Open Science Practices at the Community Coordinated Modeling Center

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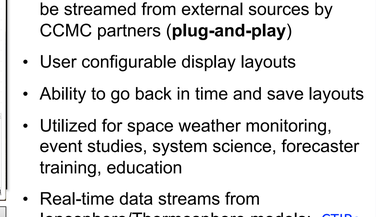
http://ccmc.gsfc.nasa.gov

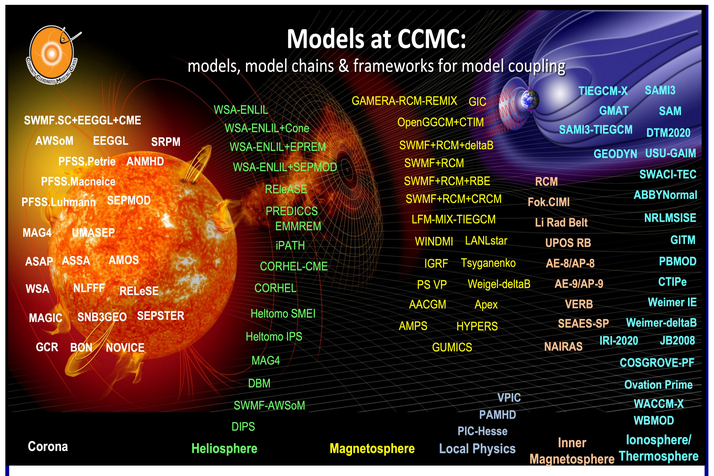
Abstract

Open Science is defined as “the principle and practice of making research products and processes available to all, while respecting diverse cultures, maintaining security and privacy, and fostering collaborations, reproducibility, and equity” by Federal Agencies. The CCMC has been practicing open science based on FAIR (Findable, Accessible, Interoperable and Reusable) principle by providing access to the state-of - the art space science and space weather models to users around the world through various simulation services such as Runs-on-Request, Instant Runs, Real time runs on iSWA system. The CCMC also provides a wide range of tools and framework to help users easily utilize modeled data. One of the tools is the official NASA open-sourced software called Kamodo. Kamodo allows users to work with complex space weather models and data with little or no coding experience. Additionally, to support transparent model validation efforts, the CCMC is providing an integrated and flexible framework called CAMEL. CAMEL allows users to seamlessly compare model outputs with observational data sets. Currently, we are working on a user-friendly database of the papers and research that used CCMC services, so that the future users will have open access to previously performed research by other users and its details. In this presentation, we will show the open tools and resources provided by the CCMC. Furthermore, we will share our new efforts to support open data and open science results.

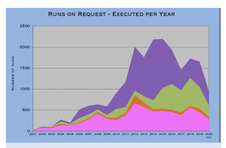
CCMC

- provides the scientific community with access to modern space research models
- tests and evaluates models
- supports transition of advances in research to space weather operations
- supports space science education





Simulation Services: Runs on Request (RoR)

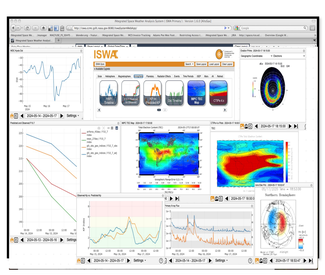


30K runs archive
Over 2,000 runs per year
400 unique users per year

CCMC Signature Service

- Permits scientists to utilize state-of-the-art models without barriers
- Enables model validations by the entire community
- Run databases can be utilized for statistical analysis and ML projects

Integrated Space Weather Analysis System ISWA



http://ccmc.gsfc.nasa.gov/ISWA

- Ingest observational and simulated **real-time data streams**
- Simulated data and widgets/cygnets can be streamed from external sources by CCMC partners (**plug-and-play**)
- User configurable display layouts
- Ability to go back in time and save layouts
- Utilized for space weather monitoring, event studies, system science, forecaster training, education
- Real-time data streams from Ionosphere/Thermosphere models: CTIPe 4.1, Ovation-Prime 2.3, Weimer 2005

Models recently added to RoR services:

- Multiscale Atmosphere Geospace Environment (MAGE) model suite version 0.75 (April 2024): a comprehensive geospace modeling framework that includes the coupled GAMERA magnetosphere, RCM ring current and ReMIX ionosphere electrostatics solver.
- Horizontal Wind Model 14 (March 2024): available to the community through RoR service. The ROR option of requesting a HWM14 model run allows users to request a longer time period compared to the Instant-Run (IR) option of the same model.

Ionosphere-Thermosphere (IT) Models available at CCMC

Runs on Request

Empirical Models

Domain	Model	Full Name: Developers
Ionosphere	*IRI (v2007, 2012, 2016, 2020)	The International Reference Ionosphere: D. Bilitza, NASA/GSFC
Thermosphere	*DTM (v2013, 2020)	The Drag Temperature Model: S. Bruinsma, CNES
	*NRLMSIS (v00, 2.0)	NRL Mass Spectrometer and Incoherent Scatter model: J. Emmert
	*JB2008	The Jacchia-Bowman 2008: W. K. Tobiska
	*HWM14 (v2014)	Horizontal Wind Model 2014: D. Drob, NRL
High-latitude Electrodynamics	Weimer2005	D. R. Weimer, VT
	*Ovation Prime (v2.3)	P. Newell, JHU APL
	Cosgrove-PF (v2.0)	Cosgrove Poynting Flux: R. B. Cosgrove, CGS, SRI Int.
Plasmasphere	BSPM (v2021)	Belgian Space Weather Integrated Forecasting Framework (SWIFF) Plasmasphere Model: Viviane Pierrard, Royal Belgian Institute for Space Aeronomy

Physics-based Models

Domain	Model	Full Name: Developers
Ionosphere	SAMI3 (v3.22)	Sami3 is Also a Model of the Ionosphere: J. Huba et al., NRL
	SAMI3 w/ HWM14/NRLMSIS	
	SAMI3 w/ TIE-GCM	
	SAMI3 w/ ICON/TIE-GCM	
Ionosphere/ Thermosphere	TIE-GCM (*v2.0, 2.5)	Thermosphere Ionosphere Electrodynamics General Circulation Model: W. Wang & M. Wiltberger, HAO, NCAR
	*GITM (v21.11)	Global Ionosphere Thermosphere Model: A. J. Ridley et al., UM
	CTIPe (v4.1)	Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics model: T. Fuller-Rowell & M. Codrescu, NOAA SEC
Scintillation	PBMOD (v6.3)	Physics Based MODels: J. Retterer, BC
Whole Atmosphere	*WACCM-X (v2.2)	Whole Atmosphere Community Climate Model With Thermosphere and Ionosphere Extension: Han-Li Liu, NCAR/HAO

Assimilative Mapping of Geospace Observations (AMGeO) will be available soon

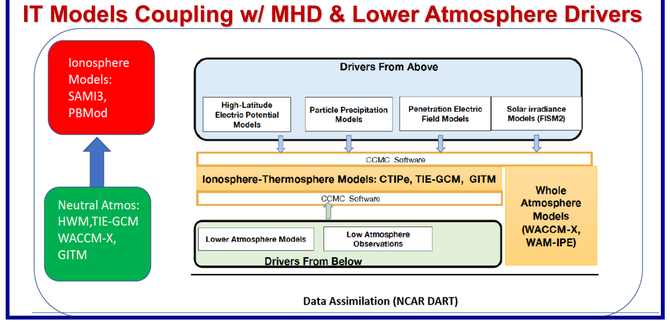
*** Ionosphere-Thermosphere models for which the source code is available to the public**

Instant Runs

Domain	Model	Full Name: Developers
Ionosphere	*IRI (v2007, 2012, 2016, 2020)	The International Reference Ionosphere: D. Bilitza, NASA/GSFC
Thermosphere	*NRLMSIS (v00, 2.0)	NRL Mass Spectrometer and Incoherent Scatter model: J. Emmert
	*HWM14 (v2014)	Horizontal Wind Model 2014: D. Drob, NRL
High-latitude Electrodynamics	Weimer2005	D. R. Weimer, VT
	*SuperDARN Convection Models (v4.3.1)	Super Dual Auroral Radar Network Convection Model: Evan G Thomas, Dartmouth College

WBMOD ionospheric scintillation model will be available soon

IT Models Coupling w/ MHD & Lower Atmosphere Drivers



CCMC Kamodo Analysis Suite

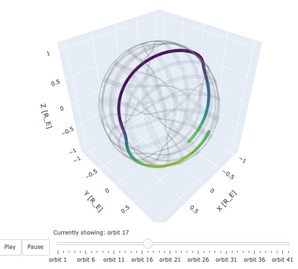
(https://ccmc.gsfc.nasa.gov/tools/kamodo/#public-code-repository)

Kamodo

- An open-source software developed by the CCMC to specifically address the complex problem of simplifying access to and utilization of the Heliophysics model data hosted at the CCMC.
- Includes model output readers and interpolation codes, unit conversion
- Handles custom data formats, grids, and interpolators ‘**behind the scenes**’
- Includes fly-through simulation outputs
- Enables utilization of simulation outputs as a virtual reality for mission planning
- Facilitates interfacing with observational data centers
- Operates with popular Python packages
- Supporting DTM, CTIPe, GITM, IRI, OpenGGCM, TIE-GCM, WACCM-X, SWMF in Jupyter Notebook
- NASA open-source software
- **Public Code Repository**
  Kamodo-Core Repo: https://github.com/nasa/Kamodo-core
  Kamodo Readers Repo: https://github.com/nasa/Kamodo
  All are welcome to contribute to the Kamodo open source project
- Ringuette, R., De Zeeuw, D., Rastaetter, L., Pembroke, A., Gerland, O., & Garcia-Sage, K. (2022). Kamodo's model-agnostic satellite flythrough: Lowering the utilization barrier for heliophysics model outputs. Frontiers in Astronomy and Space Sciences, 9, 1005977. https://doi.org/10.3389/fspas.2022.1005977
- Ringuette, R., L. Rastaetter, D. De Zeeuw, A. Pembroke, and O. Gerland (2023). Kamodo: Simplifying model data access and utilization. Adv. Space. Res. Accepted. https://doi.org/10.1016/j.asr.2023.03.033

```
var = 'rho' # variable name
SatPlot4D(var, cdf_dict['utc_time']['data'], cdf_dict['c1']['data'],
          cdf_dict['c2']['data'], cdf_dict['c3']['data'],
          cdf_dict[var]['data'], cdf_dict[var]['units'],
          'GSE', 'sph', 'GSE', 'orbit8', 'CTIPe', type = '3D',
          body = 'none', htmlfile = 'Figure17.html')
```

Satellite extraction from model: CTIPe
GSE coordinates



Neutral density along a synthetic satellite trajectory from the CTIPe model run (from *Ringuette et al., 2023*)

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

- The CCMC has been leading model-data comparison since 2008 as an unbiased evaluator. To meet the needs of the community worldwide, the CCMC developed and is hosting the CAMEL framework to support model-data comparisons more effectively and efficiently.
- The CAMEL framework utilizes:
  - CCMC Metadata Registry (CMR) for metadata of CCMC models, model runs, and numerical and nonnumerical (e.g., image) outputs.
  - Runs-on-Request (RoR) system
  - Postprocessing tools
- The CAMEL front end interactive visualization tool allows users to plot model outputs and observation data sets together while providing options to calculate various skill scores from our library of skill scores.
- The CAMEL framework provides an Application Programming Interface (API) allowing users to download data sets/output available on the CAMEL backend database into their own environment for further analysis.
- The CAMEL validation skill scores library is an official NASA open-source project (https://github.com/nasa/camel)
- Rastätter, L., Wiegand, C., Mullinix, R. E., & MacNeice, P. J. (2019). Comprehensive Assessment of Models and Events Using Library Tools (CAMEL) framework: Time series comparisons. Space Weather, 17, 845–860. https://doi.org/10.1029/2018SW002043

Time Period (TP) Database: linking storm events to model outputs

- TP database: systematically define geomagnetic storm ID (TPID) by the time of Dst min.
- Perform model simulations during the selected storm TPs using the CCMC RoR system (DTM, NRLMSIS, JB2008, CTIPe, WACCM-X, and TIE-GCM w/ several driver settings)
- All model simulation outputs are publicly available on the CCMC TP database (https://Kauai.ccmc.gsfc.nasa.gov/CMR/Timeinterval/viewAllTI)

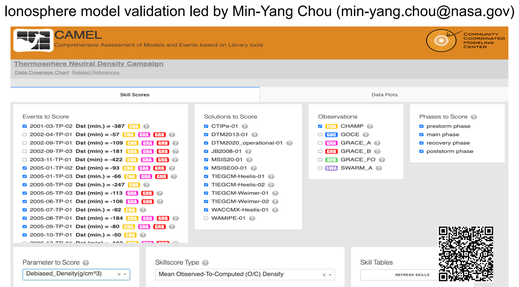
TPID	StartTime	EndTime	Max Kp	Min Dst	GM Run Series	ITM Run Series
2001-03-TP-02	2001-03-29T00:00:00Z	2001-04-04T00:00:00Z	8.667	-387.0	• SWMF-01_2001-03-TP-02_080623_2	• JB2008-01_2001-03-TP-02_030324_IT_1 • DTM2013-01_2001-03-TP-02_030324_IT_1 • DTM2020-01_2001-03-TP-02_030324_IT_1 • CTIPe-01_2001-03-TP-02_030324_IT_1 • TIEGCM-Weimer-01_2001-03-TP-02_150224_IT_1 • WACCM-X-Heelis-01_2001-03-TP-02_030324_IT_1 • TIEGCM-Heelis-01_2001-03-TP-02_030324_IT_1 • TIEGCM-Heelis-02_2001-03-TP-02_030324_IT_1 • TIEGCM-Weimer-02_2001-03-TP-02_021424_IT_1
2001-04-TP-01	2001-04-11T00:00:00Z	2001-04-14T00:00:00Z	8.333	-271.0		• DTM2020-01_2001-04-TP-01_021824_IT_1 • DTM2013-01_2001-04-TP-01_021824_IT_1 • JB2008-01_2001-04-TP-01_021824_IT_1 • TIEGCM-Heelis-01_2001-04-TP-01_023424_IT_1 • TIEGCM-Weimer-01_2001-04-TP-01_021824_IT_1 • WACCM-X-Heelis-01_2001-04-TP-01_021824_IT_1 • CTIPe-01_2001-04-TP-01_021824_IT_1 • TIEGCM-Heelis-02_2001-04-TP-01_021824_IT_1 • TIEGCM-Weimer-02_2001-04-TP-01_021824_IT_1

CCMC TP database

Any modelers can submit their model outputs to evaluate model performance.

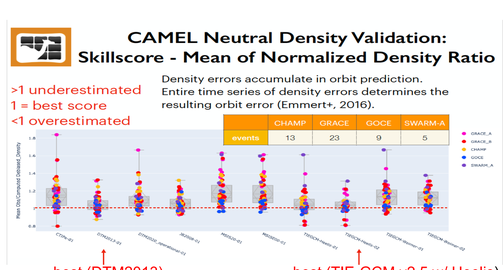
ITM model validation projects built upon CAMEL framework:

Neutral density validation led by Jack Wang (jack.c.wang@nasa.gov),
Ionosphere model validation led by Min-Yang Chou (min-yang.chou@nasa.gov)



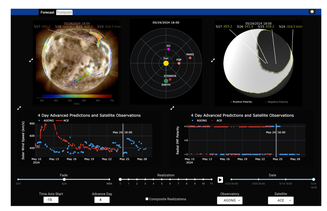
(https://webserver1.ccmc.gsfc.nasa.gov/camel/NeutralDensity/)

** Data used in the validation projects are available on the camel-data public git repository* (https://git.smce.nasa.gov/ccmc-share/camel-data)



CCMC is also

- **Hosting Simulation Results Provided by Community:**
  - Users can use and visualize the provided simulation results via the CCMC visualization services
  - e.g., WAM-IPE (Whole Atmosphere Model and Ionosphere Plasmasphere Electrodynamics) model outputs provided by NOAA SWPC
- **Hosting Community Developed Tools: e.g., WSA Dashboard**
  https://ccmc.gsfc.nasa.gov/wsa-dashboard/



: a tool for visualizing predictions of the corona and solar wind produced by the Wang-Sheeley-Arge model

- **Providing a List of Executable Papers**
  - CCMC recognizes the importance and benefit of using executable papers as one of the potential tools to increase reproducibility and transparency in the heliophysics community.
  - e.g., Chou, M.-Y et al. (2023). Validation of ionospheric modeled TEC in the equatorial ionosphere during the 2013 March and 2021 November geomagnetic storms. Space Weather, 21, e2023SW003480. https://doi.org/10.1029/2023SW003480 (https://git.smce.nasa.gov/ccmcshare/1010292023sw003480)

CCMC Metadata Registry (CMR)

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

- **Provides a hub for the community to search and obtain model outputs (real-time and historic)**
- CCMC is the first group in the US to apply SPASE (Space Physics Archive Search and Extract) metadata standards on models, simulation runs, and numerical and nonnumerical (e.g., image) outputs.
- Generating model metadata has been added as a part of the CCMC model onboarding process.
- A process for collecting metadata for all Runs on Request has been established.
- Metadata for more than 100 models and model versions are currently stored in the CMR which is being used by the CCMC website model catalog.
- Metadata from about 2,000 Runs on Request from about 50 models are currently available in the CMR.
- Currently, we are working on a user-friendly database of the papers and research that used CCMC services; By linking RoR used in research to the publication, we ensure that future users can openly access previously performed research by other users and its details.