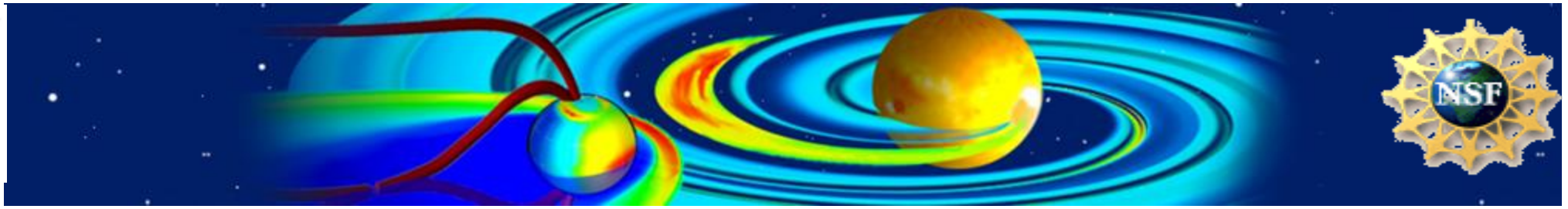


Community Coordinated Modeling Center

established in 2000 as a multi-agency partnership to enable, support, and perform research and development for the next generation of heliophysics and space weather models

Jia Yue, Masha Kuznetsova, Leila Mays & CCMC Team

2025 Community Space Weather Modeling and Data Assimilation Workshop
September 10, 2025

Multi-agency strategic investment in US space weather program

CCMC Goals

Facilitate
space weather & space science
research &
model development

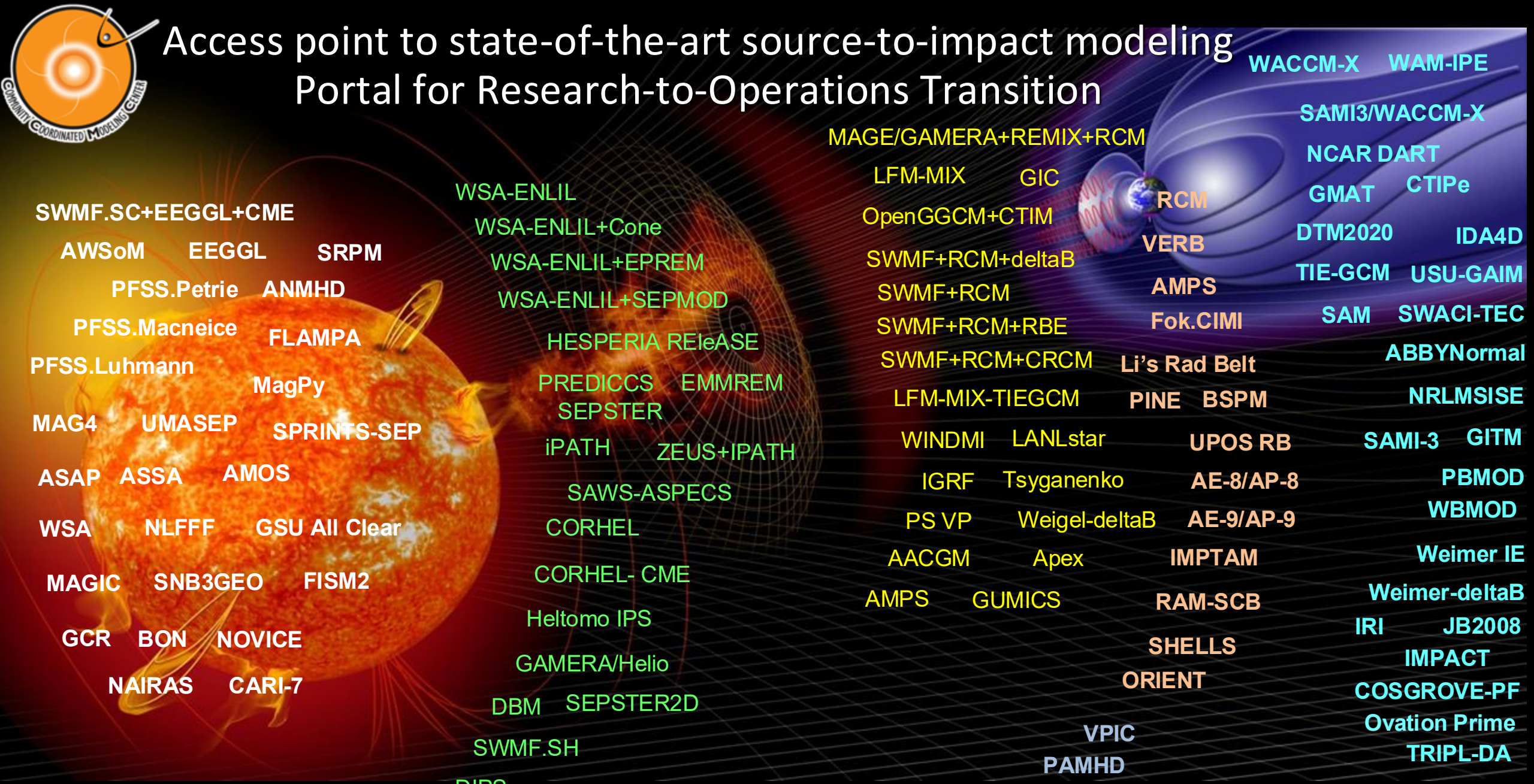
Support
transition of
advances in research to
space weather operations

Established in 2000

Original team: Michael Hesse (founding director), Masha Kuznetsova (deputy), Lutz Rastaetter

First equipment: 3 Sun Workstations
First model: SWMF (U. Michigan)

Access point to state-of-the-art source-to-impact modeling
Portal for Research-to-Operations Transition



SWMF.SC+EEGGL+CME
AWSoM
EEGGL
SRPM
PFSS.Petrie
ANMHD
PFSS.Macneice
FLAMPA
PFSS.Luhmann
MagPy
MAG4
UMASEP
SPRINTS-SEP
ASAP
ASSA
AMOS
WSA
NLFFF
GSU All Clear
MAGIC
SNB3GEO
FISM2
GCR
BON
NOVICE
NAIRAS
CARI-7

WSA-ENLIL
WSA-ENLIL+Cone
WSA-ENLIL+EPREM
WSA-ENLIL+SEPMOD
HESPERIA REleASE
PREDICCS
EMMREM
SEPSTER
iPATH
ZEUS+IPATH
SAWS-ASPECS
CORHEL
CORHEL- CME
Heltomo IPS
GAMERA/Helio
DBM
SEPSTER2D
SWMF.SH
DIPS

MAGE/GAMERA+REMIX+RCM
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
GUMICS

RCM
VERB
AMPS
Fok.CIMI
Li's Rad Belt
PINE
BSPM
UPOS RB
AE-8/AP-8
AE-9/AP-9
IMPTAM
RAM-SCB
SHELLS
ORIENT

VPIC
PAMHD
PIC-Hesse

WACCM-X
WAM-IPE
SAMI3/WACCM-X
NCAR DART
GMAT
CTIPe
DTM2020
IDA4D
TIE-GCM
USU-GAIM
SAM
SWACI-TEC
ABBYNormal
NRLMSISE
SAMI-3
GITM
PBMOD
WBMOD
Weimer IE
Weimer-deltaB
IRI
JB2008
IMPACT
COSGROVE-PF
Ovation Prime
TRIPL-DA

Corona
Heliosphere
Magnetosphere
Local Physics
Inner Magnetosphere
Ionosphere/ Thermosphere

CCMC Core Functions (382230)

* NASA Tier 1 activity, *need advocacy at HQ*

Models

- Maintaining, and expanding a **unique collection of heliophysics models**.
- On-boarding and testing state-of-the-art models (including deliverables from **LWS SC, DRIVE Centers**).
- Developing online tools for **model inputs generation.**
- Addressing **open science best practices** (e.g., containerization), version control, security requirements).
- Facilitating **model coupling** in collaboration with developers.

Validation and Community Support

- Performing **physics-based** validations. Evaluating model ability to **reproduce physical phenomena.**
- Developing tools and systems for model-data comparisons, event studies, and system science. **Adapting iSWA, DONKI, CAMEL for research projects.**
- Supporting community **open validation campaigns** (Modeling Challenges) and other community projects (e.g., **HBY and follow-on**).

Simulation Services

(Open Use of Models)

- Providing simulation services (**automated** and **expert-guided**): ***Runs-on-Request, Instant Runs, Continuous Runs.***
- Facilitating **reproducibility** of run results.
- Interfacing with simulation services emerging worldwide. Enabling **remote execution**.

Infrastructure – *prerequisite to all functions*

- Designing, maintaining, refreshing **in-house** computational infrastructure (custom, redundant, IT security compliant).
- Incorporating **NASA HPC** capabilities in CCMC infrastructure.
- Designing and maintaining environments on **AWS cloud** for collaborative on-boarding, development and analysis.
- Maintaining and upgrading **storage solutions** and **innovative data pipelines** between systems.

Open Use of Simulation Results

(Access, Post-Processing Visualization, Analysis)

- Maintaining interactive archives of simulations results **(including results produced outside of CCMC)** *with SPASE metadata,* API access, DOIs.
- Improving quality of simulation results databases. Implementing open science principles. **Linking run results with publications/phenomena**.
- Developing on-line interactive tools for visualization and analysis.
- *Developing access, interpolation, post-processing Kamodo software.*
- Enabling visualization of heliophysics results in classrooms and planetariums through OpenSpace software (also a SWR&A function).

NASA Missions Support

- Performing tailored simulations and developing visualization and analysis tools in support of NASA's mission science.
- Utilizing outputs of global simulations as a virtual reality and deriving synthetic observational data for mission planning.

Web Presence

- Designing, maintaining, and updating interactive website with Content Management System
- *Interfacing with Heliodata and other Heliophysics websites*

CCMC Functions: SW Research & Analysis Program

Grouped by SWR&A Program Strategic Goals

Mapped to relevant sections in the **Implementation** Plan for National SW Strategy and Action Plan

Analyze

- **Onboarding and evaluation** of new space weather **models and applications** including deliverables from R2O2R, SWxC **(2.5.1, 2.7)**
- Evaluation of new computational technology **(2.5.2)**
- ***CAMEL*: platform for model **validation & performance analysis** based on historic **Time Periods** and **ESEQs** (2.5.1).**
- **Impact-based validation (2.5.1, 2.5.6, 2.2.12).**
- ***OpenSpace*: interactive visualization of SW phenomena in classrooms and planetariums to **improve public awareness & education** (3.2.2).**

Predict

- **Continuous Real-time Runs (2.5.1, 2.5.4, 2.5.7, 2.7)**
- ***Scoreboards:*** Community-wide pre-event ensemble predictions **(2.5.7)**
- ***ISEP*** *(Integrated Solar Energetic Proton)* project **(2.5.7, 2.7)**
- ***iSWA*** *(Integrated Space Weather Analysis system):* custom displays of real-time simulated and observational data for SW monitoring, real-time analysis. Used by M2M SWAO, USAF/USSF, … **(2.5.7, 2.7)**
- ***DONKI:*** SW database, utilized for disseminations of notifications and reports produced by M2M SWAO **(2.5.1, 2.5.4, 2.7).**

Transition

- **Demonstrate potential** of new understanding, models and applications to improve operational space weather capabilities **(2.5.1, 2.5.7, 2.7)**
- **Collaborative Environments and R2O2R Pipelines (2.7)**
  - CCMC-SWPC Architecture for Collaborative Evaluations
  - NASA in-house CCMC-SRAG-M2M shared cloud environment

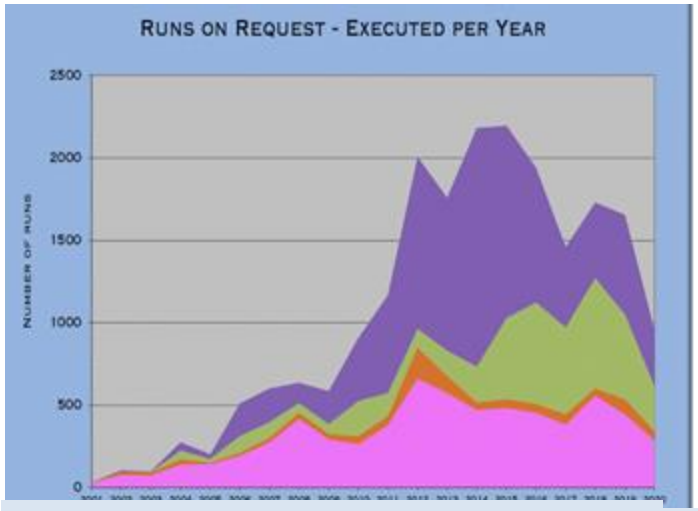
Support

- Support JSC/SRAG and M2M SWAO **(2.5.1, 2.7)**
- Support NOAA SWPC, USAF/USSF, … **(2.7)**
- Support implementation of tools for anomaly analysis (**2.11.1, 2.11.5**)

Partner

- **Partnership** and **leadership** in COSPAR International Space Weather Action Teams (ISWAT) to facilitate multiplying efforts **(3.2.1)**

CCMC Simulation Services

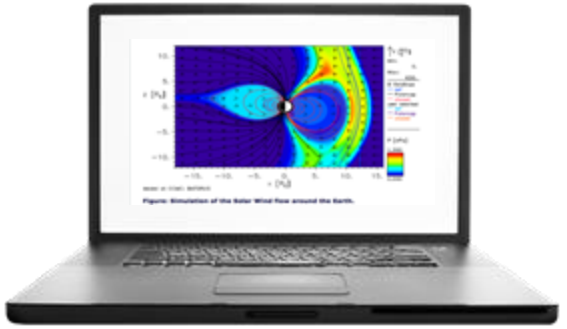


Over 2000 runs per year
400 unique users per year

Runs-on-Request Instant Runs

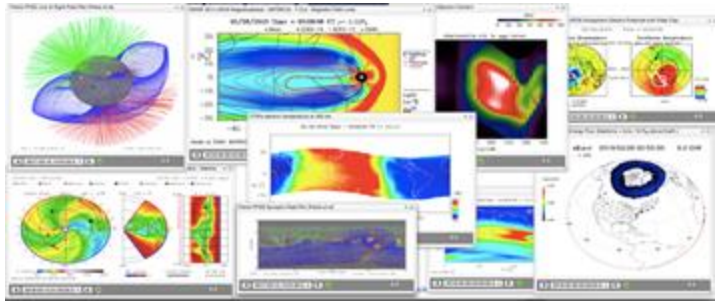
CCMC Signature Service

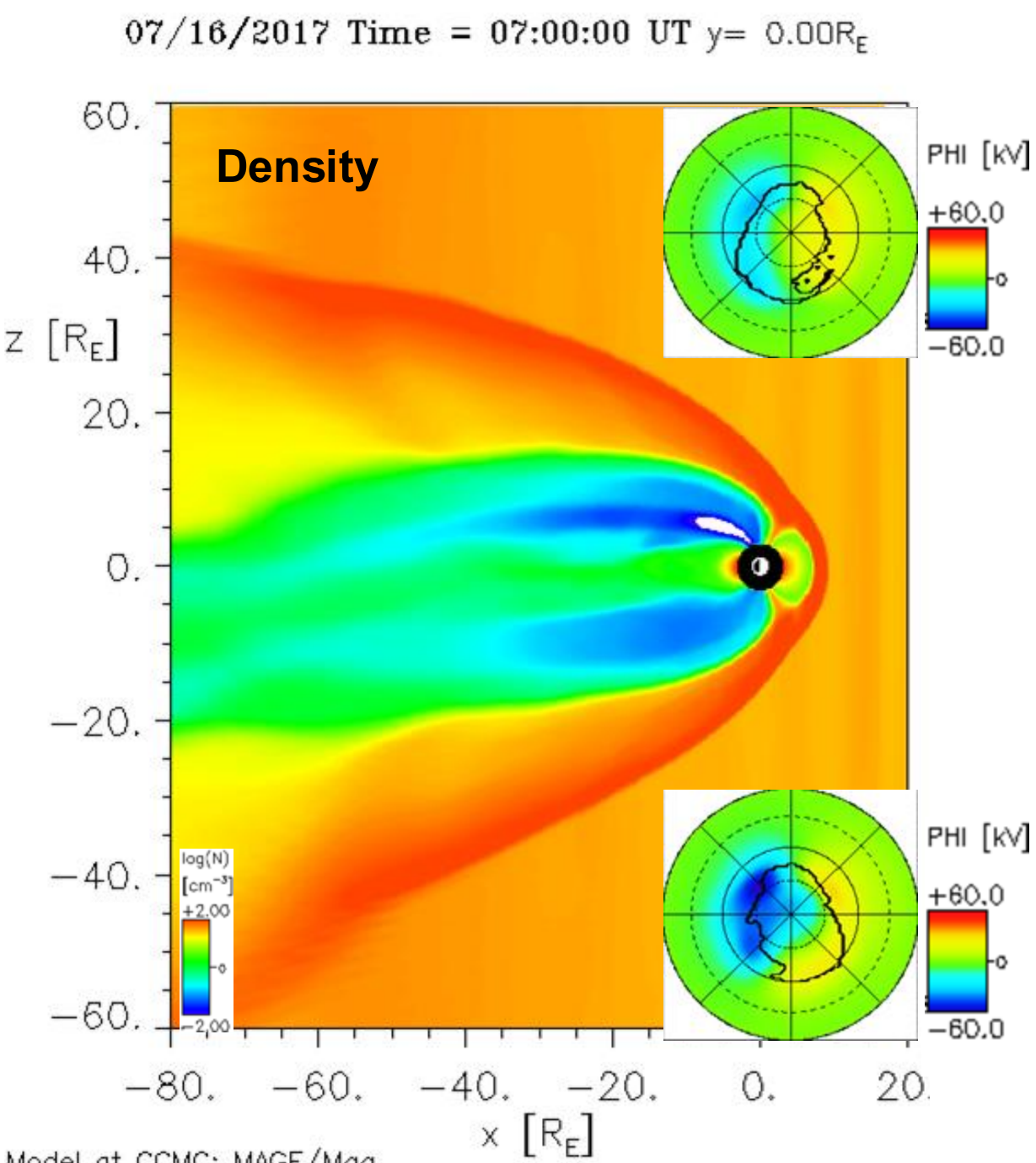
- ✓ Permits scientists to utilize & **evaluate** state-of-the-art models without barriers
- ✓ Create synergy between data analysis and scientific modeling



Continuous Runs

- ✓ Automated continuous execution utilizing real-time observational data streams
- ✓ Test model robustness and long-term performance
- ✓ Provide simulated data feeds to perpetual archive of space environment information (*ISWA – Integrated Space Weather Analysis* system)





MAGE is the First Deliverable to CCMC from NASA DRIVE Science Center for Geospace Storms (CGS)

- ❑ As of April 2024, the MAGE is now available to the community through the CCMC Runs-On-Request service

- ❑The MAGE model is a comprehensive geospace modeling framework. that includes
  - coupled GAMERA global magnetosphere,
  - ReMIX ionosphere electrostatics solver,
  - RCM ring current. **Focus on mesoscales.**

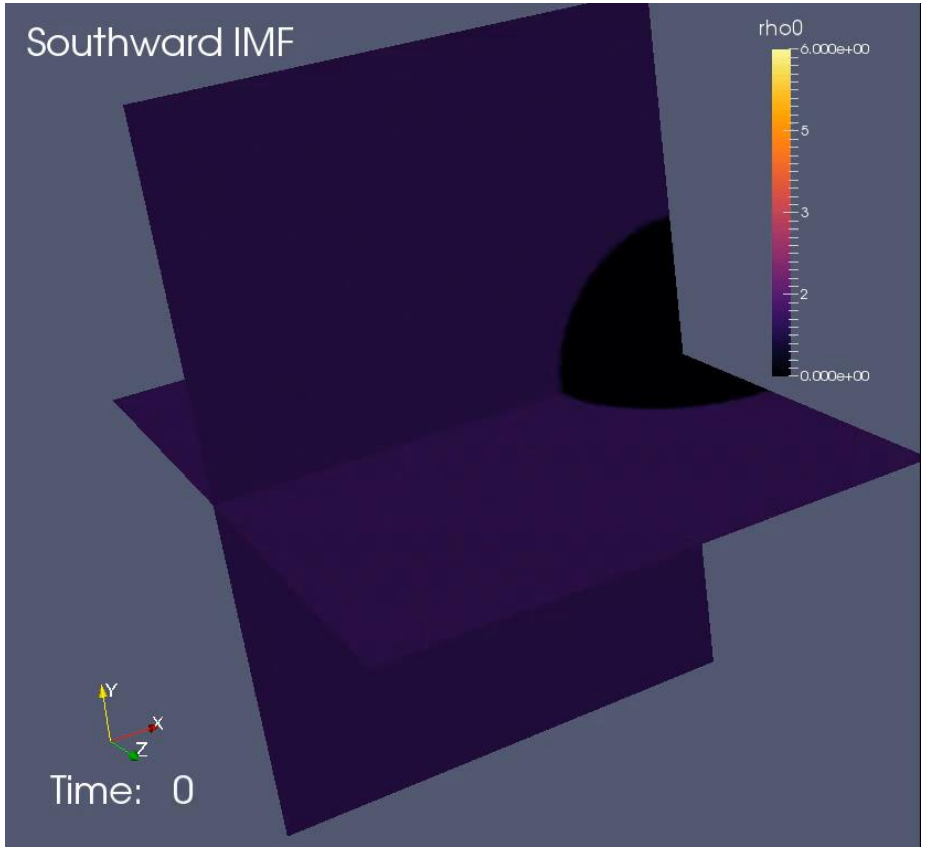
- ❑ CCMC scientists and software developers have been working together with the CGS team at the CCMC-CGS collaborative environments on Pleiades and CCMC Cloud

CCMC is Moving Beyond Single-Fluid MHD

- Hybrid and particle-in-cell (PIC) approaches enable addressing problems such as
  - ✓ Reconnection
  - ✓ waves particle interactions
  - ✓ particle energization and transport at different regions
- Global hybrid models can address turbulence on multiple scales.

HYPERS-Global runs-on-request (RoR) are available in 2D at CCMC. 3D simulations are CPU intense and coming soon.

Turbulent Magnetosheath under Southward Quasi-Radial IMF



Hybrid Particle Event-Resolving Simulator - **HYPERS** [Yuri ***Omelchenko***]

NAIRAS Model at CCMC

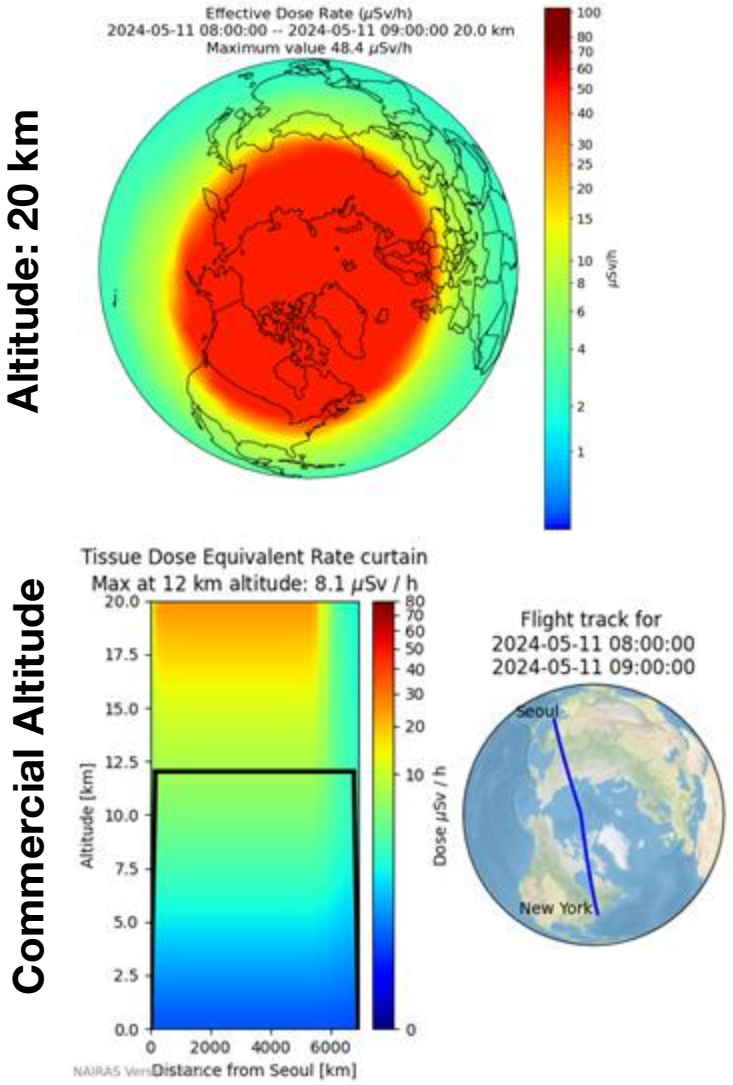
Nowcast of Aerospace Ionizing RAdiation System (NAIRAS) Model (Chris Mertens, LaRC)

- **Output products**: dose quantities for assessing human radiation exposure and radiation flux quantities for characterizing single event effects (SEE) in flight electronic systems
- **Model Domain**: Earth's surface to cislunar
- **Output availability: (1)** real-time atmospheric radiation environment, and **(2)** run-on-request (RoR) service (all products over all model domain)

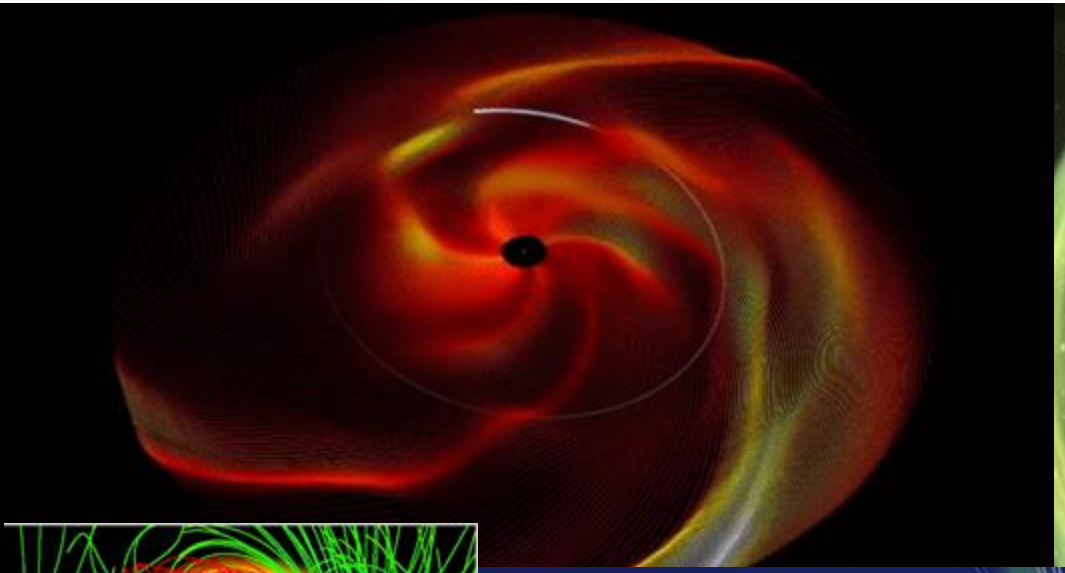
Recent News:

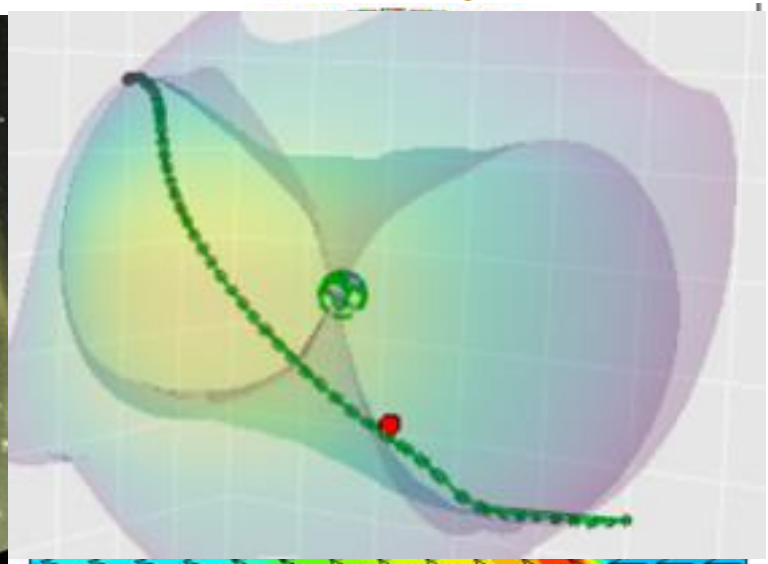
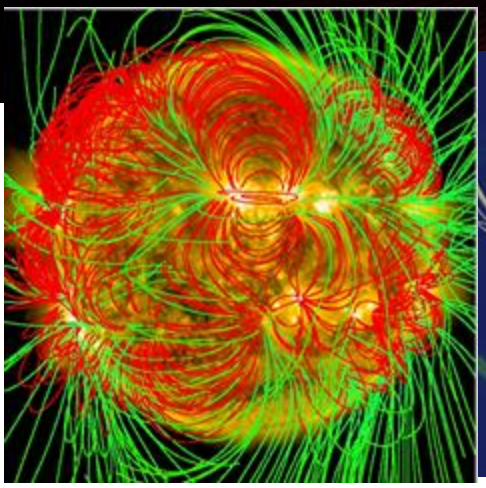
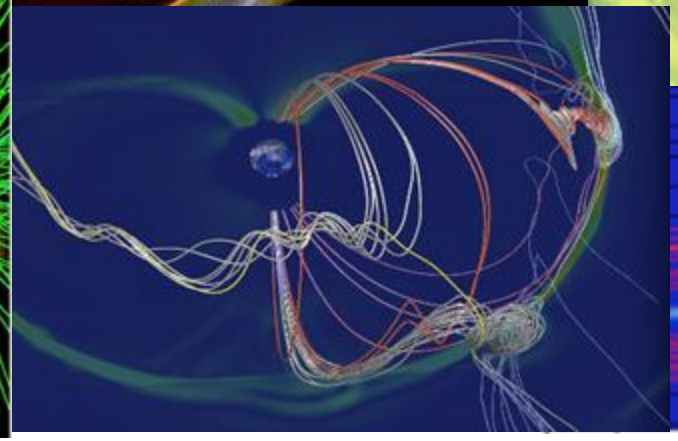
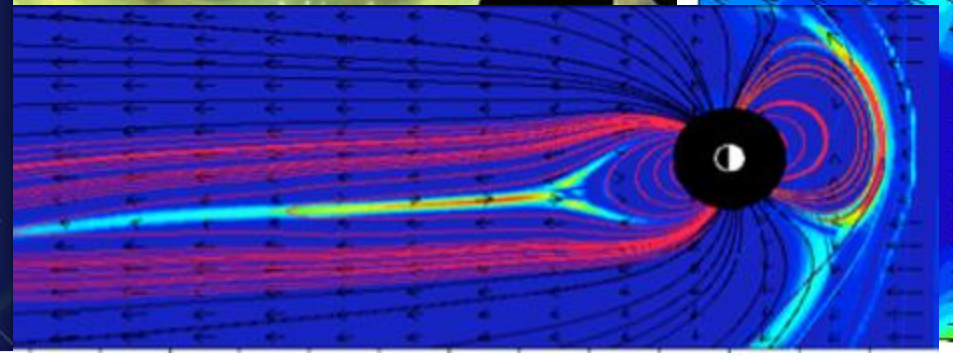
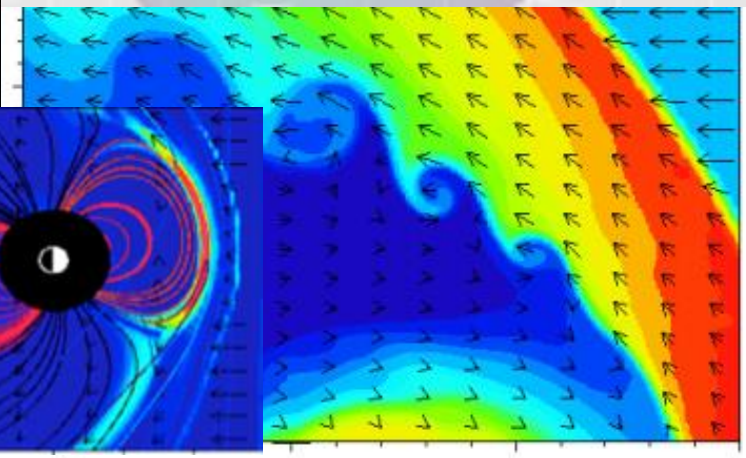
- U.S. Space Force (USSF) using NAIRAS predictions at 20 km in operations to support U2 pilot exposure.
- USSF used NAIRAS predictions to recall operational U2 flight during the May 10-12, 2024 SEP event: pilot descended to lower altitude and returned to base
- **In Progress**: Developing 3-7 hours SEP forecast of peak dose after event onset by coupling NAIRAS with UMASEP.

May 10-12, 2024 SEP Event



Interactive Visualization



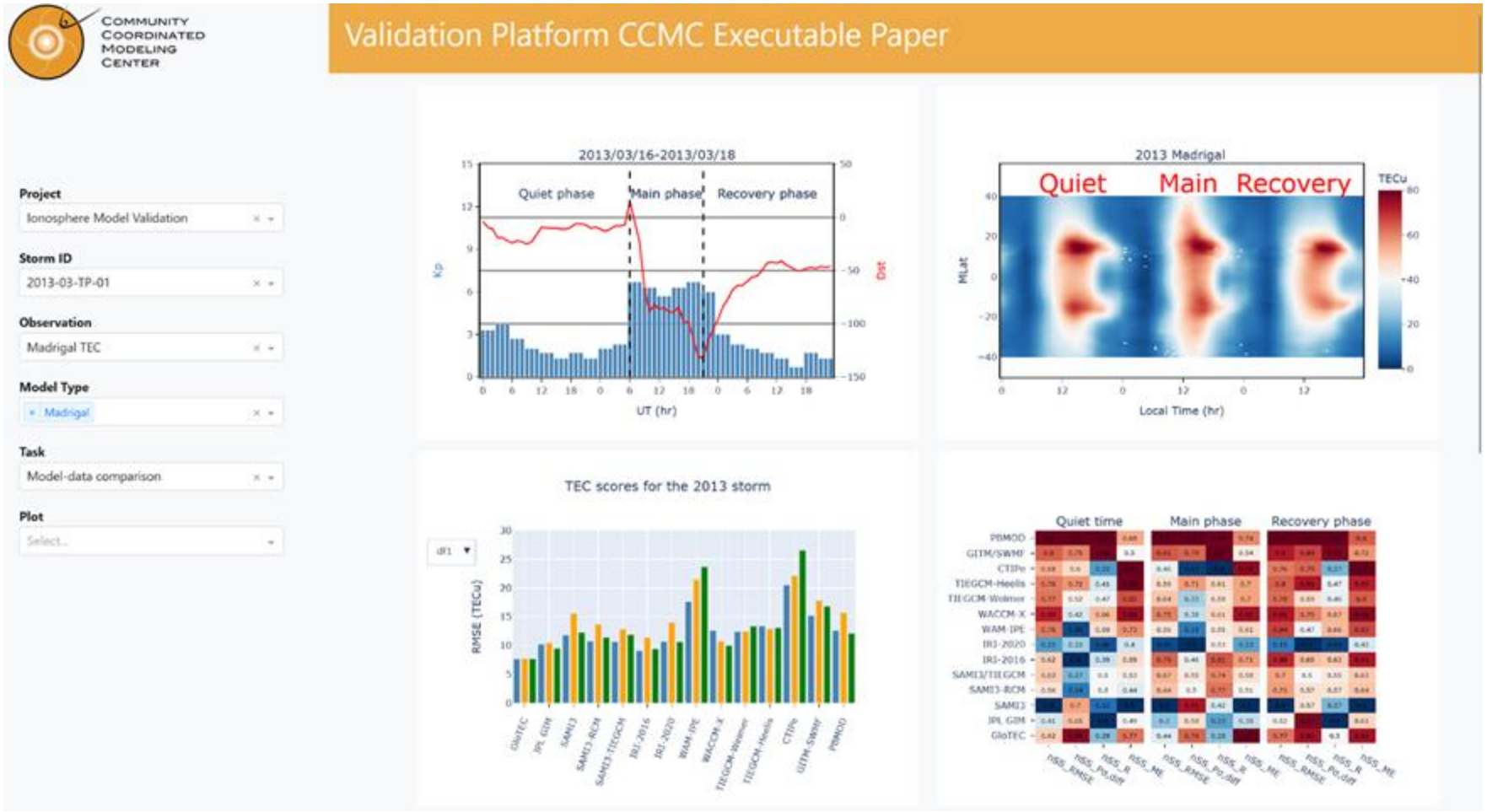
- ✓ Basic model output and derived quantities
- ✓ User-ordered custom variables
- ✓ Automated movie & time series generation
- ✓ Run series tailored for specific phenomena
- ✓ Interfaces with Planetariums

Lutz Rastaetter

Space Weather at CCMC

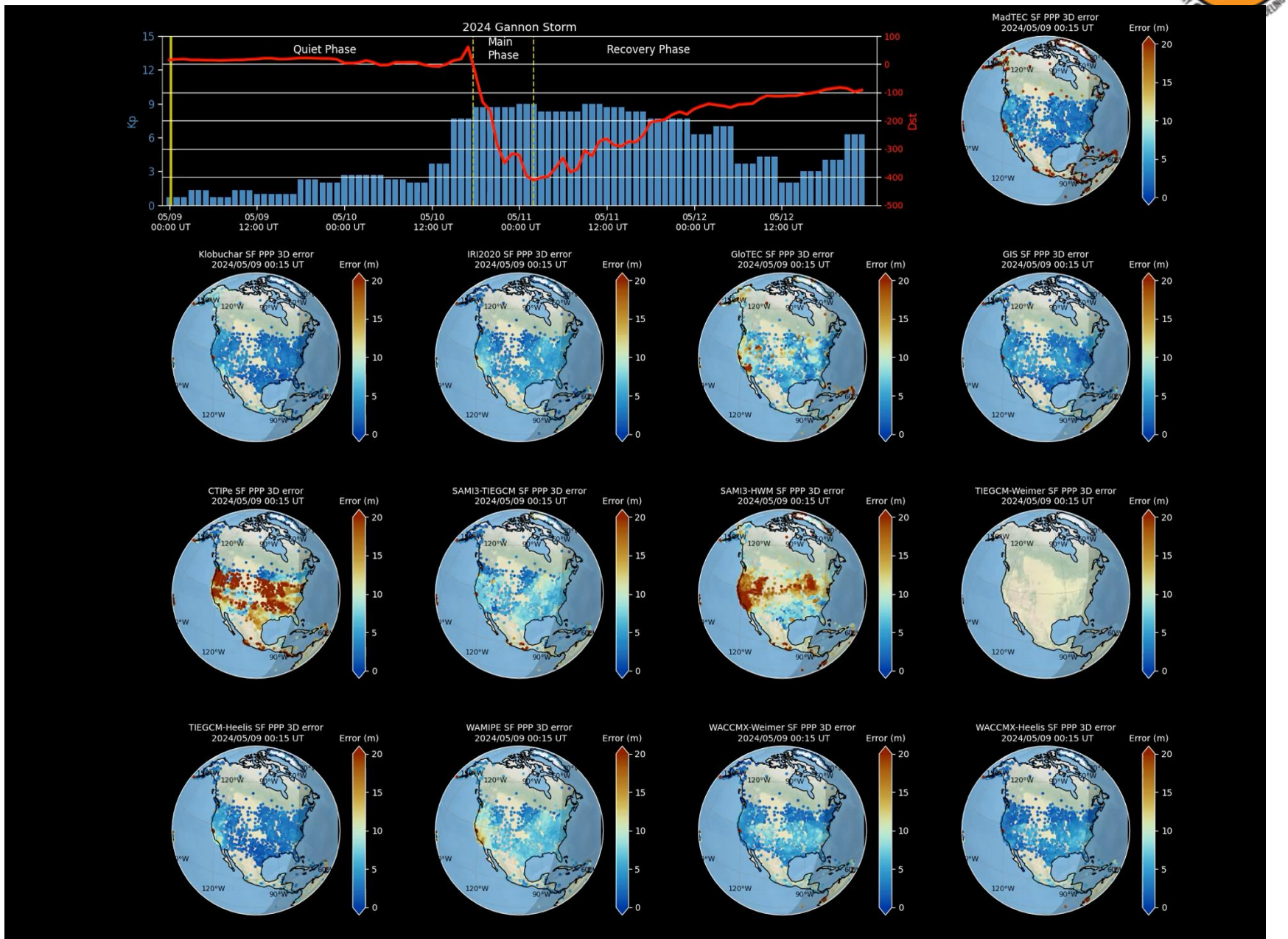
- Real-time space weather activities that require **human-in-the-loop** analyses and training, previously performed by CCMC staff, have **transitioned from CCMC to Moon-to-Mars (M2M) Office**
- CCMC continues to be the **primary interface with model developers and the research community for all model/tools onboarding** (including real-time)
- CCMC is continuing all other **real-time space weather activities** including developing real-time systems, running real-time simulations, automatic ingesting and serving information through CCMC's space weather portals and perpetual archives:
  - **iSWA** - integrated Space Weather Analysis system
  - **DONKI** - Database of Notifications, Knowledge, Information
  - **Scoreboards** – pre-event forecast collection, comparative display, and database
- M2M analysts provide entries/feeds into into DONKI, iSWA and the CME Scoreboard, when human-in-the-loop actions are required

Ionosphere and Thermosphere Visualization Platform



- A platform to visualize/display CCMC ITM projects.
  - Ionospheric TEC validation
  - Ionosonde foF2 and hmF2 validation
  - RO foF2 and TEC validation
  - Ionospheric Ray-Tracing and HamSCI
  - GNSS positioning
  - ITM Research (e.g., plasma bubbles)
  - Neutral Density

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


2024 Gannon Storm
Quiet Phase
Main Phase
Recovery Phase
Kp
Dst
05/09 00:00 UT
05/09 12:00 UT
05/10 00:00 UT
05/10 12:00 UT
05/11 00:00 UT
05/11 12:00 UT
05/12 00:00 UT
05/12 12:00 UT
MadTEC SF PPP 3D error 2024/05/09 00:15 UT
Klobuchar SF PPP 3D error 2024/05/09 00:15 UT
IRI2020 SF PPP 3D error 2024/05/09 00:15 UT
GloTEC SF PPP 3D error 2024/05/09 00:15 UT
GIS SF PPP 3D error 2024/05/09 00:15 UT
CTIPe SF PPP 3D error 2024/05/09 00:15 UT
SAMI3-TIEGCM SF PPP 3D error 2024/05/09 00:15 UT
SAMI3-HWM SF PPP 3D error 2024/05/09 00:15 UT
TIEGCM-Weimer SF PPP 3D error 2024/05/09 00:15 UT
TIEGCM-Heelis SF PPP 3D error 2024/05/09 00:15 UT
WAMIPE SF PPP 3D error 2024/05/09 00:15 UT
WACCMX-Weimer SF PPP 3D error 2024/05/09 00:15 UT
WACCMX-Heelis SF PPP 3D error 2024/05/09 00:15 UT
Error (m)

Community Space Weather Products

Scoreboards: World-wide pre-event ensemble predictions

COSPAR
ISWAT

Active

CME Flare SEP

Planning

IMF Bz

- Solar Wind
- Solar proxies: f10.7, …
- Geomagnetic Indixes: Kp, Ap, Dst
- Neutral Density

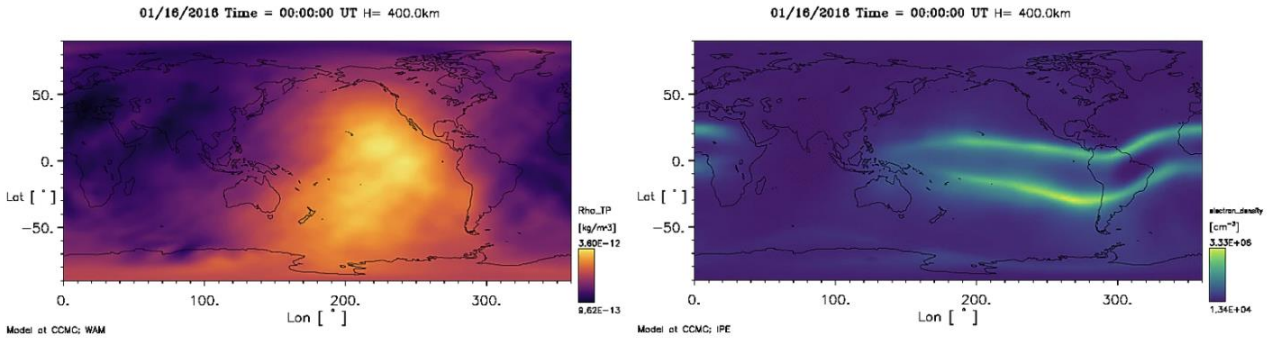
- **Collect and display** forecasts from research and operational models before the event is observed.
- Many models run locally at CCMC.
- Enables continuous validation platform (**real-time** comparisons of various forecasts)
- **Demonstrates** operational potential of new capabilities
- Enables building a Log of model performance for uncertainty assessment
- **Input from Operational Centers (SWPC, Met Office) is important for front end design.**

IMPLEMENTATION PLAN OF THE NATIONAL SPACE WEATHER STRATEGY AND ACTION PLAN

2.5.7 Facilitate community-wide pre-event ensemble predictions. [NASA]

Opportunity for Community Modeling:
Improve Models Used in Operations

WAM-IPE



- WAM-IPE installed on CCMC-SWPC shared environment at NASA Pleiades (Adam Kubaryk visited CCMC in June and helped with debugging)
- As of September 6, 2024, WAM-IPE version 1.2.4 is available to the community through Runs-on-Request (RoR)
- Next steps: implement WAM-IPE on the CCMC Cloud, work with SWORD SWxC and community on further model improvement. Initiate community modeling

Opportunities for additional activities that can be build upon existing experience and capabilities relevant to Implementation Plan for National SW Strategy and Action Plan

- Develop and maintain shared environment and a flexible framework for collaborative **development of data assimilative capabilities** (including utilization of data from commercial space weather sector)
- Facilitate collaborative development and evaluation of modular open-source flexible **modeling/forecasting systems for satellite drag** and navigation/communication

- Enable **continuity of legacy models**

CCMC is an Asset of NASA Heliophysics, NSF Facilities and the Entire Space Weather & Space Science Community

- Repository and dissemination of achievements in heliophysics modeling. Access point to state-of-the-art models
- Portal to R2O2R transition
- Resource for community-wide campaigns
- Fast response unit to evolving community and agencies needs

ENABLE ***SUPPORT*** ***FACILITATE***

Supplementary Slides

Enabling the Science

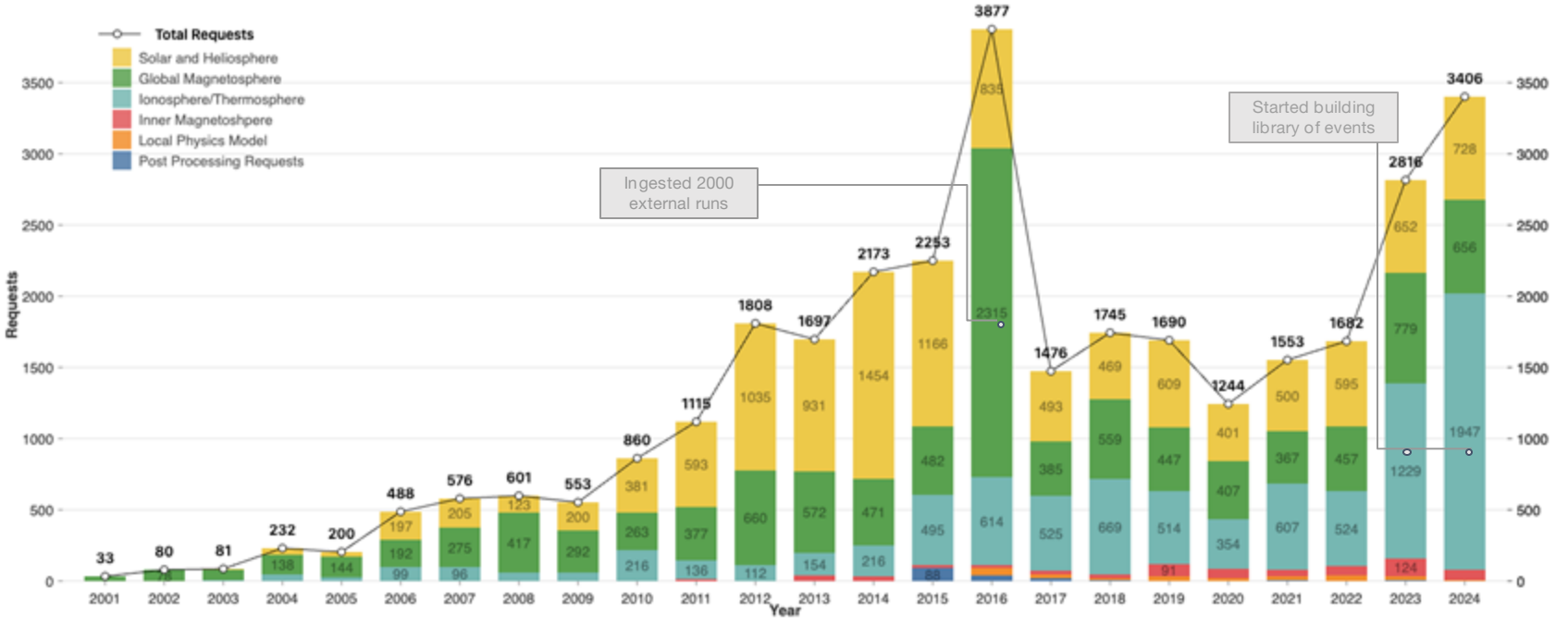
ROR Archive (per month)

- 30 full-result downloads
- 100 movie visualizations
- 700 plot visualizations
- 10k visualized images
- 300k page views
- 850k data file downloads

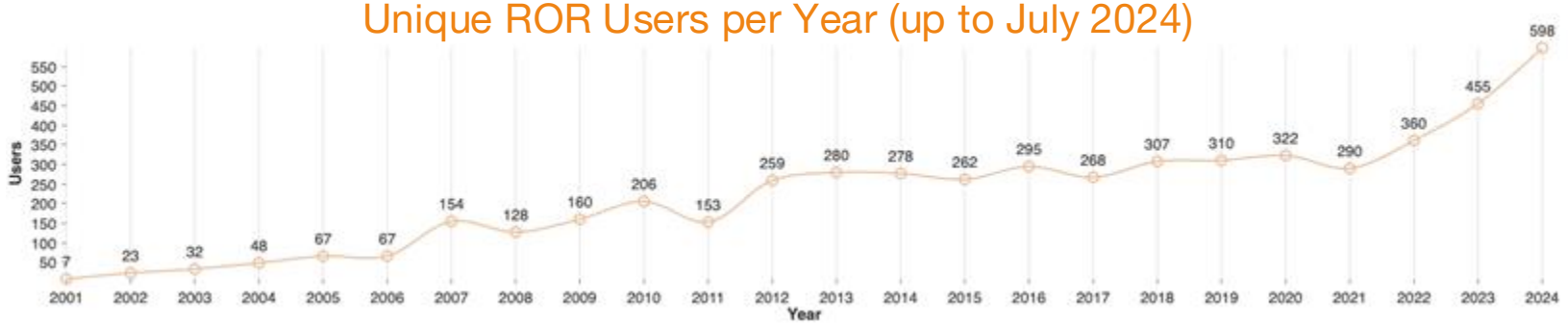
Last 3 years

- 134 new publications
- 1400 unique users from 200 countries

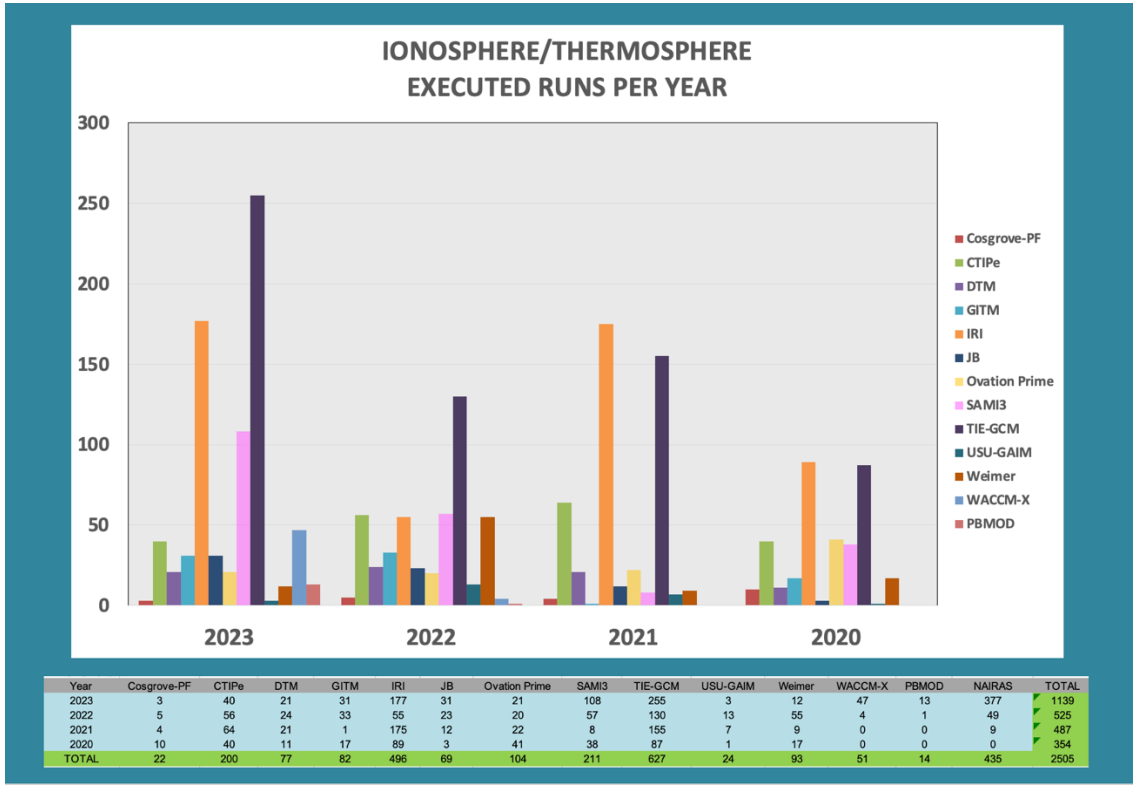
ROR Requests per Year (up to July 2024)



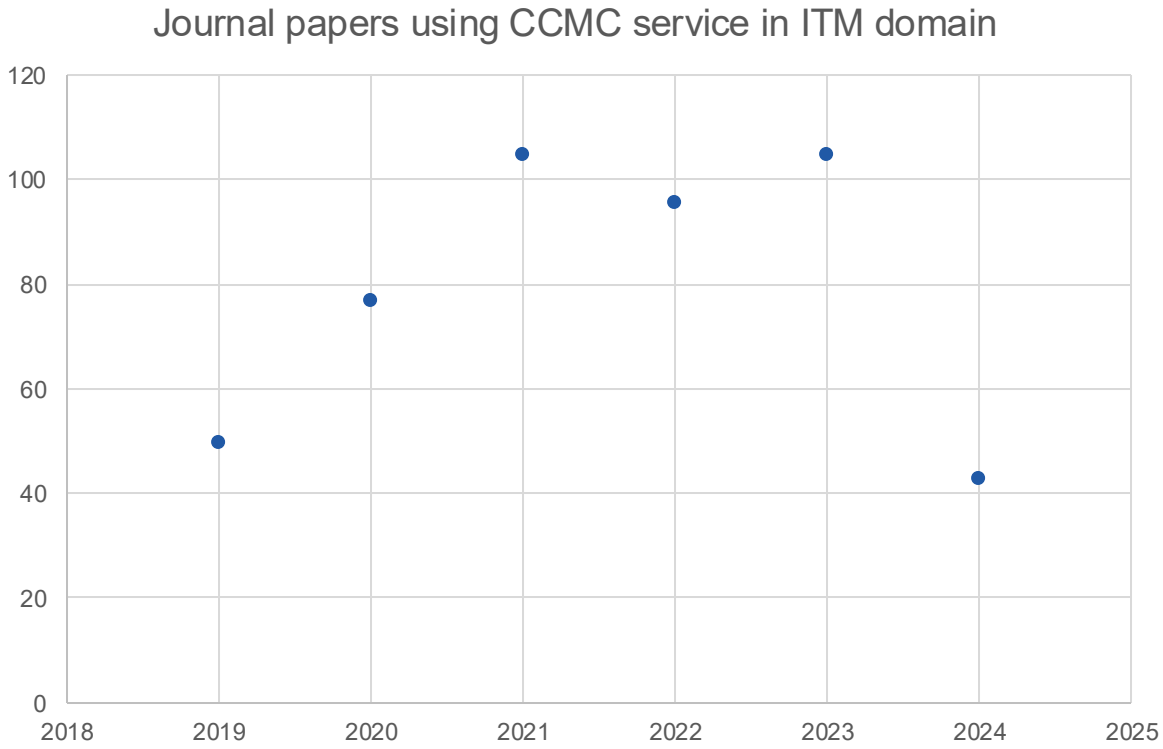
Unique ROR Users per Year (up to July 2024)



Statistics of Ionosphere-Thermosphere-Mesosphere model usage during 2022-2024



Year	Cosgrove-PF	CTIPe	DTM	GITM	IRI	JB	Ovation Prime	SAMI3	TIE-GCM	USU-GAIM	Weimer	WACCM-X	PBMOD	NAIRAS	TOTAL
2023	3	40	21	31	177	31	21	108	255	3	12	47	13	377	1139
2022	5	56	24	33	55	23	20	57	130	13	55	4	1	49	525
2021	4	64	21	1	175	12	22	8	155	7	9	0	0	9	487
2020	10	40	11	17	89	3	41	38	87	1	17	0	0	0	354
TOTAL	22	200	77	82	496	69	104	211	627	24	93	51	14	435	2505



On-going open science activities

- Working with LSW SC, DRIVE Centers, SWxC to enable community use of early outcomes.
- All CCMC staff members taking **Open Science 101** training
- Organized community workshop on open science in modeling (June, 2024)
- Modelers request CCMC to lead in introducing standards and guidance on **open science best practices**
- Linking CCMC runs with **publications, phenomena, new research results/findings.**
- Visualization/analysis of **results produced outside of CCMC, remote execution.**
- Initiated World Geospace Storm Modeling Challenges and Geospace Scoreboards (part of **HBY support**).
- Created Open Science Studio (OSS) platform to support **hands-on training** to compile and run models.
- Initiated **Heliophysics Open Modeling Environment (HOME)** movement for collaborative advancing open science in modeling.

* Need advocacy at HQ for CCMC role in advancing open science

NASA CCMC – NOAA SWPC Working Together

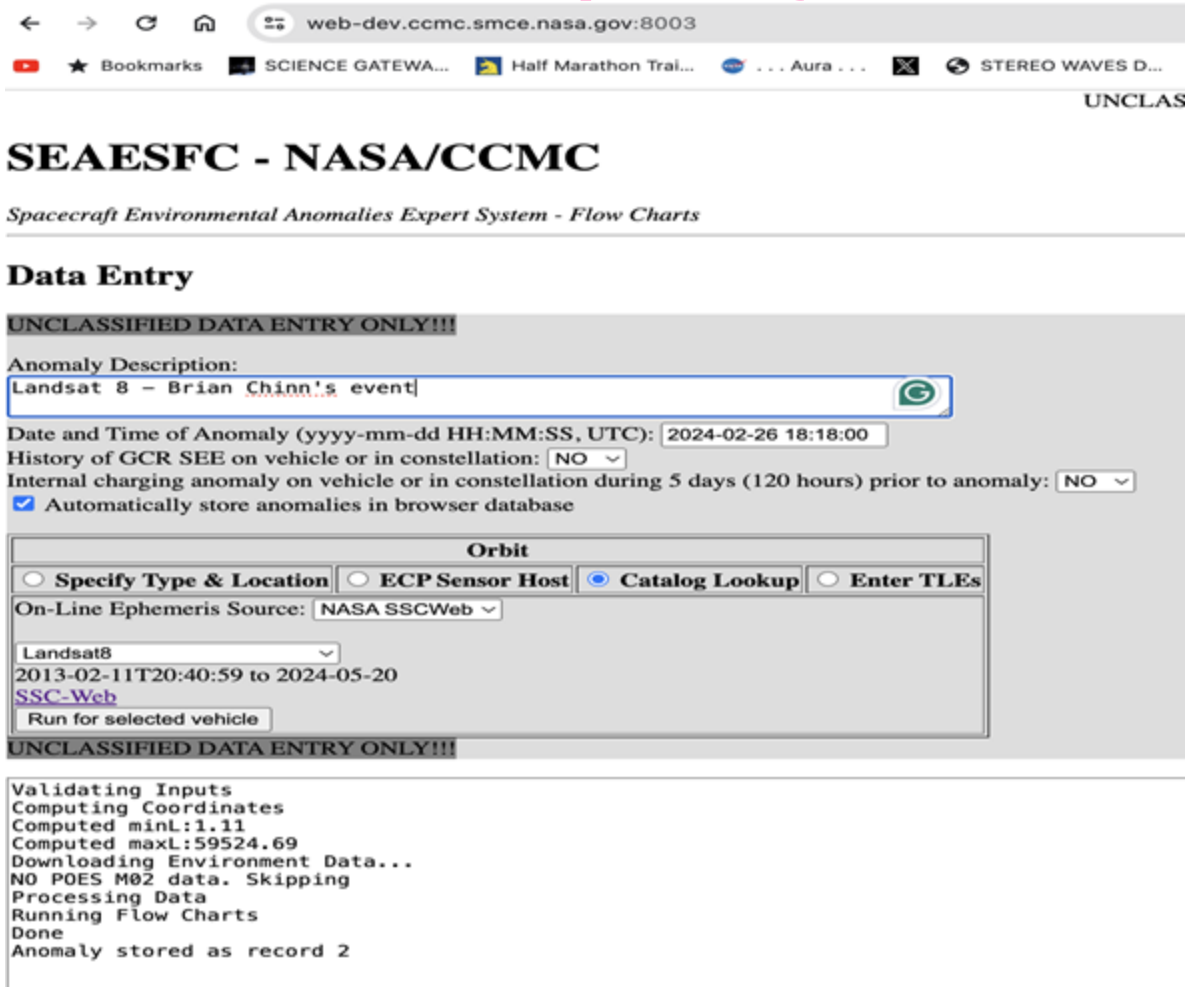
20-year partnership since CCMC establishment. Major successes:

- Demonstrated potential of WSA-ENLIL for operational forecasting (2006-2009)
- **Geospace model transition** to operations at NOAA/SWPC (2013 - 2015)
  - SWMF selected as a first physics-based geospace operational model
- Project under NASA-NOAA MOU Annex (2017-2020): Assess whether model upgrades improve CME arrival time prediction?
- CCMC-SWPC 'Architecture for Collaborative Evaluation' (2020 – present) - shared cloud environment mirroring operational settings
- On-going transition of UMASEP from ACE to SWPC Testbed

Model Evaluation Projects

- How well model output is consistent with initial assumptions?
- How well can model reproduce space weather phenomena?
- **How useful is a model for space weather applications?**
  - Evaluations based on historic time intervals
  - Modeling Challenges for recent/ongoing storms
  - Pre-Event **Forecasting Methods Scoreboards**.
- Archives and display system for model evaluation results.

SEAES-FC (Spacecraft Environmental Anomalies Expert System - Flow Charts)

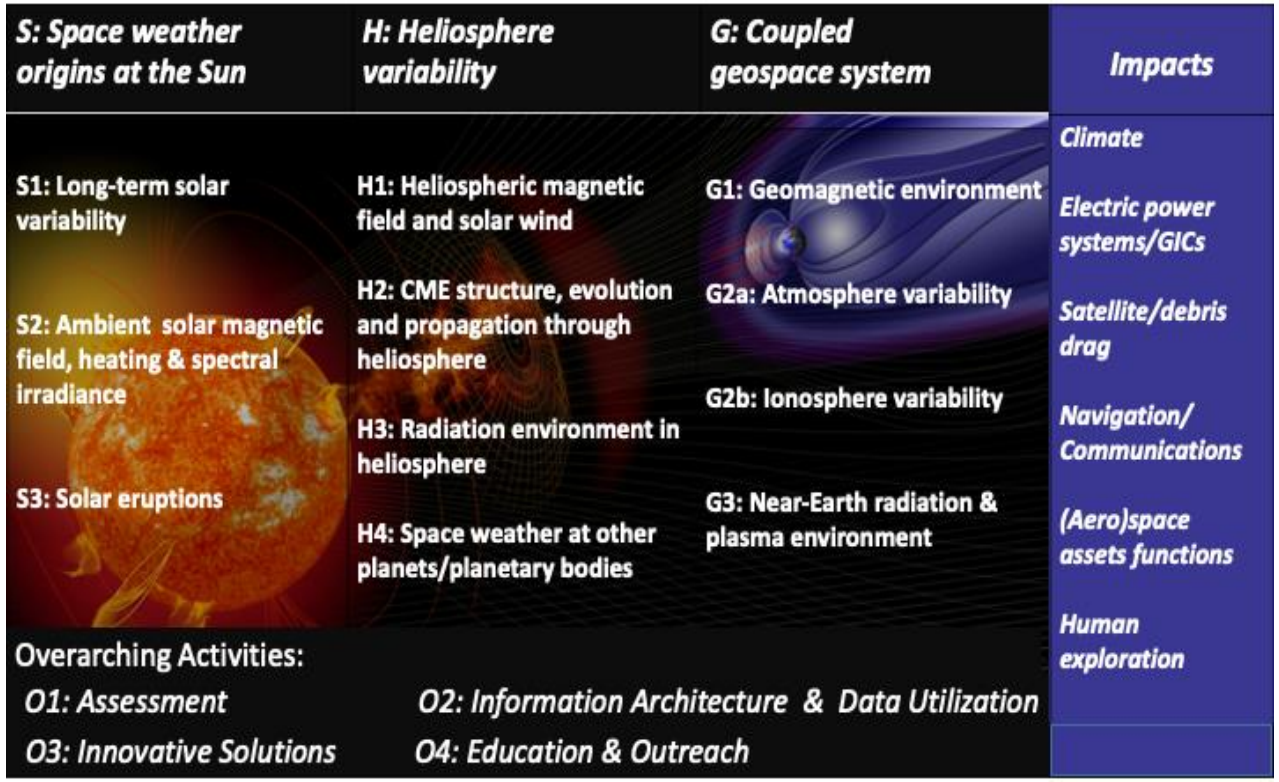


- Used by Moon-to-Mars Space Weather Analysis Office to support spacecraft anomaly resolution for NASA missions and joint missions
- Used by some of the mission teams (including joint missions with USGS, NOAA) ***directly*** for their anomaly analyses

- ICESat-2 went into safe mode on May 10. Its ATLAS (Advanced Topographic Laser Altimeter System) went back to science mode on June 20.
- Aqua and Aura came within minutes of having to go into safe mode.

International Space Weather Action Teams

Hub for self-organized open collaborations



Examples of Action Teams aligned with Space Weather Programs:

O1-02: Quantification of Uncertainties in Space Weather Forecasts
H3-04: CLEAR: All Clear SEP Predictions (L. Zhao)
S3-05: Understanding the Onset of CMEs/Eruptive Flares (aligned with LWS Focus Science Team)

Groups or individuals working on specific topic across the field of space weather can register a new ***Action Team*** team and open it for others to join.

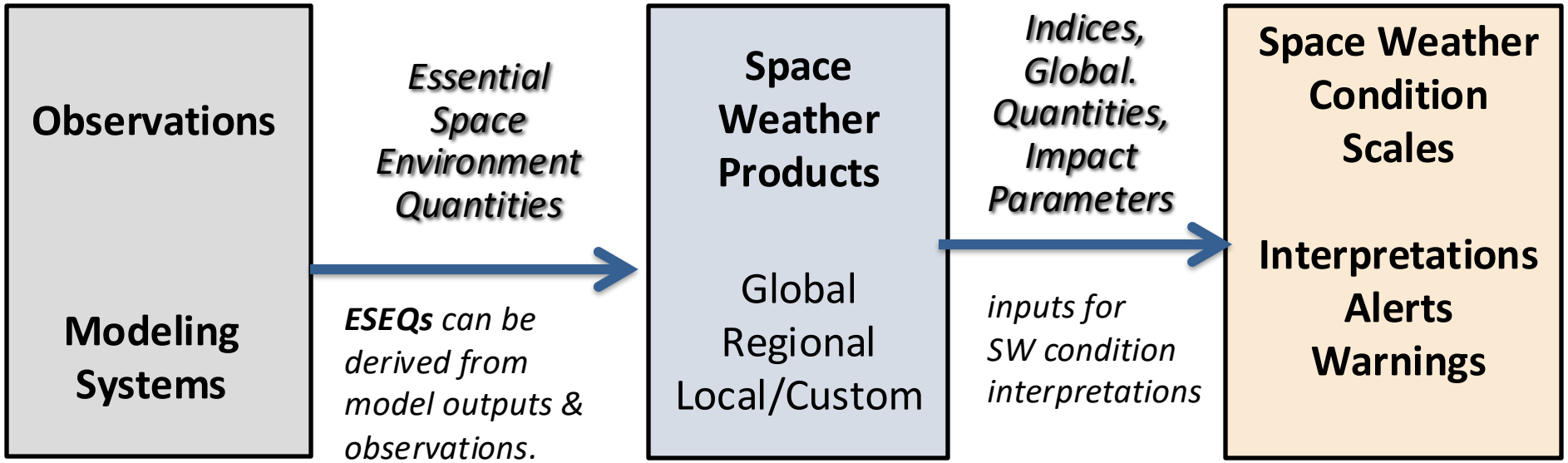
ISWAT is an **effort multiplier**. Maximise return on investments by national/regional programs

Status: 70+ Action Teams, 16 Clusters, 690+ active members, 50+ countries, 400+affiliations

https://iswat-cospar.org

Working Meetings:
2020 (Florida, USA)
2022 (Coimbra, Portugal)
Mini-ISWAT@ESWW2023-2024
Feb 10 – 14, 2025 (Florida, USA)

Flow of Space Weather Information



Observational data used as base for data products, inputs and data assimilation for modeling systems

- **Global/Regional p**roducts are used as a base for SW Conditions Scales, interpretations **(***Will there be an event? How Intense will it be***?)** Can be tailored for user groups.
- **Local/custom** products are tailored for specific users.

Partnerships

- Collaborative on-boarding and improvements with model developers utilizing custom shared environments at the CCMC Cloud
- Partnership with NASA/JSC Space Radiation Analysis Group (SRAG) and M2M SW Analysis Office on *NASA-in-house R2O Pipeline* in support of Human Exploration
  - *CCMC and SRAG work as one team, weekly tag-ups, coordinated hiring*
- Partnership with NOAA/SWPC and shared proving ground Architecture for Collaborative Evaluation (ACE). Plan to get involved in SW Prediction Testbed.
- International partnerships through active participation in COSPAR International Space Weather Action Teams (ISWAT)
- Restarting our partnership with USAF/Space Force

Open Science in Modeling

Open use of models

Open use of simulation results

Open validation and R2O2R

Open development & open source

Open collaborations

- ✓ CCMC is enabling open use of models and model outputs for over 20 years
- ✓ 5+ years to build trust. Now modelers are proposing implementation at CCMC
- ✓ Leadership in community-wide validation projects

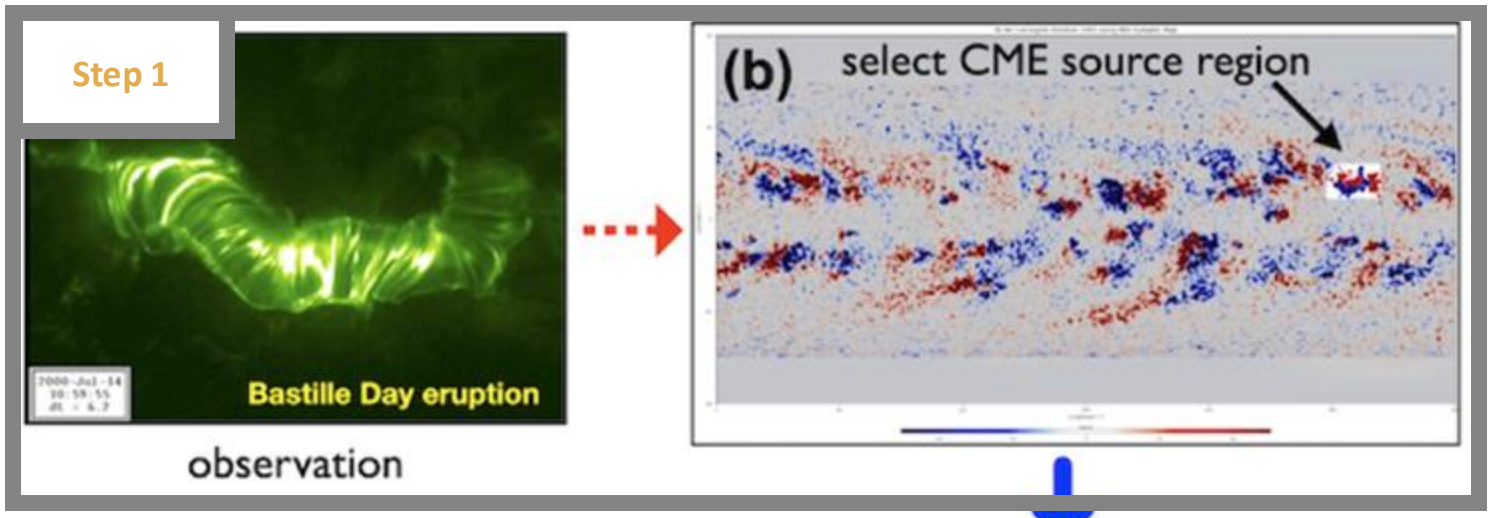
- ✓ CCMC-developed software are **NASA open source**
- ✓ Distribution of source code: with **explicit approval** from developers

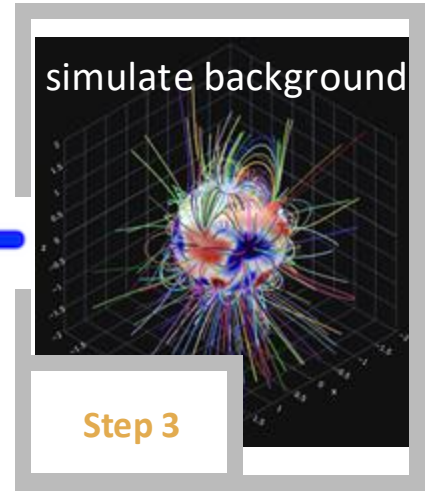
- ✓ CCMC maintains **shared environments** on AWS cloud and NASA HECC for **collaborative on-boarding and improvements**
- ✓ Ready to support **community modeling** to maximize return on an open source policy

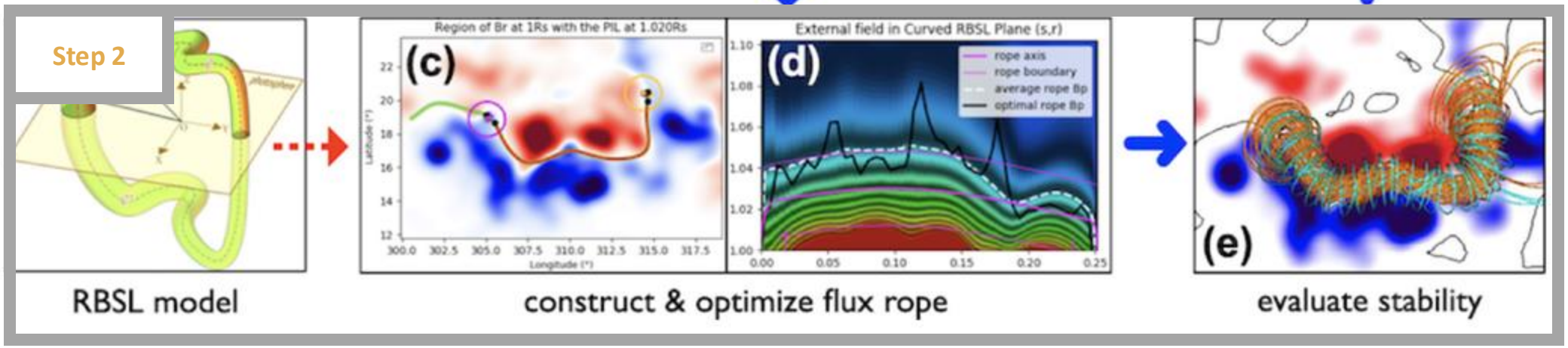
Open collaboration is a key

TRUST ***INFRASTRUCTURE*** ***EXCITEMENT***

How To Create Your Solar Storm With CORHEL-CME? (Predictive Science)



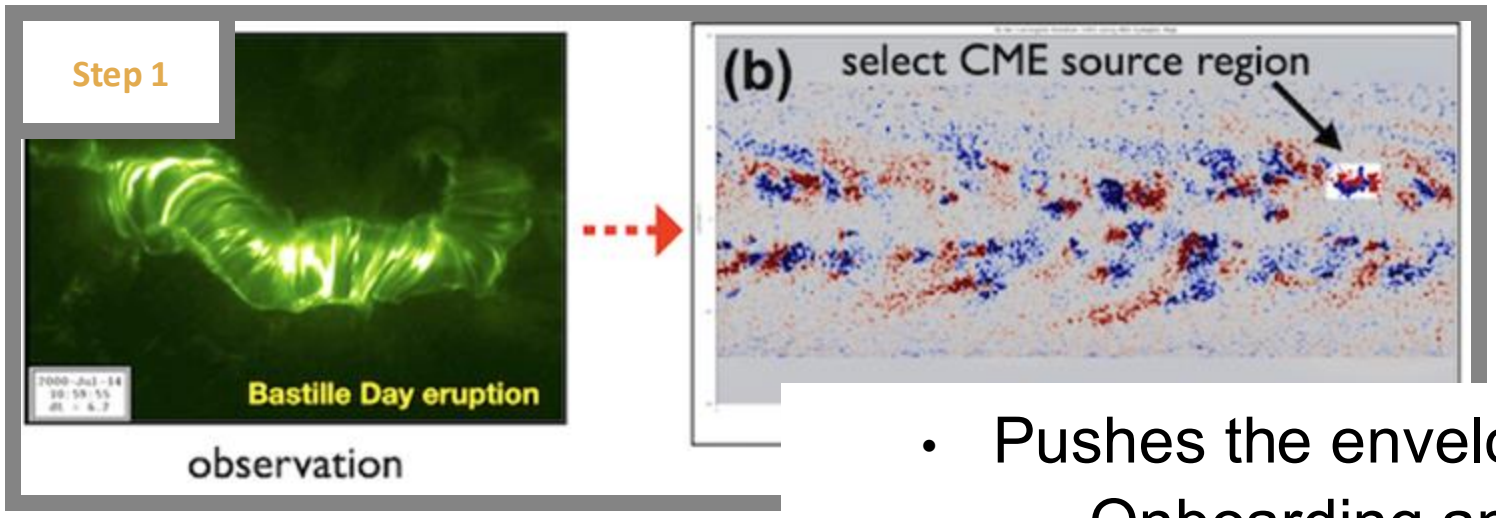


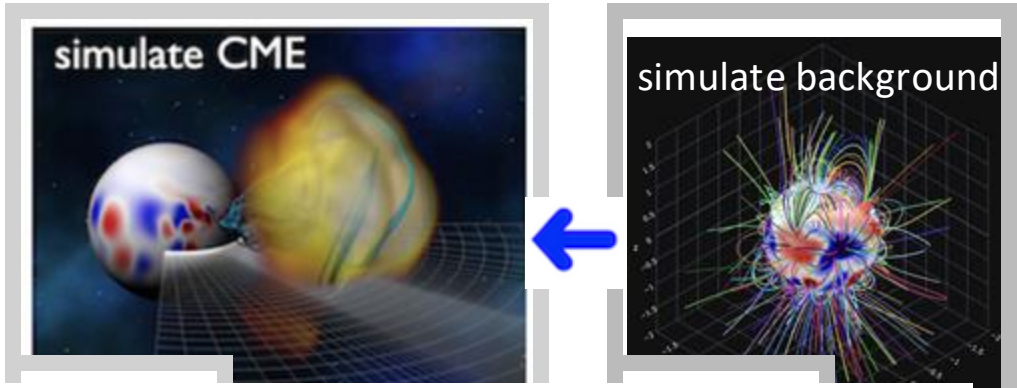


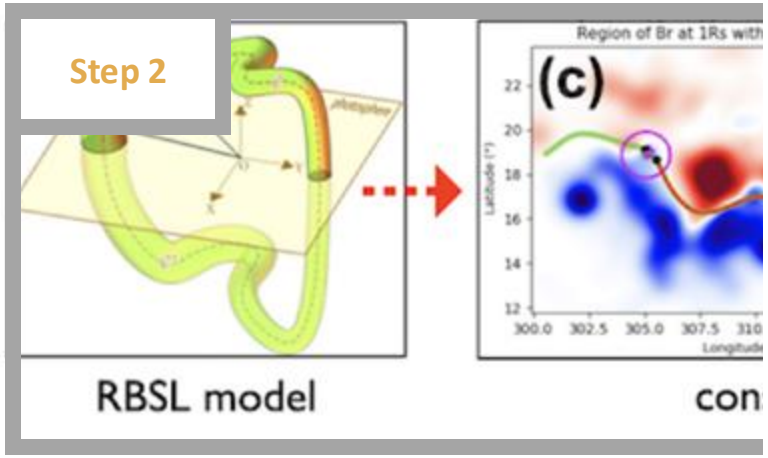
First LWS Strategic Capability Deliverable

Credit: Adapted from Linker et al., 2023 - arXiv:2311.03596

How To Create Your Solar Storm With CORHEL-CME? (Predictive Science)

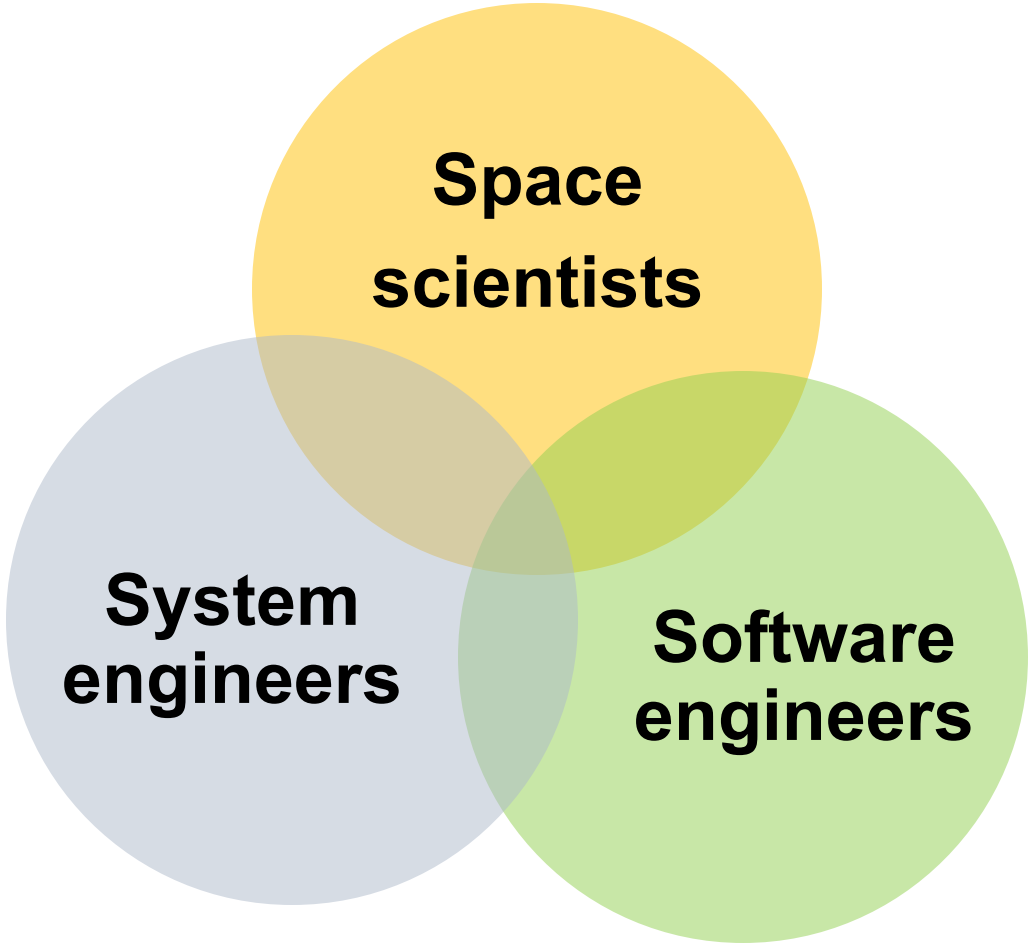






- Pushes the envelope in terms of the complexities of
  - Onboarding and CCMC/Developer interaction
  - Supporting complex run sequences
  - GPU use
  - Cloud use
  - User interface design
  - User training and interaction with staff scientists
  - Result post-processing and delivery

CCMC Team



30+ CCMC staff members

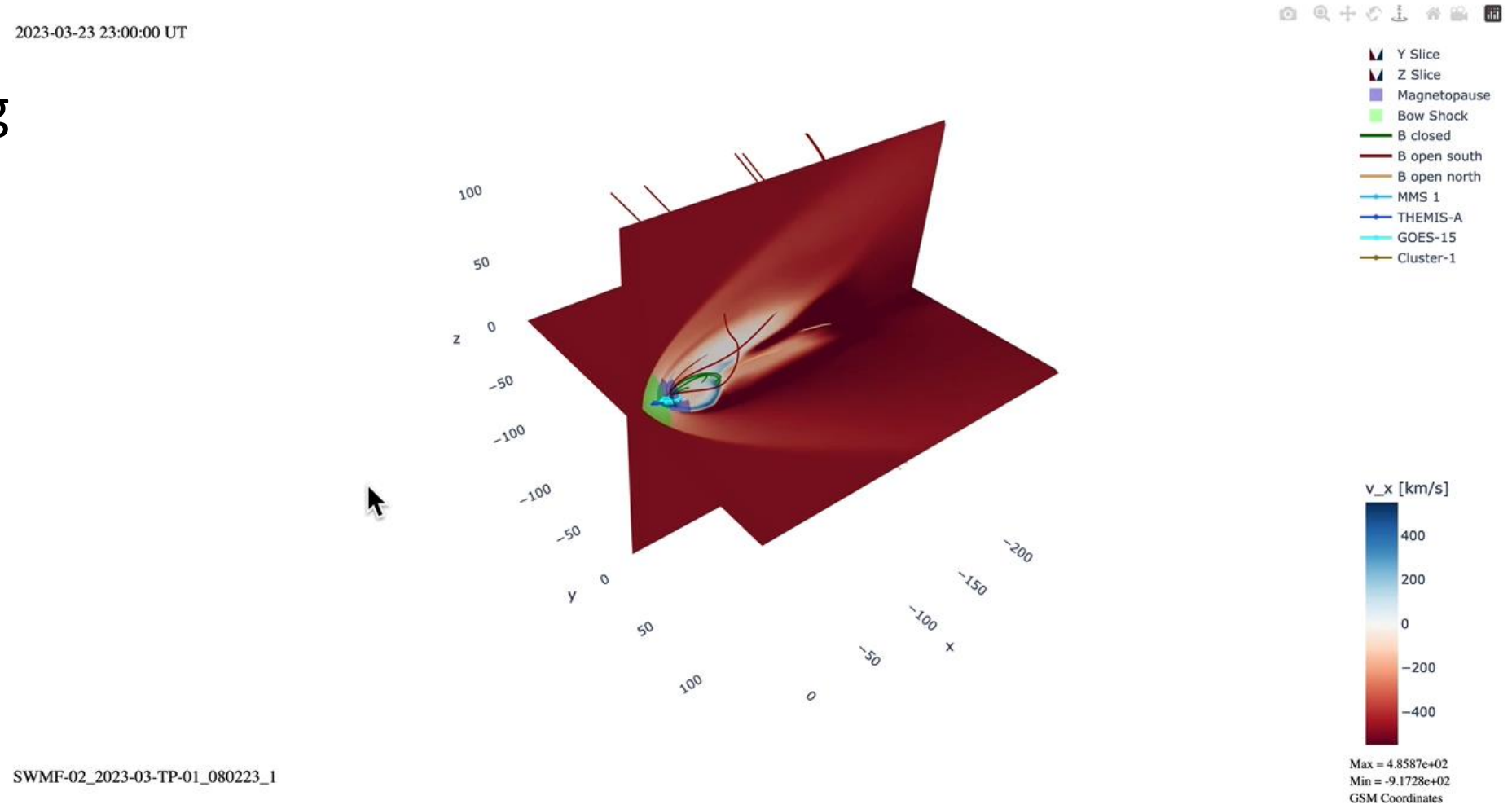
Working together as one

Extended team:

Model developers, CCMC collaborators at GSFC, JSC/SRAG, MSFC, LaRC

Recent Upgrades to 3D Visualization

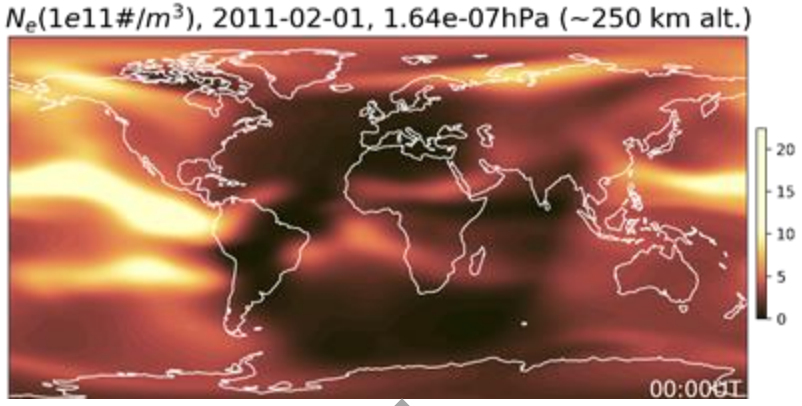
- Interactive viewing
  - rotate, pan, zoom
- Extracted surfaces
  - bow shock, magnetopause
- Magnetic field line tracing
  - last closed
- Satellite position overlays



Opportunity for Community Modeling

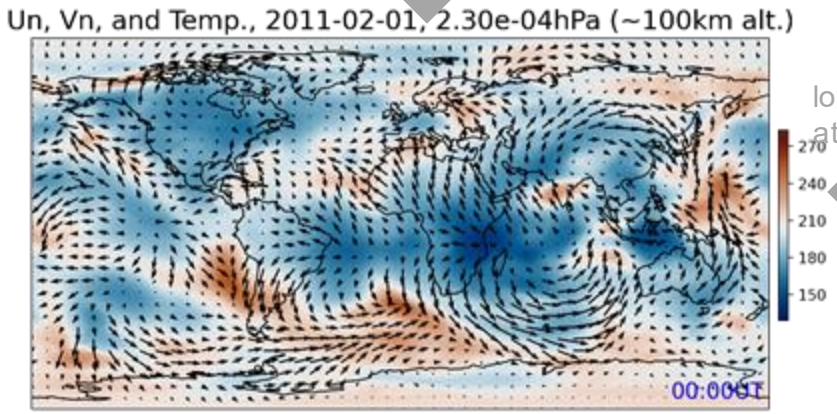
Develop New Capabilities and Demonstrate Transformative Operational Potential

WACCM-X

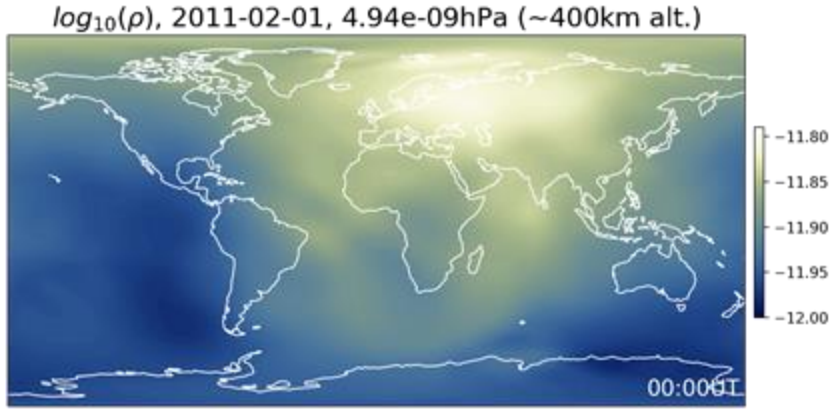


dynamics-chemistry coupling

ion-neutral coupling



lower-upper atm. coupling



- Whole Atmosphere Community Climate Model –eXtended
- Implemented at CCMC
- Model domain from surface to 500 and 700 km
- Couples to ocean, sea ice, and land components, enabling studies of thermospheric/ionospheric coupling with the lower atmosphere
- Coupled with SAMI3