

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

M. Kuznetsova & CCMC Team

October 17, 2024

Software



Chiu Wiegand (Lead)



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Anders Lundkvist

Simulation services software



Scoreboard - world-wide ensemble forecasts







Visualization and analysis software

CCMC-Vis





Scientists

Domain experts Model POCs Missions Support Validation



Peter Macneice (Lead)





Leila Mays (Lead)



Claudio Corti



Chris Light (postdoc)



Martin Reiss

Helio



Sandro Taktakishvili



Christine Verbeke (50%)







Lutz Rastaetter

Kinetic



Liutauras Rusaitis (postdoc)



Joshua Pettit (postdoc)





Jia Yue (ITM Lead)

Ionosphere **Thermosphere**





Jack Wang

Min-Yang Chou



Reza Janalizadeh Choobbasti



Yuta Hozumi (postdoc)



Yihua Zheng (Lead)

Near Earth

Radiation & Plasma

Environment

Sandeep Kumar (postdoc)







Bob Robinson

Infrastructure: Prerequisite for all Functions

Infrastructure team





Tina Tsui





Edgar Russell



Poly Manessis

Matt Lesko



Damian Barrous-Dume

Phil Poole



- Design and maintain CCMC **hybrid infrastructure** (on-prem, CCMC Cloud and NASA/HECC)
- Explore and implement new technologies and innovative system engineering solutions
- Respond to NASA security requirements
- Enhance operations with **Next Gen storage systems**, virtual machines and file transfer pipeline innovation



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** AMOS ASSA ASAP NLFFF GSU All Clear **WSA** FISM2 SNB3GEO MAGIC GCR BON NOVICE NAIRAS CARI-7

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

DIPS

Heliosphere

MAGE/GAMERA+REMIX+RCM LFM-MIX GIC RCI **OpenGGCM+CTIM** VERB SWMF+RCM+deltaB AMPS SWMF+RCM Fok.CIMI SWMF+RCM+RBE SWMF+RCM+CRCM Li's Rad Belt LFM-MIX-TIEGCM PINE LANLstar **WINDMI** Tsyganenko **IGRF** Weigel-deltaB **PS VP** AACGM IMPTAM Apex AMPS **GUMICS RAM-SCB** SHELLS ORIENT VPIC PAMHD **PIC-Hesse Magnetosphere Local Physics**

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

WAM-IPE

lonosphere/ Inner Magnetosphere Thermosphere

WACCM-X

BSPM

UPOS RB

AE-8/AP-8

AE-9/AP-9

Corona

ORDINATED M

CCMC Model Catalog includes links to public repositories

<u>SWMF</u>

Space Weather Modeling Framework - coupled runs u components

Public Repository

ໍ່ Public Repository

Version: 2023

TIE-GCM

Version: 2.0

WACCMX

Version: 2.2

Status: Production

Runs-on-Request

Ionosphere Extension

Runs-on-Request

Status: Production

Status: Production

→ Runs-on-Request 🌮 Public Repository

Continuous/RT Run (ISWA data tree)

J	Ambient Solar Wind
	Atmosphere Expansion
	Bow-shock
	Bursty Bulk Flows
	Coronal Holes
	Coronal Mass Ejection Arrival

Phenomena

Thermosphere Ionosphere Electrodynamics General Circulatio EUHFORIA Heliosphere

EUropean Heliospheric FORecasting Information Asset He (CME)

tatuses

 \checkmark

Production

Result Only

Source Only

Onboarding

Retired

Status: Result Only

MLSO_K-Cor_CMEs

MLSO K-Cor Automated CME Catalog

Whole Atmosphere Community Climate Model With Thermosp Version: 1.0

Status: Result Only

Continuous/RT Run (ISWA data tree)

Continuous/RT Run (SEP Scoreboard Intensity)

🗘 Continuous/RT Run (SEP Scoreboard Probability)

Search by ...



REAL PROFILE

Open Science – linking CCMC services to publications



- List of publications mentioning CCMC services (Runs on Request, Real Time runs/iSWA)
- We are creating database linking the list to simulation runs using CCMC models
- We sort the publications by model domain, simulation type, time period, phenomena
- Work in Progress (so far):

	SH	GM	ITM	Total
# of Papers Published	50	75	57	182
# of Runs	338	339	546	1,223

Input from users needed

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)



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





Major Model Upgrades



Ambient Wind

- WSA
 - Update to V6.1
 - Forecast dashboard web application
- GAMERA-Helio now available through RoR
- ENLIL version update

Flux-rope CMEs

- SWMF AWSoM-R LWS strategic capability deliverable
- CORHEL-CME LWS strategic capability deliverable

SEPs

- SWMF MFLAMPA SEP shock acceleration and transport
- iPATH real-time runs
- **SEPMOD** RoR and real-time runs



- Erupting flux ropes
- Heating mechanisms
- SEP transport and fluxes

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



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

Community Coordinated Modeling Center

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

Coupled Geospace System of Systems

(multiple domains with different spatial scales and underlying physical phenomena)



Physics-based modeling approach

- to understand structure and dynamics of geospace system and its response to solar wind drivers
- model ground magnetic perturbations dB/dt (driving GICs)
- put observations into global context

Implementation of inner magnetosphere (IM) is critical for geomagnetic environment modeling.

Global geospace models at CCMC with IM=RCM (Rice Convection Model)

- SWMF/Geospace
- OpenGGCM
- MAGE/Geospace

SWMF/Geospace upgrade and new interface



The latest SWMF/Geospace implementation for Runs-on-request (V2023) offers **preset** and **custom** simulation settings

Preset options include:

- simulation settings similar to what is utilized in operations at NOAA/SWPC;
- high resolution settings tailored for geomagnetic storm studies

Generate **runs series** for popular phenomena (e.g., geomagnetic storms). CCMC is executing run series with pre-set simulation setting for over 150 **time periods** (starting with recent storms):

https://kauai.ccmc.gsfc.nasa.gov/CMR/TimeInterval/viewAllTI



Global dynamics (Dst) and boundary locations (magnetopause stand off distance) during storms are well reproduced. Mesoscale processes are not well modeled or understood. Missing physics.

07/16/2017 Time = 07:00:00 UT y= $0.00R_{\rm E}$



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



Whole Atmosphere Community Climate Model – eXtended (WACCM-X), first whole atmosphere model at CCMC

15

 $N_e(1e11\#/m^3)$, 2011-02-01, 1.64e-07hPa (~250 km alt.)



dynamics-chemistry coupling



- 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

ion-neutral coupling



WAM-IPE Implemented at CCMC for Runs-on-Request



- 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)
- Caveat: In CCMC RoR setting, WAM-IPE is running without data assimilation utilized in the *operational WAM-IPE Forecast System (WFS)*.
- Next steps: work with SWORD SWxC and community on further model improvement
- Opportunities for improvements: add polar electric field models, and middle atmosphere nudging

CCMC is Moving Beyond Single-Fluid MHD

- Hybrid and particle-in-cell (PIC) approaches enable addressing problems such as
 - ✓ Reconnection
 - \checkmark 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*]

Kinetic modeling helps us understand the electron physics



Electron-scale reconnection structures are seen in MMS data and kinetic simulations

Origin of crescent-shaped electron velocity distribution functions





Velocity Distribution Functions for Local Physics





Region of Reconnection

Reconnection site can be inferred using the shape of the velocity distribution function

Lutz Rastaetter, Maria M. Kuznetsova

Velocity Distribution Functions for Local Physics (Future)







Recent Upgrades to 3D Visualization

2023-03-23 23:00:00 UT

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



Max = 4.8587e+02 Min = -9.1728e+02 GSM Coordinates

SWMF-02_2023-03-TP-01_080223_1



Interactive Space Weather Analysis (ISWA) System

https://ccmc.gsfc.nasa.gov/tools/iSWA/





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ISWA HAPI Timeline Builder

ISWA Super Timeline

		🖃 🗁 SWMF	🖃 🛅 Solar Particle and Electron Flux (5-minute)
		mp_standoff_noon_lt	E P1
		geosynchronus_orbit	E P5
		• SWMF2008	P10
		🛨 🚞 SWMF2008atGOES13	F P30
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SWMF2011 RT Runs	ACE RT Data	TGSM	🛨 🛄 He
SWMF2023 KT Runs Maanetopause Standoff Distance	SWPC RT Solar Wind Data		🗄 🛄 Hn
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Cpcps: ionosphere cross polar-cap electric potential differer KB index	Geomagnetic Components and Total Field (I-minute)	🔹 🚞 DSCOVR	
E AE index	Solar Particle and Electron Flux (5-minute)	GOES-P	
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OpenSpace Visualization Platform

NSF

A tool to visualize everything in the universe.









Assets and Services



- 30+ CCMC staff members: **domain experts, software developers, system engineers** working together. Trusted working relations with model developers.
- Simulation services: Runs-on-Request, Continuous runs, Instant Runs.
- Tools for space weather monitoring, analysis and forecasting, e.g. ISWA, DONKI.
- Tools for metrics and validation, model-data and multi-model comparisons. Evaluation of science quality. Demonstration of operational potential:

CAMEL (historic time periods), **Scoreboards** (pre-event ensemble forecasts)

- One-NASA Space Weather: partnerships with JCS/SRAG, MSFC, LaRC
- Expanding partnership with NOAA/SWPC
- Partnership with international community through ISWAT (enable, support, facilitate)
- New technologies and innovative solutions:
 - Shared collaborative environments on the AWS (CCMC Cloud)
 - Containers, continuous integration and delivery, automatic fail-over
 - State-of-the-art data assimilation tools
 - Utilization of GPU

