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Academic influence index evaluation report of geographic simulation models (2022)☆

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ABSTRACT

Recent years have witnessed a significant increase in the availability and number of geographic simulation models across various domains, leading to challenges in evaluating their relative value. Traditional model evaluations typically compare simulation results with measured data or other models. This report presents the application of the newly "Model Academic Influence Index (MAI)" method which focuses on evaluating a model's academic contributions. It offers both annual and lifetime index, and reflects the model's major application areas covered. The report evaluates the MAI of 205 models and 22 methods in 2022 from trusted digital repositories and emphasizes the importance of open-source models, providing URLs and licenses. Recognizing the complexity and importance of this task, we invite ongoing discussion and feedback from the modeling community. This report aims to support more informed decision-making in academia and the public and promote the development of a more open and scientific modeling profession and community.

1. Introduction

Recent years have witnessed a significant increase in the availability and number of geographic simulation models across various domains, including earth and environmental science, human and social geography, and related fields (Janssen et al., 2020; Chen et al., 2023). This increase in the number of available models to investigate scientific challenges in these domains leads to the question of how to independently assess the relative value of a model. Current research on the cognition of geographic simulation models is mainly focused on the completeness of model descriptions and comparisons of the use and influence of models. When users must decide which model to use, they may need to rely on evaluations, recommendations, scientific literature, or other metrics (e.g., the number of times a model has been downloaded from a repository). In terms of geographic simulation model evaluation, the primary evaluation approach is to compare the simulation results of a model with measured data or with the simulation results of other models, and evaluations of geographic simulation models are based on statistical indices (e.g., Coupled Model Intercomparison Project (CMIP), and Multi-scale synthesis and Terrestrial Model Intercomparison Project (MsTMIP), among others (Huntzinger et al., 2013; Eyring et al., 2016)). Such intermodal comparisons are extremely valuable. However, we recognize that there are other indicators of the utility and value of a model, beyond its ability to replicate observed data.

This report presents the application of a new classification index, the "model academic influence index (MAI)" method that includes multiple types of indicator data and their relative importance, the duration of model availability, and the application areas covered by the model (Xu et al., 2022). By including these factors, a more comprehensive evaluation of the actual influence of geographic simulation models can be made. This method quantifies the MAI by the summation of five weighted academically relevant indices, including the number of: 1) publications, 2) research grant invention patents, 3) funded research projects, 4) literature citations of publications, and 5) literature citations of patents. The MAI provides an annual index and a lifetime index by controlling the time range of index data. The annual MAI is an indicator of the academic influence of the model for a certain year, while the lifetime MAI quantifies the academic influence of a model since the year it was released. It is worth noting that the year of model release is considered in this report to be the year of the earliest publication of all identified papers, patents, and projects related to a model. The calculation formula of the method can be found at https://geomodeling.njnu.edu.cn/MAI.

While enabling a more objective evaluation, the MAI of geographic simulation models also provides more comprehensive information for researchers, developers, and users. The two most immediate advantages are as follows: For researchers who develop models, they put a lot of effort into building models, the MAI offers a pathway to attain recognition for their work. This acknowledgment serves as a powerful motivator, spurring them to continually refine and improve their models. At the same time, for researchers who use models, especially interdisciplinary researchers, either novices or not, the MAI evaluation of models provides objective criteria for helping to select a model, so it promotes a more informed decision-making process for potentially different model applications.

2. The MAI evaluation results

This report divides geographic simulation models into two categories, namely *models* and *methods*. Geographic simulation models are

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Table 1
Model evaluation list.

Full Name	Abbreviation	Major Application Areas	2022 Score	Lifetime Score	Source Code URL	Open-Source License
Soil and Water Assessment Tool	SWAT	Water Science and Technology; Environmental Engineering; Pollution	4.68	5.38	http://swat.tamu.edu/software/swat-executables/	GPL-3.0
Weather Research and Forecasting Model	WRF	Atmospheric Science; Earth and Planetary Sciences	4.54	5.09	https://github.com/wrf-model/WRF	https://github.com/wrf-model/WRF/blob/master/LICENSE.txt
PHREEQC		Geochemistry and Petrology; Pollution; Environmental Chemistry	4.41	5.29	https://www.usgs.gov/software/phreeqc-version-3	https://water.usgs.gov/software/help/notice/
Community Multiscale Air Quality	CMAQ	Atmospheric Science; Environmental Science	4.37	5.11	https://www.github.com/USEPA/cmaq	MIT
Variable Infiltration Capacity	VIC	Water Science and Technology; Earth and Planetary Sciences	4.23	4.95	https://github.com/UW-Hydro/VIC/	MIT
Community Earth System Model	CESM	Atmospheric Science; Earth and Planetary Sciences	4.20	4.91	https://github.com/escomp/cesm.git	NCSA
Agricultural Production Systems sIMulator	APSIM	Agronomy and Crop Science; Soil Science	4.13	4.88	https://github.com/APSIMInitiative/ApsimX	https://github.com/APSIMInitiative/ApsimX/blob/master/LICENSE.md
Decision Support System for Agrotechnology Transfer	DSSAT Model	Agronomy and Crop Science; Soil Science	4.12	4.81	https://github.com/DSSAT/dssat-csm-os	BSD-3-Clause
Geographical detector		Ecology; Environmental Science; Earth and Planetary Sciences; Management, Monitoring, Policy and Law	4.12	4.40	https://github.com/gsnrguo/QGIS-Geographical-detector	GPL-2.0
CNRM-CM5		Atmospheric Science; Water Science and Technology; Global and Planetary Change; Management, Monitoring, Policy and Law	4.06	4.68	https://github.com/VortexFDC/CS-VortexCloud.CNRM-CM5	Not specified
Global Forecast System	GFS	Atmospheric Science; Earth and Planetary Sciences	4.06	4.82	https://github.com/NOAA-EMC/global-workflow	LGPL-3.0
GFDL-ESM2M		Atmospheric Science; Water Science and Technology; Environmental Engineering; Global and Planetary Change	4.05	4.63		
Storm Water Management Model	SWMM	Water Science and Technology; Environmental Engineering	4.04	4.72	https://github.com/USEPA/Stormwater-Management-Model	Public domain
AquaCrop		Agronomy and Crop Science; Water Science and Technology	4.01	4.59	https://github.com/thomasdkelly/aquacrop	Apache-2.0
Integrated Valuation of Ecosystem Services and Tradeoffs	InVEST	Ecology; Management, Monitoring, Policy and Law; Nature and Landscape Conservation	4.01	4.49	https://github.com/natcap/invest	Apache-2.0
MRI-CGCM3		Atmospheric Science; Water Science and Technology; Global and Planetary Change; Management, Monitoring, Policy and Law	3.95	4.54		
Community Climate System Model	CCSM4	Atmospheric Science; Oceanography; Global and Planetary Change	3.89	4.88	http://www.cesm.ucar.edu/models/ccsm4.0/	Not Specified
Simulating WAves Nearshore	SWAN	Oceanography; Environmental Engineering	3.88	4.73	https://swanmodel.sourceforge.io/download/download.htm	GPL-2.0
Delft3D		Oceanography; Water Science and Technology; Environmental Engineering	3.86	4.67	https://oss.deltares.nl/web/delft3dfm/get-started	AGPL-3.0
Regional Ocean Modeling System	ROMS	Oceanography; Geology	3.82	4.76	https://github.com/kshedstrom/roms	Not specified
Comprehensive Air Quality Model with Extensions	CAMx	Environmental Science; Atmospheric Science	3.82	4.49	https://camx-wp.azurewebsites.net/download/source/	https://camx-wp.azurewebsites.net/Files/LICENSE_v7.20.txt
Hydrologic Engineering Center - River Analysis System	HEC-RAS	Water Science and Technology; Earth and Planetary Sciences	3.79	4.32		
LISFLOOD		Water Science and Technology; Earth and Planetary Sciences	3.76	4.48	https://ec-jrc.github.io/lisflood/	EUPL-1.2
GFDL-ESM2G		Atmospheric Science; Water Science and Technology; Management, Monitoring,	3.73	4.35		

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Table 1 (*continued*)

Full Name	Abbreviation	Major Application Areas	2022 Score	Lifetime Score	Source Code URL	Open-Source License
		Policy and Law; Global and Planetary Change				
Environmental Policy Integrated Climate	EPIC	Agronomy and Crop Science; Soil Science; Environmental Engineering	3.70	4.48	https://epicapex.tamu.edu/epic/	GPL-3.0
WOrld FOod STudies	WOFOST	Agronomy and Crop Science; Soil Science	3.67	4.26	https://CRAN.R-project.org/package=Rwofost	GPL(≥3.0)
Carnegie-Ames-Stanford approach	CASA	Ecology; Earth and Planetary Sciences; Environmental Chemistry; Atmospheric Science; Environmental Science	3.66	4.50	https://github.com/SPass-space/NASA-CASA	Not specified
Urban Growth Model	UGM	Management, Monitoring, Policy and Law; Environmental Science; Nature and Landscape Conservation	3.60	4.36	https://github.com/Rise-group/urban_growth_framework	MIT
Canadian Earth System Model	CanESM	Atmospheric Science; Water Science and Technology; Earth and Planetary Sciences; Management, Monitoring, Policy and Law	3.57	4.06	https://gitlab.com/cccma	GPL-2.0
Hydrologiska Byråns Vattenbalansavdelning	HBV	Water Science and Technology	3.56	4.23	https://github.com/johnrobertcraven/hbv_hydromodel	MIT
CMCC-CMS		Atmospheric Science; Water Science and Technology; Global and Planetary Change	3.56	4.09	https://github.com/provocon/coremedia-build-docker	Apache-2.0
The Hydrologic Engineering Center's-Hydrologic Modeling System	HEC-HMS	Water Science and Technology; Environmental Science	3.54	4.08		
EPANET		Water Science and Technology	3.50	4.34	https://github.com/OpenWaterAnalytics/EPANET	MIT
GEOtop		Geology; Geochemistry and Petrology; Oceanography	3.48	4.60	https://github.com/geotopmodel/geotop	GPL-3.0
Whole Atmosphere Community Climate Model	WACCM	Atmospheric Science; Geophysics	3.48	4.35		
CSIRO-Mk3.6.0		Atmospheric Science; Water Science and Technology; Environmental Engineering	3.46	4.11		
Fire Dynamics Simulator	FDS	Geotechnical Engineering and Engineering Geology; Environmental Engineering	3.45	4.07	https://github.com/firemodels/fds	https://github.com/firemodels/fds/blob/master/LICENSE.md
FGOALS-g2		Atmospheric Science; Global and Planetary Change; Earth and Planetary Sciences	3.42	4.12		
Ecopath with Ecosim	EwE	Ecological Modeling; Oceanography	3.39	4.38	https://github.com/kakearney/ecopathlite-pkg	MIT
Root Zone Water Quality Model	RZWQM	Agronomy and Crop Science; Soil Science	3.38	4.19		
MIKE URBAN		Water Science and Technology; Environmental Engineering	3.34	3.95		
International Reference Ionosphere		Space and Planetary Science; Geophysics	3.34	4.44	https://github.com/rilma/pyIRI2016	MIT
Ball-berry		Atmospheric Science; Agronomy and Crop Science; Forestry	3.31	4.18	https://github.com/USDA-ARS-ACSL/PhotoSynthesisModule	Not Specified
LPJ-GUESS		Global and Planetary Change; Ecology; Earth-Surface Processes; Earth and Planetary Sciences	3.28	4.22	https://github.com/biometry/rLPJGUESS	Not specified
Boreal Ecosystem Productivity Simulator	BEPS	Atmospheric Science; Forestry; Ecology; Earth and Planetary Sciences; Soil Science	3.28	3.94	https://github.com/JChen-UToronto/BEPS_hourly_site	GPL-3.0
Beijing Climate Center Climate System Model	BCC_CSM	Atmospheric Science; Ecology; Water Science and Technology; Environmental Engineering	3.28	3.87		
Princeton Ocean Model	POM	Oceanography; Atmospheric Science	3.28	4.60	https://github.com/MalikJordan/pyPOM1D	BSD-3-Clause
AeoLiS		Space and Planetary Science	3.27	4.13	https://github.com/openearth/aeolis	GPL-2.0
SLEUTH Model		Management, Monitoring, Policy and Law; Environmental Science; Ecology	3.26	4.02	https://github.com/sostenibilidad-unam/sleuth_automation	GPL-3.0
ParFlow		Water Science and Technology	3.26	4.01	https://github.com/parflow/parflow	LGPL-2.1

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Table 1 (*continued*)

Full Name	Abbreviation	Major Application Areas	2022 Score	Lifetime Score	Source Code URL	Open-Source License
International Reference Ionosphere Model	IRI	Space and Planetary Science; Geophysics	3.25	4.13	http://irimodel.org	Not Specified
Distributed Hydrology Soil Vegetation Model	DHSVM	Water Science and Technology; Earth and Planetary Sciences	3.22	4.00	https://github.com/pnnl/DHSVM-PNNL	Not specified
Hadley Centre Global Environment Model	HadGEM	Atmospheric Science; Earth and Planetary Sciences; Environmental Engineering; Water Science and Technology	3.22	3.75		
Mineos		Geophysics; Space and Planetary Science; Plant Science	3.20	4.03	https://github.com/geodynamics/mineos	GPL-2.0
Agricultural Policy/ Environmental eXtender	APEX Model	Water Science and Technology; Agronomy and Crop Science; Environmental Engineering	3.19	3.90	https://github.com/QingyuFeng/GeoAPEXOL	MIT
DRAINMOD		Water Science and Technology; Agronomy and Crop Science	3.19	4.11	https://github.com/d-v-d-k/Set-DrainModeTemp	Not specified
MRI-ESM1		Atmospheric Science; Management, Monitoring, Policy and Law; Oceanography	3.17	3.68		
Sacramento Soil Moisture Accounting Model	SAC-SMA	Water Science and Technology	3.17	4.11	https://github.com/NOAA-OWP/sac-sma	https://github.com/NOAA-OWP/sac-sma/blob/master/LICENSE
Modular Ocean Model	MOM	Oceanography; Atmospheric Science	3.12	4.37	https://github.com/mom-ocean/MOM5	LGPL-3.0
California Puff	CALPUFF	Environmental Science; Waste Management and Disposal	3.12	3.71		
Precipitation-Runoff Modeling System	PRMS	Water Science and Technology	3.10	4.04	https://github.com/nhm-usgs/prms	Not specified
Topography based Hydrological Model	TOPModel	Water Science and Technology; Environmental Engineering	3.10	4.02	https://github.com/ICHydro/topmodel	GPL-2.0
Global Biosphere Management Model	GLOBIOM	Management, Monitoring, Policy and Law; Ecology	3.05	3.58		
LOAD ESTimator	LOADEST	Water Science and Technology; Environmental Engineering; Pollution	3.05	3.92	https://water.usgs.gov/software/loadest/	https://water.usgs.gov/software/help/notice/
Hadley Centre Coupled Model	HadCM	Atmospheric Science; Water Science and Technology; Global and Planetary Change; Oceanography	3.01	4.13		
Thermosphere Ionosphere Electrodynamics General Circulation Model	TIE-GCM	Geophysics; Space and Planetary Science	3.01	4.01	http://www.hao.ucar.edu/modeling/tgcm/download.php	https://www.hao.ucar.edu/modeling/tgcm/doc/userguide/html/_downloads/tiegcmlicense.txt
QUAL2K		Water Science and Technology; Environmental Engineering; Pollution	3.01	3.69	https://github.com/UU-Hydro/DYNQUAL	GPL-3.0
International Geomagnetic Reference Field Model	IGRF	Space and Planetary Science; Geophysics	2.99	3.85	https://github.com/bluegreen-labs/igrf	AGPL-3.0
Model for Energy Supply Strategy Alternatives and their General Environmental Impact	MESSAGE	Management, Monitoring, Policy and Law	2.94	3.96		
Anuga		Environmental Engineering; Water Science and Technology; Atmospheric Science; Environmental Science	2.94	3.39	https://github.com/GeoscienceAustralia/anuga_core	https://github.com/GeoscienceAustralia/anuga_core/blob/main/LICENCE.txt
Integrated Biosphere Simulator	IBIS	Atmospheric Science; Global and Planetary Change; Ecology; Forestry	2.94	3.95	https://doi.org/10.3334/ORNLDAAC/808	Not specified
Simultaneous Heat and Water	SHAW Model	Water Science and Technology; Soil Science; Agronomy and Crop Science	2.93	3.77	https://github.com/adrienne-marshall/shaw	Not specified
SHETRAN		Water Science and Technology; Environmental Engineering	2.92	3.88	https://github.com/nclwater/Shetran-public	GPL-3.0
Penn State Integrated Hydrologic Model	PIHM	Water Science and Technology; Environmental Engineering	2.92	3.57	https://github.com/PSUmodeling/MM-PIHM	MIT
AGricultural Non-Point Source Pollution Model	AGNPS	Water Science and Technology; Agronomy and	2.90	3.75	https://www.ars.usda.gov/southeast-area/oxford-ms/national-sed	https://www.usda.gov/policies-and-links

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Table 1 (*continued*)

Full Name	Abbreviation	Major Application Areas	2022 Score	Lifetime Score	Source Code URL	Open-Source License
		Crop Science; Environmental Engineering			imentation-laboratory/watershed-physical-processes-research/research/agnps/agnps-software-download/	
GLObal Production Efficiency Model	GLO-PEM	Ecology; Earth and Planetary Sciences; Global and Planetary Change; Computers in Earth Sciences; Forestry	2.89	3.79		
The Unstructured Grid Finite Volume Coastal Ocean Model	FVCOM	Oceanography; Atmospheric Science; Water Science and Technology	2.88	3.76	https://github.com/FVCOM-GitHub/fvcom	https://github.com/FVCOM-GitHub/FVCOM/blob/main/LICENSE.md
TURBINS		Pollution; Geology; Waste Management and Disposal; Management, Monitoring, Policy and Law; Environmental Engineering	2.87	3.50	https://github.com/csdms-contrib/turbins	GPL-2.0
Regional Hydro-Ecologic Simulation System	RHESSys	Water Science and Technology; Ecology; Environmental Engineering	2.87	3.58	https://github.com/RHESSys/RHESSys	Not specified
InfoCrop		Agronomy and Crop Science; Soil Science	2.87	3.75		
Parallel Ice Sheet Model	PISM	Earth-Surface Processes; Water Science and Technology	2.86	3.48	https://github.com/pism/pism	GPL-3.0
MODPATH		Water Science and Technology; Environmental Chemistry	2.85	3.95	https://www.usgs.gov/software/modpath-particle-tracking-model-modflow	https://water.usgs.gov/software/help/notice/
SPAtially Referenced Regressions On Watershed attributes	SPARROW	Environmental Engineering; Waste Management and Disposal; Ecology	2.85	3.00	https://github.com/jsta/sparrow_1992-phosphorus	Not specified
pyGIMLi		Geophysics; Water Science and Technology	2.85	3.11	https://github.com/gimli-org/gimli	https://github.com/gimli-org/gimli/blob/master/README.md
The Dynamic Land Ecosystem Model	DLEM	Atmospheric Science; Ecology; Global and Planetary Change; Environmental Chemistry	2.84	3.79		
SNOW-17		Water Science and Technology	2.82	3.70	https://github.com/NOAA-OWP/snow17	https://github.com/NOAA-OWP/snow17/blob/master/LICENSE
GModel		Nature and Landscape Conservation; Management, Monitoring, Policy and Law; Pollution; Agronomy and Crop Science	2.81	3.34	https://github.com/ibaned/gmodel	BSD-3-Clause
CAESAR-Lisflood		Earth-Surface Processes; Environmental Engineering; Water Science and Technology	2.80	3.39	https://sourceforge.net/projects/caesar-lisflood/	GPL-3.0
Horizontal Wind Model	HWM	Space and Planetary Science; Atmospheric Science	2.79	3.82	https://github.com/lgpedersen/hwm14	MIT
NRLMSISE-00 Model		Space and Planetary Science; Atmospheric Science	2.78	3.64	https://github.com/alesmorse/nrlmsise-00	LGPL-3.0
Hogback		Earth-Surface Processes; Geology	2.76	3.85	https://github.com/Glader011235/Hogback/	MIT
UrbanSim		Environmental Science; Ecological Modeling	2.76	3.78	https://github.com/udst/urbansim	BSD-3-Clause
Fully Nonlinear Boussinesq Wave Model	FUNWAVE	Environmental Engineering	2.75	3.14	http://chinacat.coastal.udel.edu/programs/funwave/funwave.html	GPL-3.0
Soil-Plant-Air-Water	SPAW	Agronomy and Crop Science; Water Science and Technology; Soil Science	2.72	3.26		
ETWatch		Water Science and Technology; Earth and Planetary Sciences; Agronomy and Crop Science	2.69	3.43		
AxiSEM		Geophysics; Space and Planetary Science	2.68	3.18	https://github.com/geodynamics/axisem	GPL(≥3.0)
MIT General Circulation Model	MITgcm	Oceanography; Atmospheric Science	2.67	3.87	https://github.com/MITgcm/MITgcm	MIT
Los Alamos sea ice Model	CICE Model	Oceanography; Atmospheric Science; Earth and Planetary Sciences	2.67	3.68	https://www.cesm.ucar.edu/models/cice	Not specified
GFlex		Plant Science; Geophysics; Agronomy and Crop Science; Waste Management and Disposal	2.67	3.07	https://github.com/umn-earth-surface/gFlex	GPL-3.0

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Table 1 (*continued*)

Full Name	Abbreviation	Major Application Areas	2022 Score	Lifetime Score	Source Code URL	Open-Source License
Bedload transport Model	BEDLOAD	Water Science and Technology; Earth-Surface Processes	2.65	2.79	https://github.com/csdms-contrib/midas	Not Specified
Geomorphology-Based Eco-Hydrological Model	GBEHM	Water Science and Technology; Environmental Engineering; Environmental Chemistry	2.63	3.02		
GeoClaw		Earth and Planetary Sciences; Oceanography; Geophysics; Geotechnical Engineering and Engineering Geology	2.57	3.26	https://github.com/clawpack/geoclaw	BSD-3-Clause
Integrated Farm System Model	IFSM	Agronomy and Crop Science; Soil Science	2.56	3.57		
First Institute of Oceanography-Earth System Model	FIO-ESM	Oceanography; Water Science and Technology; Atmospheric Science	2.53	3.12		
System Approach to Land Use Sustainability	SALUS	Agronomy and Crop Science; Soil Science	2.53	3.42		
SPECFEM2D		Geophysics; Geochemistry and Petrology	2.52	3.09	https://github.com/SPECFEM/specfem2d	GPL-3.0
The Wang-Sheeley-Arge	WSA	Space and Planetary Science	2.52	3.72	https://ccmc.gsfc.nasa.gov/models/WSÃv.2.2/	Not specified
River Temperature Model		Water Science and Technology; Environmental Engineering	2.51	3.34	https://github.com/permamodel/River-temp-python	Not specified
Flux-PIHM		Water Science and Technology; Atmospheric Science	2.50	3.12	https://github.com/PSUmodeling/MM-PIHM	MIT
Environment for Geoprocessing Objects	Dinamica EGO	Nature and Landscape Conservation; Management, Monitoring, Policy and Law; Environmental Engineering	2.45	3.06	https://github.com/LucasUfmg/Dinamica-EGO	Not specified
RLS90		Environmental Science	2.44	3.13		
Ground-water and Surface-water FLOW Model	GSFLOW	Water Science and Technology; Environmental Engineering	2.42	3.16	https://www.usgs.gov/software/gsflow-coupled-groundwater-and-surface-water-flow-model	https://water.usgs.gov/software/help/notice/
Ice Sheet System Model	ISSM	Earth and Planetary Sciences; Earth-Surface Processes	2.41	3.31	https://issm.jpl.nasa.gov/download/	https://issm.jpl.nasa.gov/download/
RT-Flux-PIHM		Earth and Planetary Sciences; Water Science and Technology	2.38	2.75	https://github.com/PSUmodeling/BioRT-Flux-PIHM	MIT
BioRT-Flux-PIHM		Earth and Planetary Sciences; Water Science and Technology	2.38	2.75	https://github.com/PSUmodeling/BioRT-Flux-PIHM	MIT
SWAP-EPIC		Agronomy and Crop Science; Water Science and Technology	2.38	3.30		
European community Earth-System Model	EC-EARTH	Atmospheric Science; Environmental Engineering; Oceanography; Ecology	2.37	2.64		
CitcomS		Geophysics; Space and Planetary Science	2.36	3.94	https://github.com/geodynamics/citcoms	GPL-2.0
Symphonie		Oceanography; Atmospheric Science	2.35	3.61	https://github.com/hustvl/Symphonies	MIT
World Induced Technical Change Hybrid Model	WITCH	Management, Monitoring, Policy and Law; Environmental Science	2.35	3.35	https://github.com/witch-team/witchmodel	Apache-2.0
Regional Integrated Environmental Model System	RIEMS	Atmospheric Science; Environmental Science	2.35	3.13		
Sea Level Affecting Marshes Model	SLAMM	Oceanography; Ecology; Management, Monitoring, Policy and Law	2.34	2.45	https://github.com/WarrenPinnacle/SLAMM6.7	CPL-1.0
Cellular Automaton Evolutionary Slope And River Model	Caesar	Earth-Surface Processes; Earth and Planetary Sciences	2.33	3.39		
OlaFlow		Environmental Engineering	2.33	2.63	https://github.com/phicau/olaFlow	GPL-3.0
MT3D-USGS		Water Science and Technology	2.32	2.86	https://github.com/MODFLOW-USGS/mt3d-usgs	Not specified
Global Ionosphere Thermosphere Model	GITM	Space and Planetary Science; Geophysics	2.31	3.61	https://github.com/aaronjridley/GITM	Apache-2.0
ECBILT-CLIO		Global and Planetary Change; Geology	2.30	3.69		
Ecomsed		Oceanography; Geology	2.29	3.48	https://github.com/hongruwang/ECOMSEDV13	Not specified
Steady-State Spectral Wave Model	STWAVE	Environmental Engineering; Water Science and Technology	2.29	3.18	https://github.com/csdms-contrib/turbins	GPL-2.0
Eulerian-Lagrangian CIRCulation	ELCIRC	Oceanography; Geotechnical Engineering and Engineering Geology	2.26	2.89	http://www.stccmop.org/CORIE/modeling/elcirc	Not Specified

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Table 1 (*continued*)

Full Name	Abbreviation	Major Application Areas	2022 Score	Lifetime Score	Source Code URL	Open-Source License
Geophysical Institute Permafrost Laboratory	GIPL	Earth and Planetary Sciences; Atmospheric Science; Oceanography; Water Science and Technology; Soil Science	2.26	2.99	https://github.com/Elchin/GIPL	MIT
Bedrock Fault Scarp		Earth-Surface Processes; Geophysics	2.26	3.49	https://github.com/csdms-contrib/bedrock_fault_scarp	GPL-2.0
PyLith		Geophysics; Geochemistry and Petrology	2.26	3.11	https://github.com/geodynamics/pylith	https://github.com/geodynamics/pylith/blob/main/LICENSE.md
Semi-implicit Eulerian–Lagrangian Finite Element	SELFE	Environmental Engineering; Oceanography	2.25	2.35	http://www.stccmop.org/CORIE/software/selfe/recent.html	GPL-2.0
Potential Field Source Surface Model		Space and Planetary Science	2.19	3.57	https://github.com/dstansby/pfsspy	GPL-3.0
Spatially Explicit Integrated Modeling System	SEIMS	Environmental Engineering	2.18	2.56	https://github.com/lreis2415/SEIMS	GPL-3.0
Ovation Prime		Atmospheric Science	2.17	2.88	https://sourceforge.net/projects/ovation-prime/	Not specified
Tapio-Z decoupling Model		Environmental Engineering; Environmental Chemistry	2.16	2.53		
Plasmasphere Model		Space and Planetary Science; Geophysics	2.16	3.80	https://github.com/NOAA-SWPC/IPE	GPL-3.0
Kudryavtsev Model		Environmental Chemistry; Pollution; Earth-Surface Processes; Global and Planetary Change	2.13	2.96	https://github.com/wk1984/Ku_Model	Not specified
WBMsed		Global and Planetary Change; Earth-Surface Processes; Water Science and Technology; Environmental Chemistry	2.13	2.95	https://github.com/csdms-contrib/wbmsed	GPL-2.0
Model for the Assessment of Greenhouse Gas Induced Climate Change	MAGICC	Management, Monitoring, Policy and Law; Atmospheric Science; Environmental Science	2.13	3.61		
Earth Gravitational Model 1996	EGM96	Computers in Earth Sciences; Geology; Earth and Planetary Sciences	2.12	3.27	https://cddis.nasa.gov/926/egm96/egm96.html	Public domain
HEIFLOW		Water Science and Technology; Earth-Surface Processes	2.09	2.56	https://github.com/DeepHydro/Visual-HEIFLOW	GPL-3.0
Ensemble Framework For Flash Flood Forecasting	EF5	Water Science and Technology	2.09	2.35	https://github.com/HyDROSLab/EF5	Not Specified
Underworld2		Geophysics; Space and Planetary Science	2.07	2.43	https://github.com/underworldcode/underworld2	LGPL-3.0
General Ecosystem Simulator	GUESS	Ecology; Earth and Planetary Sciences; Earth-Surface Processes; Forestry; Atmospheric Science	2.06	3.43		
Hazard United States – Multi-Hazard	HAZUS-MH	Water Science and Technology; Atmospheric Science	2.06	2.57		
Atmosphere-Vegetation Interaction Model	AVIM	Atmospheric Science; Earth and Planetary Sciences	2.05	2.91		
One-Dimensional Transport with Inflow and Storage	OTIS	Water Science and Technology	2.04	3.40	https://water.usgs.gov/software/OTIS	https://water.usgs.gov/software/help/notice/
SPECFEM3D Cartesian		Geophysics	2.04	2.24	https://github.com/SPECFEM/specfem3d	GPL-3.0
CAMS-CSM		Atmospheric Science	2.03	2.71		
CSIRO-Mk3L-1-2		Global and Planetary Change; Oceanography	2.02	2.90	https://github.com/UW-Hydro/RBM	GPL-2.0
Grain Hill	GrainHill	Agronomy and Crop Science	1.99	2.60	https://github.com/gregtucker/grain_hills	Not Specified
Stream avulsion Model		Earth-Surface Processes; Geology	1.97	3.27	https://github.com/KWeatherwalks/AvulsionModel	MIT
MARSSIM		Health, Toxicology and Mutagenesis; Waste Management and Disposal	1.97	2.93	https://github.com/csdms-contrib/marssim	Not specified
Geomorphic Model of Barrier, Estuarine, and Shoreface Translations	GEOMBEST	Oceanography; Earth-Surface Processes	1.95	2.68	https://github.com/csdms-contrib/geombest	Not Specified
Rice Convection Model		Geophysics; Space and Planetary Science	1.94	3.68	https://github.com/SWMFsoftware/RCM2	https://polyformproject.org/licenses/noncommercial/1.0.0/
SPECFEM3D GLOBE		Geophysics	1.94	2.67	https://github.com/SPECFEM/specfem3d_globe	GPL-3.0

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Table 1 (*continued*)

Full Name	Abbreviation	Major Application Areas	2022 Score	Lifetime Score	Source Code URL	Open-Source License
Coupled Magnetosphere Ionosphere Thermosphere Model	CMIT Model	Geophysics	1.94	3.21		
MarshMorpho2D		Water Science and Technology	1.91	2.07	https://github.com/csdms-contrib/MarshMorpho2D	BSD-2-Clause
The Larval TRANSport Lagrangian Model	LTRANS	Oceanography	1.91	2.75	https://github.com/LTRANS/LTRANSv.2b	MIT
The TELEMAC system		Water Science and Technology; Oceanography	1.89	2.98	https://github.com/ogoe/OpenTelemac	GPL-3.0
BurnMan		Geophysics; Space and Planetary Science	1.87	3.12	https://github.com/geodynamics/burnman	GPL-2.0
OceanWaves		Environmental Engineering; Oceanography	1.85	2.78	https://github.com/csdms-contrib/oceanwaves	MIT
Frozen Ground Model		Water Science and Technology; Management, Monitoring, Policy and Law; Atmospheric Science	1.84	2.33		
Open Geospace General Circulation Model	OpenGGCM	Space and Planetary Science	1.80	3.06		
The Jacchia-Bowman 2008 Empirical Thermospheric Density Model		Atmospheric Science	1.78	2.19		
Coastline Evolution Model	CEM	Earth-Surface Processes; Earth and Planetary Sciences; Oceanography	1.76	2.69	https://github.com/csdms-contrib/cem	MIT
Modular Finite-Difference Ground-Water Flow Model	MODFLOW	Water Science and Technology	1.75	2.99	https://github.com/MODFLOW-USGS/modflow6	Public domain
TopoFlow		Water Science and Technology; Earth-Surface Processes; Ecological Modeling	1.75	2.78	https://github.com/peckhams/topoflow36	MIT
Alfven Wave Solar Atmosphere Model	AWSoM_R	Space and Planetary Science	1.72	2.30		
Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model	CTIPe	Atmospheric Science; Space and Planetary Science	1.70	2.79		
SEEP2D		Water Science and Technology; Environmental Engineering; Geotechnical Engineering and Engineering Geology	1.70	2.57		
Parameterized Ionospheric Model	PIM	Earth and Planetary Sciences; Space and Planetary Science	1.68	3.08		
IceFlow		Geology; Earth-Surface Processes	1.64	3.31	https://github.com/awickert/IceFlow	GPL-3.0
Chesapeake Bay Operational Forecast System	CBOFS2	Oceanography; Environmental Engineering	1.64	2.18		
Basin and Landscape Dynamics	Badlands	Earth-Surface Processes	1.59	2.69	https://github.com/badlands-model/badlands	GPL-3.0
DeltaRCM		Earth-Surface Processes; Geophysics	1.58	2.83	https://github.com/DeltaRCM/pyDeltaRCM	MIT
Miami Isopycnic Coordinate Ocean Model	MICOM	Oceanography; Atmospheric Science	1.56	3.92		
HydroTrend		Geology; Oceanography	1.55	3.40	https://github.com/kettner/hydrotrend	MIT
The Drag Temperature Model		Space and Planetary Science	1.51	3.03	https://github.com/swami-h2020-eu/mcm	https://github.com/swami-h2020-eu/mcm/blob/45e2e09b02d1ebdf984ae19e6ef727e9a93c6cfe/LICENSE
KWAVE		Geophysics; Oceanography; Geology	1.51	2.84	https://github.com/ucl-bug/k-wave	LGPL-3.0
Comprehensive Inner-Magnetosphere Ionosphere Model	CIMI	Space and Planetary Science	1.50	2.57		
HiResFlood-UCI		Water Science and Technology	1.46	2.73		
MARM5D		Earth and Planetary Sciences; Geophysics; Earth-Surface Processes	1.45	2.47	https://github.com/csdms-contrib/marm5d	GPL-2.0
Development of a European MultiModel Ensemble system for seasonal to inTERannual prediction	Demeter	Atmospheric Science	1.45	3.64	https://github.com/JGCRI/demeter	https://github.com/JGCRI/demeter/blob/main/LICENSE
Coastal Dune Model		Earth-Surface Processes; Geology	1.42	2.67	https://github.com/csdms-contrib/Coastal-Dune-Model	Not Specified

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Table 1 (*continued*)

Full Name	Abbreviation	Major Application Areas	2022 Score	Lifetime Score	Source Code URL	Open-Source License
QUODDY		Oceanography; Atmospheric Science	1.41	3.44	https://www-nml.dartmouth.edu/Software/quoddy/	Not specified
SImulation COde for POLythermal Ice Sheets	SICOPOLIS	Earth-Surface Processes; Earth and Planetary Sciences	1.40	3.16	https://gitlab.awi.de/sicopolis/sicopolis	GPL-3.0
Routines to Model the ocean carbonate system	Mocsy	Earth and Planetary Sciences; Pollution	1.33	2.05	https://github.com/jamesorr/mocsy	MIT
Gc2d		Geochemistry and Petrology; Geophysics	1.27	2.47	https://github.com/csdms-contrib/gc2d	Apache-2.0
Madingley Model		Ecology	1.25	2.66	https://github.com/SHoeks/MadingleyCPP-openMP	Not specified
Sedflux		Geology; Oceanography	1.25	3.25	https://github.com/mcflugen/sedflux	MIT
SEAM3D		Water Science and Technology	1.22	2.79		
Water Flow Model for Lake Catchment	WATLAC	Water Science and Technology	1.06	2.67		
Relativistic Electron Alert System for Exploration		Atmospheric Science; Geophysics; Forestry; Oceanography	1.06	2.15		
CitcomCU		Geophysics; Space and Planetary Science	1.04	2.90	https://github.com/geodynamics/citcomcu	GPL-2.0
Lithosphere and Mantle Evolution Model	LaMEM	Geophysics	1.04	2.37	https://github.com/UniMainzGeo/LaMEM	MIT
SHIELDOSE		Space and Planetary Science	0.90	2.45	https://essr.esa.int/project/shieldose-2q-software-library-for-calculating-ionising-dose-in-simple-geometries-from-particle-flux-spectra	https://essr.esa.int/license/european-space-agency-community-license-v2-4-weak-copyleft-type-2
AquaTellUs		Geology; Stratigraphy; Environmental Engineering	0.87	1.12	https://github.com/csdms-contrib/aquatellus	Not specified
STVENANT		Environmental Science; Ecology; Earth-Surface Processes	0.65	2.21	https://github.com/csdms-contrib/stvenant	Not Specified
Distributed Routing Rainfall-Runoff Model	DR3M	Water Science and Technology; Environmental Science	0.59	2.24	http://water.usgs.gov/software/DR3M/	Public domain
Earth-Moon-Mars Radiation Environment Module	EMMREM	Atmospheric Science	0.59	2.51		
Fok Ring Current Model	FRC	Geophysics	0.59	1.84		

all tools used to abstract and simplify geographical phenomena, processes, or systems of the real world, but their definitions and differences are as follows:

Models: For the purposes of the MAI, models are defined as complex software frameworks for abstracting and simulating geographic phenomena or processes, usually coupled with many mathematical and physical models. They are designed to synthesize and simulate the interactions of multiple factors, to more realistically reflect the dynamics of geographic phenomena.

Methods: For the purposes of the MAI, methods are viewed as specific techniques or steps used to implement a geographic simulation. In contrast to models, methods are usually simpler and may consist of a few theoretical formulas, simple tools, or data processing methods.

In total, this report evaluates the MAI of 205 models and 22 methods and presents them individually. These models and methods are elected from the CoMSES trusted digital repositories, including CSDMS, OpenGMS, CIG. We present the MAI for these models and methods in Table 1 and Table 2 below. The index data used to calculate the MAI in this report are up to December 31, 2022. Note that these MAI scores do not reflect the suitability of the model for any particular purpose, nor are they intended to indicate the capability of the model to provide accurate simulations.

As academicians, we generally favor models for which the source code is open source and freely available for investigation, over so called "black box" models (e.g. where only executables are made available) and we advocate for the enhancement of such models. However, these distinctions are more challenging to capture in the MAI score. As an alternative, we provide for the open-source code-based models an URL pointing to the code and indicate the license of each model in Table 1.

2.1. *The MAI evaluation results of models*

The results of the models' MAI can be found in Table 1.

2.2. *The MAI evaluation results of methods*

The results of the methods' MAI can be found in Table 2.

3. Discussion

To evaluate the precision of our index data acquisition technique, we explored the relationship between the gathered index data and the models. Our analysis involved checking the correlation between index data and models, specifically verifying if the terms in the index data text that matched model names accurately represented the intended models. Given the extensive size of our index dataset, we randomly selected 10 % of the publication, patent, and project data for each model for this evaluation, ensuring at least one of each type was included. Table 3 presents the number of checks conducted and their outcomes for publications, patents, and project data, excluding literature citation indices since these don't necessarily include the model names. Considering the index data's high degree of accuracy (exceeding 90 %), we regard the data as reliable. However, there is potential for further enhancement with more sophisticated methods in the future.

The development and release of MAI evaluation report is a complex but important task. We understand that like other evaluation reports, it might initiate a discussion, for which we are open. We understand that evaluating models is a serious and challenging endeavor, but wanted to start that discussion by presenting the newly developed MAI

Table 2
Method evaluation list.

Full Name	Abbreviation	Major Application Areas	2022 Score	Lifetime Score
Geographically Weighted Regression	GWR	Environmental Science; Management, Monitoring, Policy and Law; Pollution; Earth and Planetary Sciences	4.69	5.22
Inverse Distance Weighted	IDW	Pollution; Environmental Engineering; Water Science and Technology; Environmental Chemistry; Environmental Science	4.36	5.23
Revised Universal Soil Loss Equation	RUSLE	Earth-Surface Processes; Water Science and Technology; Soil Science; Environmental Science	4.25	4.95
Climate Model Intercomparison Project	CMIP	Atmospheric Science; Earth and Planetary Sciences	4.21	4.75
Empirical Bayesian Kriging		Pollution; Environmental Science; Environmental Chemistry; Water Science and Technology	3.51	4.08
Wind Erosion Equation	WEQ	Earth-Surface Processes; Soil Science; Agronomy and Crop Science; Ecology	3.48	4.07
Non Local Means Filtering		Geotechnical Engineering and Engineering Geology; Geology; Water Science and Technology	3.29	3.98
TopoToolbox		Earth-Surface Processes; Earth and Planetary Sciences	3.29	3.86
Local Polynomial Interpolation		Environmental Science; Environmental Engineering; Earth-Surface Processes; Water Science and Technology	3.18	3.79
Icepack		Pollution; Environmental Engineering; Environmental Chemistry; Waste Management and Disposal	3.13	3.92
Global Polynomial Interpolation		Environmental Engineering; Water Science and Technology; Environmental Science; Pollution; Geology	3.08	3.46
Open Field Operation and Manipulation	OpenFOAM	Environmental Engineering	3.07	3.73
Hydrological Model Assessment and Development	Hydromad	Environmental Engineering; Ecological Modeling	2.40	3.29
Kernel Interpolation With Barriers		Oceanography; Pollution	2.32	2.80
RivMAP		Environmental Engineering; Earth-Surface Processes; Earth and Planetary Sciences	2.27	2.77
Moving Window Kriging		Computers in Earth Sciences; Environmental Science; Pollution	2.26	2.71
Floodwater Depth Estimation Tool	FwDET	Water Science and Technology; Earth and Planetary Sciences	2.20	2.64
International Land Model Benchmarking	ILAMB	Earth and Planetary Sciences; Global and Planetary Change	2.13	3.47
Iceages		Earth-Surface Processes; Earth and Planetary Sciences	1.94	3.16
Bedrock Erosion Model		Earth-Surface Processes; Geophysics	1.78	2.65
PIHMgis		Environmental Engineering	1.74	2.87
SunnySlope		Management, Monitoring, Policy and Law; Environmental Engineering; Environmental Chemistry	0.87	1.71

Table 3
Correlation check results.

	Paper	Patent	Project
Sample Number	10896	1738	2508
Accuracy (%)	97.3	95.1	93.3

classification index. We recognize that there could be flaws in the information and data provided, so we expect to release new reports on a regular basis, and encourage feedback from the modeling community to improve the information reported here.

There are an ever-growing number of models for the next generation of earth system science to simulate social and physical processes. This report uses a recently published method and applies it to a large sample of such models, using rapid discovery of models to lay the foundation for semantic relation networks and other geographic-related domains throughout the modelling community.

We are convinced that through this scientific and innovative approach, the MAI will provide more accurate, effective, and reliable decision support for the academic community and the general public. We are committed to promoting the development of academic evaluation systems, promoting greater attention and discussion, and working together to build a more open and scientific modelling profession and community. At the same time, we urge model developers to make the source code of their models freely available 24/7, preferably on platforms that have adopted FAIR principles (Findable, Accessible, Interoperable, Reusable (Chue Hong et al., 2021)) and obtain a DOI (e.g. CoMSES Net (Rollins et al., 2014), OpenGMS (Chen et al., 2020; Xu et al., 2024), CSDMS (Peckham et al., 2013; Tucker et al., 2022), HydroShare (Tarboton et al., 2014, 2024)), thereby enabling clearer and ongoing tracking of the academic influence of the models, and maximizing practical application value (Barton et al., 2020, 2022a, 2022b; Chen et al., 2021).

CRediT authorship contribution statement

Kai Xu: Data curation, Investigation, Methodology, Writing – original draft. **Daniel P. Ames:** Methodology, Writing – review & editing. **Albert J. Kettner:** Methodology, Writing – review & editing. **C. Michael Barton:** Methodology, Writing – review & editing. **Anthony J. Jakeman:** Methodology, Writing – review & editing. **Renyu Chen:** Data curation, Validation. **Min Chen:** Conceptualization, Investigation, Methodology, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The datasets used in this report can be accessed via the public API of Scopus, ScienceDirect, the Google Public Patents database, and the Global Funded Research database (http://www.funresearch.cn). Due to the provisions of the data providers, these datasets cannot be redistributed externally.

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