to validate model upgrades (2017 - 2020)





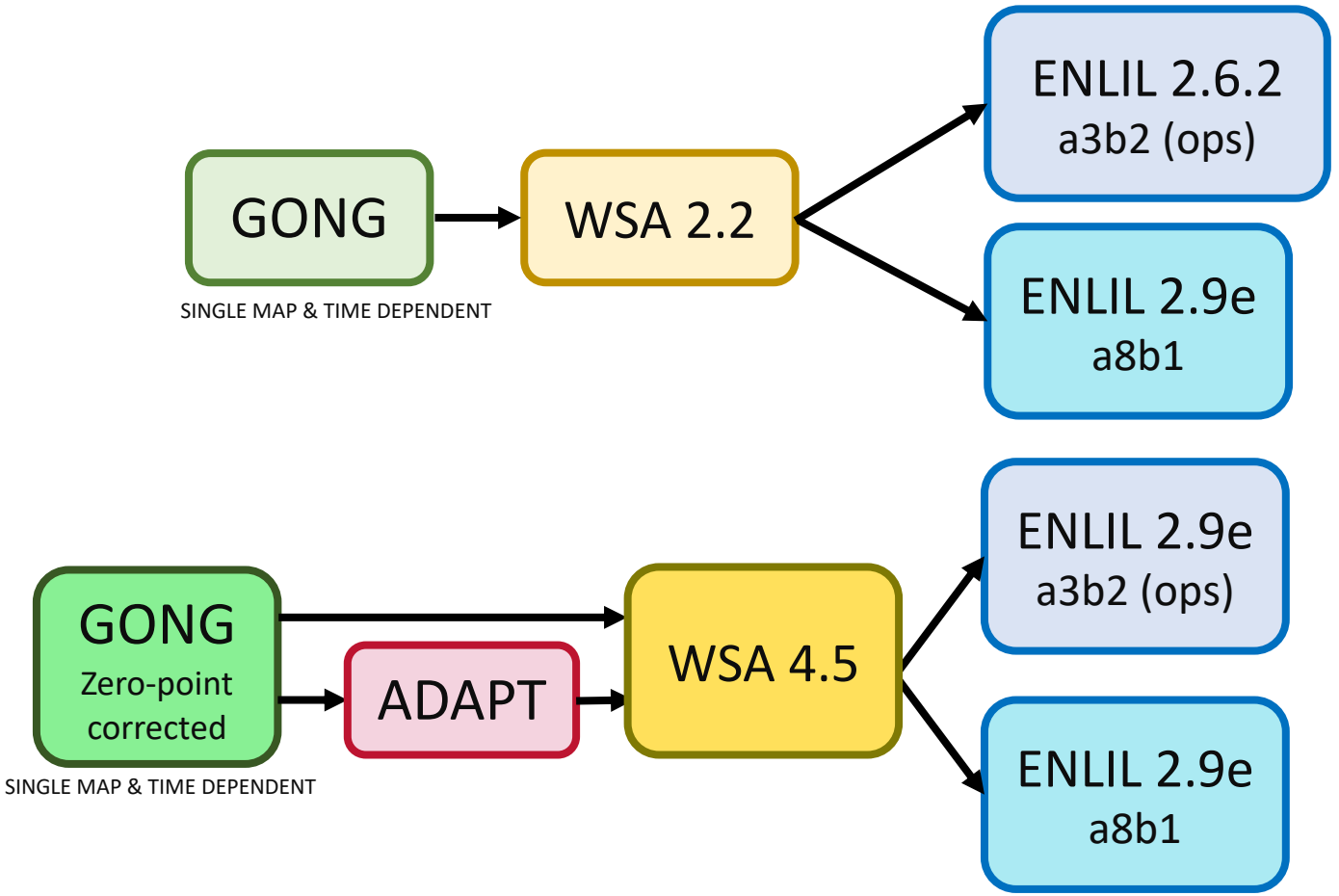




NOAA SWPC / CCMC MOU Annex
CME Arrival Time

- Tested if model upgrades improve CME arrival time prediction
- CCMC performed and analyzed over 1200 simulations
- **Result:** ADAPT and time-dependent driven simulations decrease CME arrival times errors by 6 hours for GONG zero-point corrected inputs.
- Final report was delivered in May 2020

CCMC performed over 1200 simulation variations:



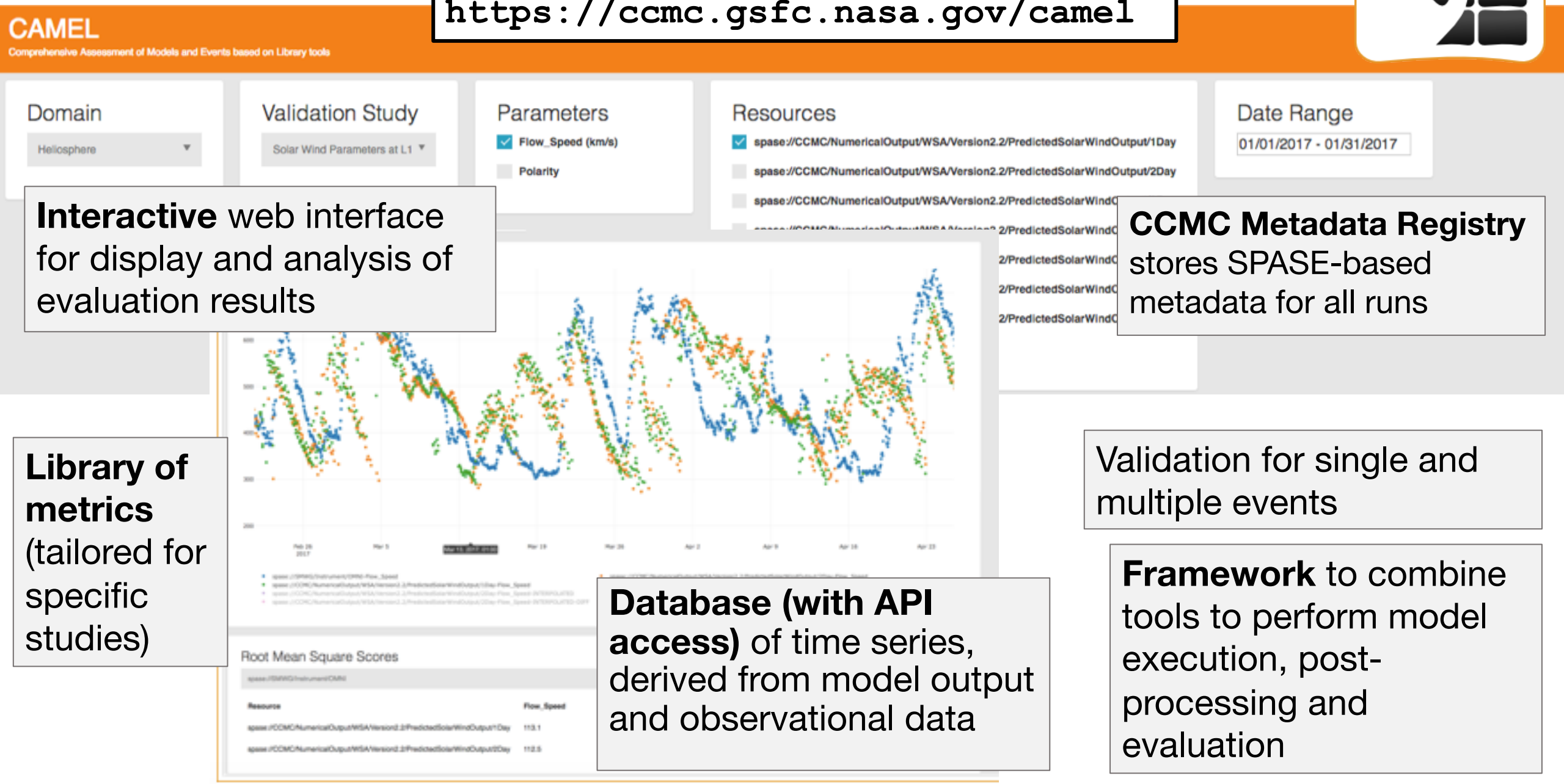
https://ccmc.gsfc.nasa.gov/annex/

Validation: Opportunities for Improvement

- Better community involvement and coordination, including operations
  - Community agreement on metrics selection and validation approach
  - Community definition of Essential Space Environment Quantities
  - COSPAR ISWAT teams
- Better preparation of observations and their uncertainties
  - Involving data experts on validation teams
  - Some observations are actually techniques/models themselves
- Better care in comparing models
  - Validation studies with different designs cannot be directly compared
- Better transparency and collaboration in validation studies
  - Providing data and necessary details – how were forecasts were constructed? How was validation performed?
  - CCMC CAMEL tool

Comprehensive Assessment of Models and Events based on Library tools (CAMEL)

https://ccmc.gsfc.nasa.gov/camel



Interactive web interface for display and analysis of evaluation results

CCMC Metadata Registry stores SPASE-based metadata for all runs

Library of metrics (tailored for specific studies)

Database (with API access) of time series, derived from model output and observational data

Validation for single and multiple events

Framework to combine tools to perform model execution, post-processing and evaluation

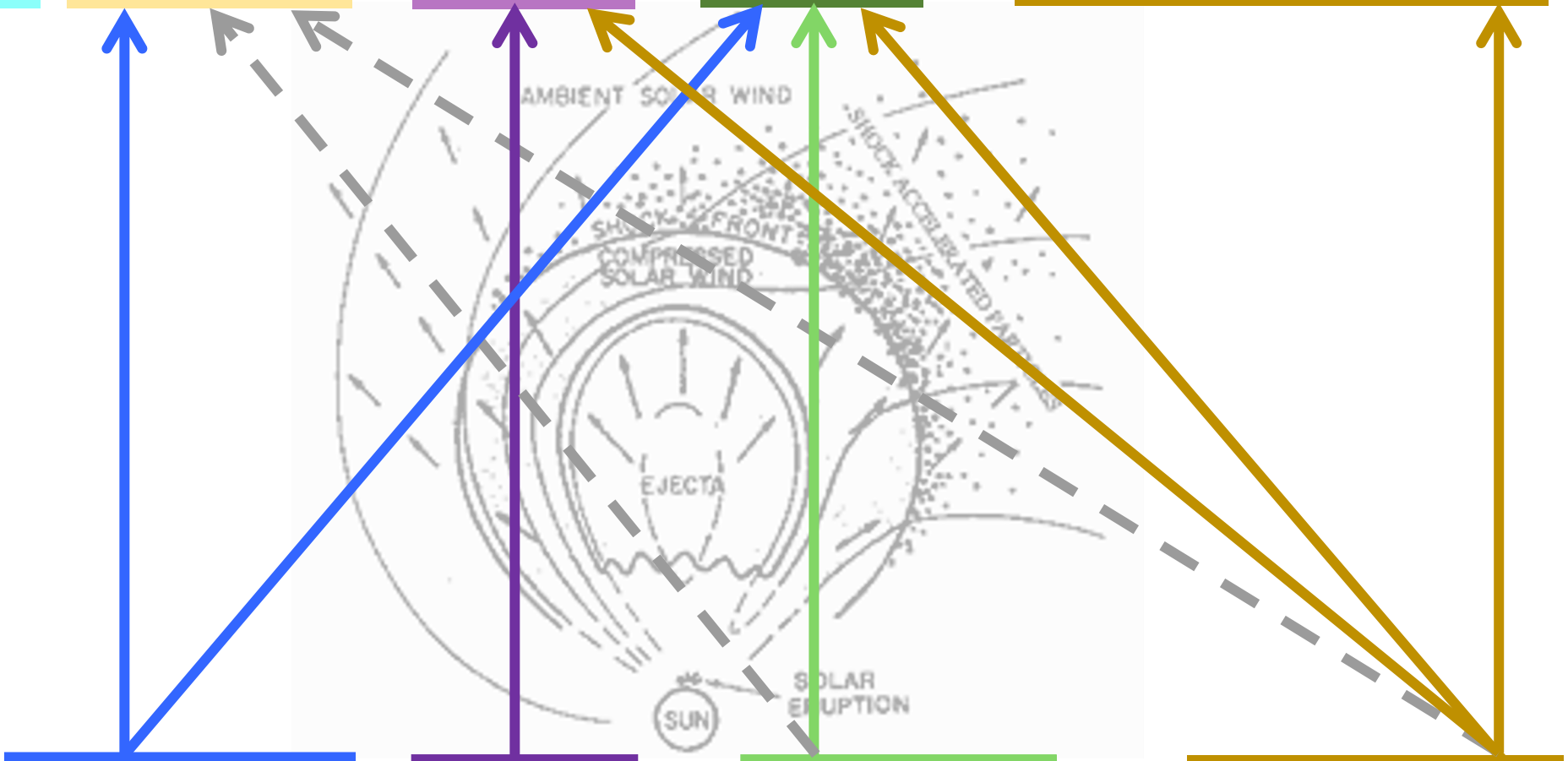
R2O: Opportunities for improvement

- **NASA/NSF:** It is necessary to fund model development (science and applied) to achieve forecast improvements, model validation, and model transition. If the agencies want to see R2O progress, it must be funded.
- **Developers/CCMC:** Research models delivered to CCMC are rarely ready for production, CCMC staff makes preparations
- **Developers:** Are often not thinking about real-time/operational uses of their models. CCMC sometimes guides/suggests.
- **Developers/CCMC:** need to be creative about how their scientific model improvements could be used for real time forecasts. CCMC can sometimes suggest chaining or coupling with another model.
- **SWPC/CCMC:** collaborate more closely on the evaluation and transition process (Space Weather Proving Grounds)

Example: Coupled Heliosphere and SEP models

SEP MODELS

Zhang model | SEPMOD | iPATH | EPREM | SWMF: FLAMPA or Kota SEP | SPARX



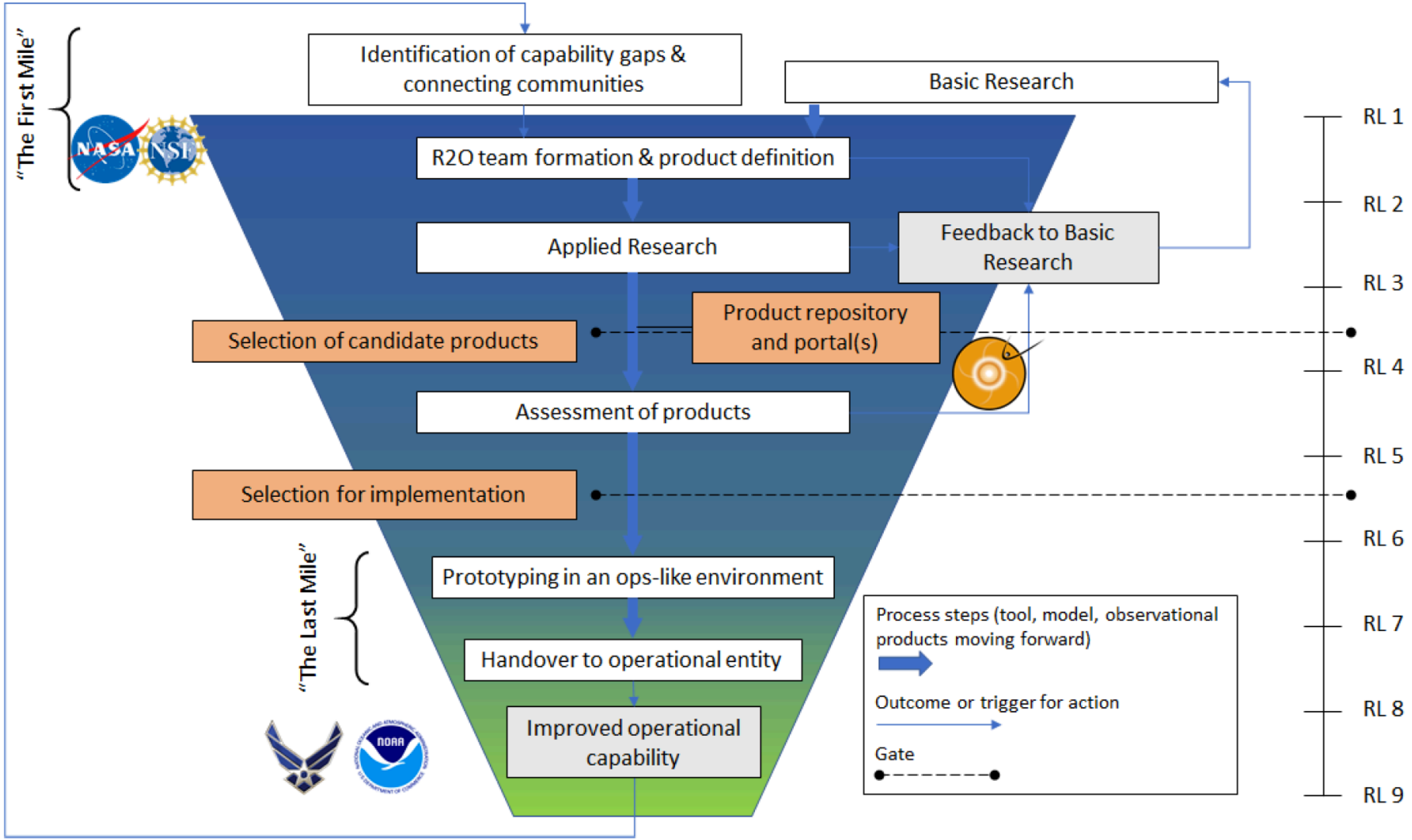
SOLAR-HELIOSPHERE MHD MODELS

WSA-ENLIL+Cone | ZEUS-3D | CORHEL (MAS) | SWMF: AWSoM-R

Hydrodynamic CME | *Flux Rope CME (Titov-Demoulin, Gibson-Low)*

Modelers: N. Arge, D. Odstrcil, J. Luhmann, J. Linker, N.Schwadron, M. Gorby, I.Sokolov, G. Li, S. Dalla, M. Zhang

Space Weather Proving Grounds



Future ideas: L5 & heliospheric space weather

- Magnetograms: reduce errors in background solar wind prediction (Mackay et al., 2016, ApJ); useful for flare prediction models; useful for solar index prediction
- EUV and magnetograms: track active region development with longer lead times for probabilistic flare and CME onset forecasting.
- Heliospheric Imagers: update CME arrival time forecasts, and subselect/constrain ensemble forecasts.
- Solar wind: provide high speed stream forecasts; subselect ensemble solar wind predictions (e.g. WSA-ADAPT).
- Coronagraphs and EUV: reduce CME measurement errors.
- Solar energetic particle : useful for SEP models, and provide connectivity information relevant for forecasting.

Thank you
&
please join the community validation effort!

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