WCRP
World Climate Research Programme

ESMO
Earth System Modelling and Observations

Working Group on Numerical Experimentation - WGNE

Co-chairs: *Nils Wedi (ECMWF, Int.), Ariane Frassoni (INPE, Brazil)*

ESMO Secretariat: *Fanny Adloff et al*

Core of WGNE membership: global (research) experts who are vested in enhancing the emerging capacities of operational meteorological modelling centers

https://www.wcrp-esmo.org/working-groups/the-working-group-on-numerical-experimentation

- ***Many thanks to the outgoing members***
  - ***Nils Wedi (ECMWF)***
  - ***Guenther Zaengl-DWD (Germany)***
  - ***Oscar Alves-BOM (Australia)***
  - ***Jian Sun-CMA (China)***

World Climate Research Programme

Earth System Modelling and Observations

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- *Ariane Frassoni-INPE/CPTEC (Brazil, co-chair)*
- *Tim Graham-Met Office (UK)*
- *Romain Roehrig-CNRM/MeteoFrance (France)*
- *Peter Lauritzen-NCAR (USA)*
- *Fanglin Yang-NOAA/NCEP/EMC (USA)*
- *Mohau Jacob Mateyisi-CSIR (South Africa)*
- *Ankur Srivastava-IITM (India)*
- *Masashi Ujiie-JMA (Japan)*
- *Ron McTaggart-Cowan-ECCC (Canada)*
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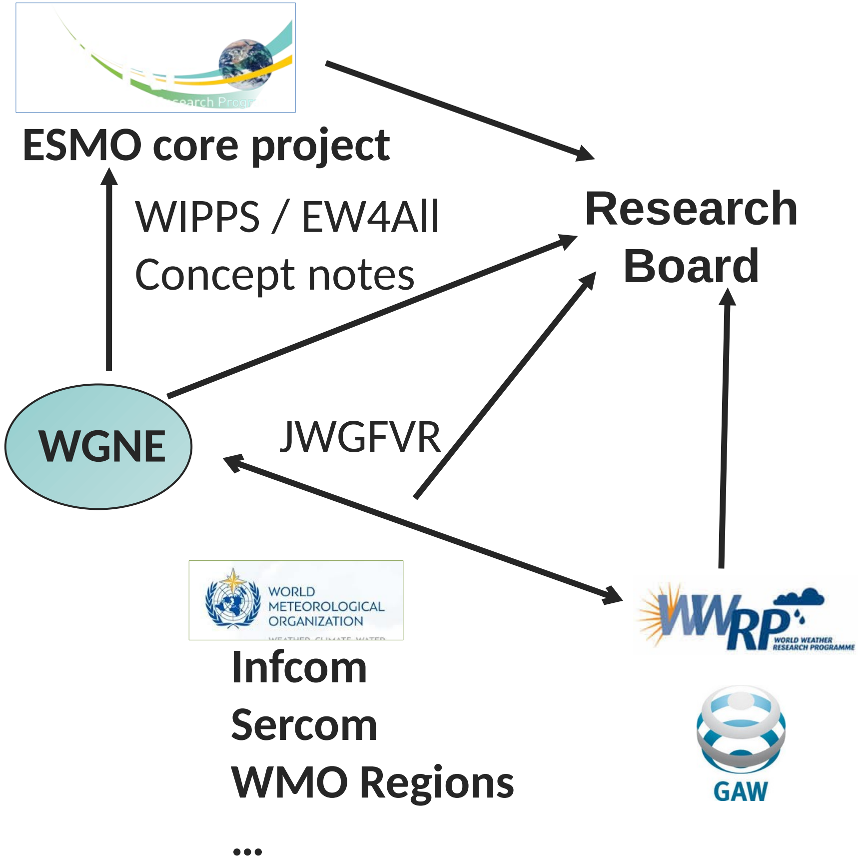
WGNE

The core of WGNE membership consists predominantly of **global (research) experts who are vested in enhancing the emerging capacities of operational meteorological modelling centers**



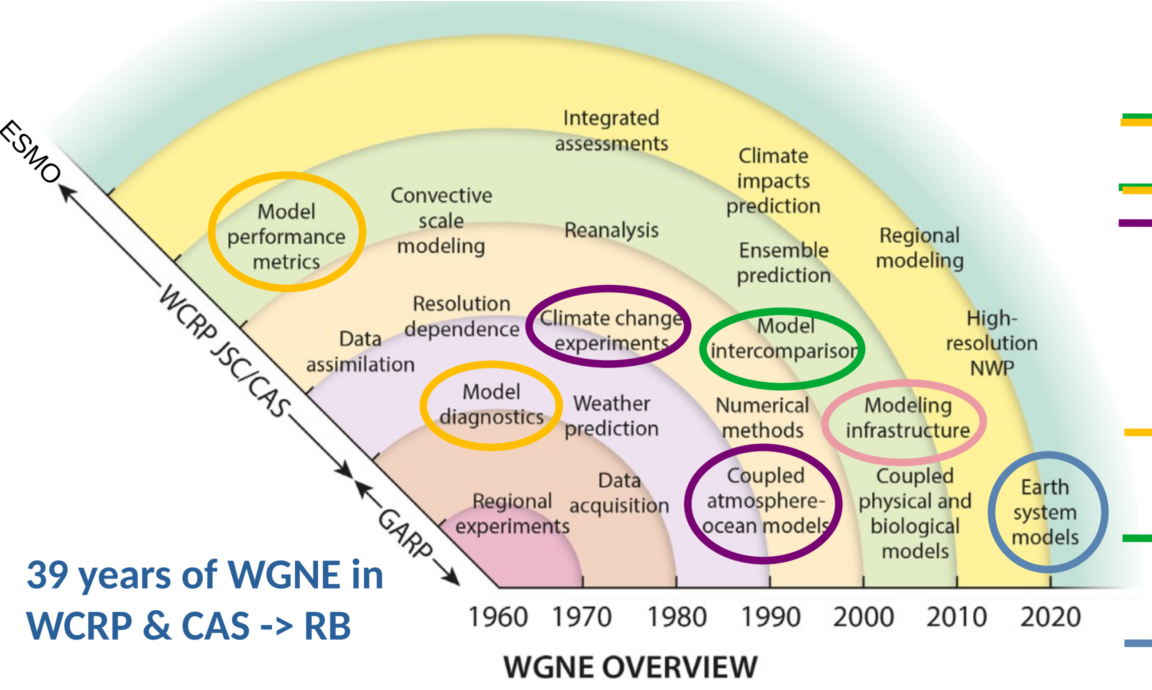
WGNE evolution

WCRP World Climate Research Programme

ESMO Earth System Modelling and Observations

WGNE was stablished in 1968

“The main objectives for this working group were to set up a programme of numerical experiments and to coordinate the distribution of the work among the cooperating research groups.” GARP, 1970



Adapted from Gates, 2015

39 years of WGNE in WCRP & CAS -> RB

- 1980 - WCRP established by WMO/ICSU / JSC (Joint Scientific Committee) established for WCRP
- 1985 - First Session of WGNE, re-established for WCRP JSC and CAS, Boulder
- 1990 - AMIP (Atmospheric Model Intercomparison Project) established by PCMDI and WGNE
- 1991 - TC Intercomparison project
- 1996 - WGCM established by CLIVAR and WGNE; CMIP established by WGCM
- 1997 - WWRP established in cooperation with GEWEX
- 2007 - 3rd WGNE Workshop on Systematic Errors in Climate and NWP Models, San Francisco
- 2008 - GAW established in WWRP
- 2010 - CMMP (Climate Model Metrics Panel) established by WGNE/WGCM
  - WGNE Table overview
- 2017 - 25y Implementation of TC Fct verification
- 2019 - WGNE SE Survey
- 2019/2020 - WMO Constituent Bodies Reform
- 2020 - WGNE evolution - ESM focus
  - WGNE Recommendations for HPC/Exascale

WGNE contributions to ESMO

- Identify, prioritise, link and understand common systematic errors across time-scales in Earth system models
- Encourage quality assurance through facilitation of intercomparison and exchange of internationally accepted model evaluation information
- Harnessing emerging technologies & HPC

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WGNE projects

Active projects

- South American Regional Model Verification Pilot project: Enhancing the assessment of regional forecasts to contribute to the EW4All initiative – jointly with JWGFVR
- The MJO SST sensitivity Model Intercomparison Project (MSMIP)
- Model Uncertainty — Model Intercomparison Project (MUMIP)
- Ocean initialisation Project
- Evaluating the Impact of Aerosols on NWP and S2S

Previous projects

- The Surface Flux Intercomparison project
- Global model comparison: DIMOSIC Different models – same initial conditions
- Intercomparison of precipitation forecasts by operational global models
- The Drag Project
- The Grey Zone project
- To cite a few …

Systematic Errors in Weather and Climate Models

WCRP World Climate Research Programme

ESMO Earth System Modelling and Observations

LIVERMORE NATIONAL LABORATORY

Workshop Summary: The 3rd WGNE Workshop on Systematic Errors in Climate and NWP Models

Peter Gleckler, Martin Miller, Jim Hack, Dave Bader, Ken Sperber, Karl Taylor

April 22, 2008

SYSTEMATIC ERRORS IN WEATHER AND CLIMATE MODELS

Nature, Origins, and Ways Forward

Ayrton Zadra, Keith Williams, Ariane Frassoni, Michel Rixen, Ángel F. Adames, Judith Berner, François Bouyssel, Barbara Casati, Hannah Christensen, Michael B. Ek, Greg Flato, Yi Huang, Falko Judt, Hai Lin, Eric Maloney, William Merryfield, Annelize Van Niekerk, Thomas Rackow, Kazuo Saito, Nils Wedi, and Priyanka Yadav

BAMS, 2018

Systematic Errors in Weather and Climate Models

Challenges and Opportunities in Complex Coupled Modeling Systems

Ariane Frassoni, Carolyn Reynolds, Nils Wedi, Zied Ben Bouallègue, Antonio Caetano Vaz Caltabiano, Barbara Casati, Jonathan A. Christophersen, Caio A. S. Coelho, Chiara De Falco, James D. Doyle, Laís G. Fernandes, Richard Forbes, Matthew A. Janiga, Daniel Klocke, Linus Magnusson, Ron McTaggart-Cowan, Morteza Pakdaman, Stephanie S. Rushley, Anne Verhoef, Fanglin Yang, and Günther Zängl

BAMS, 2023

Lower complexity in models helped to identify model errors with less resources	HighRes ocean models -> way to reduce long-standing warm/saline biases and errors in the Gulf Stream separation and in the deep ocean	HighRes ocean models -> improvements in the parameterization of turbulent flow reduce SE (biases in SST, sea surface height, salinity, and regional variability)
Diurnal cycle of precipitation poorly simulated	Biases in the intensity, distribution, diurnal cycle and timing of max precipitation; transition regimes; organization HighRes models + stochastic perturbations can help to reduce SE	HighRes modeling - better rep of precip-related processes - timing, propagation, diurnal cycle Seasonal migration of the precipitation belts are better represented Errors in oceanic convection/precip & amplitude of precip diurnal cycle over land remain

WGNE-systematic errors workshop

5th WGNE workshop on **systematic errors in weather and climate models,** Montreal, Canada, 2017

Systematic Errors in Weather and Climate Models: Nature, Origins, and Ways Forward, *Zadra et al*, *2017* https://doi.org/10.1175/BAMS-D-17-0287.1

6th WGNE workshop, Reading, ECMWF, 2022 *https://events.ecmwf.int/event/241*

Systematic Errors in Weather and Climate Models: Challenges and Opportunities in Complex Coupled Modeling Systems, *Frassoni*, *Reynolds*, *Wedi et al 2023* https://doi.org/10.1175/BAMS-D-23-0102.1

7th WGNE workshop 2026
in South America

WMO IMO-WMO

WGNE contributions

- Identify, prioritise, link and understand common systematic errors across time-scales in Earth system models
- Encourage quality assurance through facilitation of intercomparison and exchange of internationally accepted model evaluation information – Strong collaboration with the **JWGFVR**
- Harnessing emerging technologies & HPC

Statistical verification over South America

- Thanks to *Task Team on Reviewing NWP Standardized Verification (TT-NWPSV)*
- Proposition to expand the WMO official verification regions to uncovered regions of the world.
- **Soon SA will have standard verification results which will be a great advance for our region!**
- There are also tentative initiatives to facilitate verification of regional models

Thanks to R. De Elia and N. Wedi

Met Office

Forecast Errors in Weather and Climate Models 2013 → 2023

Tim Graham & colleagues

Based on a range of global models

Area	Parameter	Forecast range								
		T+24 RMSE	T+24 10-year RMSE change	% difference	T+72	T+72 10-year RMSE change	% difference	T+120	T+120 10-year RMSE change	% difference
NH	pmsl	82,4417	67,0675	-22,9	211,6148	173,4242	-22,0	398,8079	354,9571	-12,4
NH	500 hPa GPH	6,5992	5,244	-25,8	20,7134	17,0331	-21,6	41,8865	37,211	-12,6
NH	250 hPa wind	3,3205	2,8675	-15,8	7,5864	6,7353	-12,6	12,5156	11,6188	-7,7
NH	250 hPa temp	0,6437	0,5743	-12,1	1,4889	1,3209	-12,7	2,3724	2,1715	-9,3
TR	850 hPa wind	1,6936	1,5059	-12,5	2,643	2,4518	-7,8	3,2955	3,1333	-5,2
TR	250 hPa wind	3,0121	3,1105	3,2	5,3702	5,5818	3,8	7,0235	7,3234	4,1
TR	250 hPa temp	0,3827	0,4454	14,1	0,6646	0,7205	7,8	0,8236	0,8538	3,5
SH	pmsl	96,6029	69,2929	-39,4	266,07	206,771	-28,7	507,1582	435,204	-16,5
SH	500 hPa GPH	8,343	6,1211	-36,3	26,2052	20,1679	-29,9	51,8982	44,0892	-17,7
SH	250 hPa wind	3,3525	2,952	-13,6	8,1274	6,9988	-16,1	13,6093	12,2837	-10,8
SH	250 hPa temp	0,665	0,5999	-10,9	1,5812	1,3605	-16,2	2,5117	2,2335	-12,5

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Emerging technologies & HPC & R2O

ESMO Earth System Modelling and Observations

CONCEPT NOTES

The Research Board has drafted six concept notes [-]

- Advancing Earth System Modelling - DRAFT
- Advancing Earth System Observations - DRAFT
- Data Handling and the Application of Artificial Intelligence in Environmental M...
- Innovation in Regions - DRAFT
- Science for Services - DRAFT
- Exascale Computing and Data

WMO Concept Note on Exascale Computing and Data

Concept note on use of AI and data exploitation in environmental modelling

WMO Research Board - Task Team on Exascale, Data Handling and AI

Contributing authors: Adrian Hines, Bubacar Bah, Dominique Berod, Veronique Bouchet, Pascale Braconnot, Wenchao Cao, Mark Govett, Tim Graham, Yuki Honda, Emile Jansons, Michel Jean, Bryan Lawrence, Jürg Luterbacher, Kris Rowe, Martin Schultz, Martin Visbeck.

Affiliations in the Acknowledgments

September 13, 2021

C1 Advancing Earth System Modelling

Drafting team: Andy Brown, Veronique Bouchet, Antonio Busalacchi, Gregory Carmichael, Chris Davis, Francisco Doblas Reyes, Yihong Duan, Greg Flato, Sarah Jones, Craig McLean, Jerry Meehl, M Rajeevan, Carolyn Reynolds, Paolo Ruti, Catherine Senior, Ranjeet Sokhi, Martin Visbeck, Matt Wheeler, Keith Williams

March 2021

Conclusions for the 2024-2027 timeframe

1. **Significant improvements over last decade** on high-impact weather and multi-model hemispheric scores
2. Identified hazards **benefit from progress in land-surface modelling, higher horizontal resolution and integration with hydrological modelling** within land-surface schemes
3. **ML/AI can improve systematic errors**, **timeliness of delivery and uncertainty estimation**
4. **EW4All** challenges WMCs readiness to **make available open Earth-system data** and **accelerate novel access patterns (including compute)**
5. **Need to actively involve and enable WMO regions** to improve regional verification and comparison to global simulations, **enable regionally conducted, event-based verification (e.g. WGNE/JWGFVR pilot project)**

WGNE terms of reference

Identify, prioritise, link and understand common systematic errors and their solutions across different time-scales in coupled ESMs, sharing this information across the model development community.

Assess the use of innovative approaches, in particular machine learning for Earth system modelling
Provide guidance to utilise exascale computing for Earth system modelling, e.g. to overcome scalability issues and capture trends.

Identify technological and scientific trends in Earth system modelling and share information on trends in global data-processing and forecasting systems across major modelling centers.
Share information and provide advice on the right level of complexity required in increasingly coupled ESMs for a particular application.

Encourage quality assurance through facilitation of intercomparison and exchange of internationally accepted model evaluation information relevant to their efficient and accurate use in operational weather & climate services.

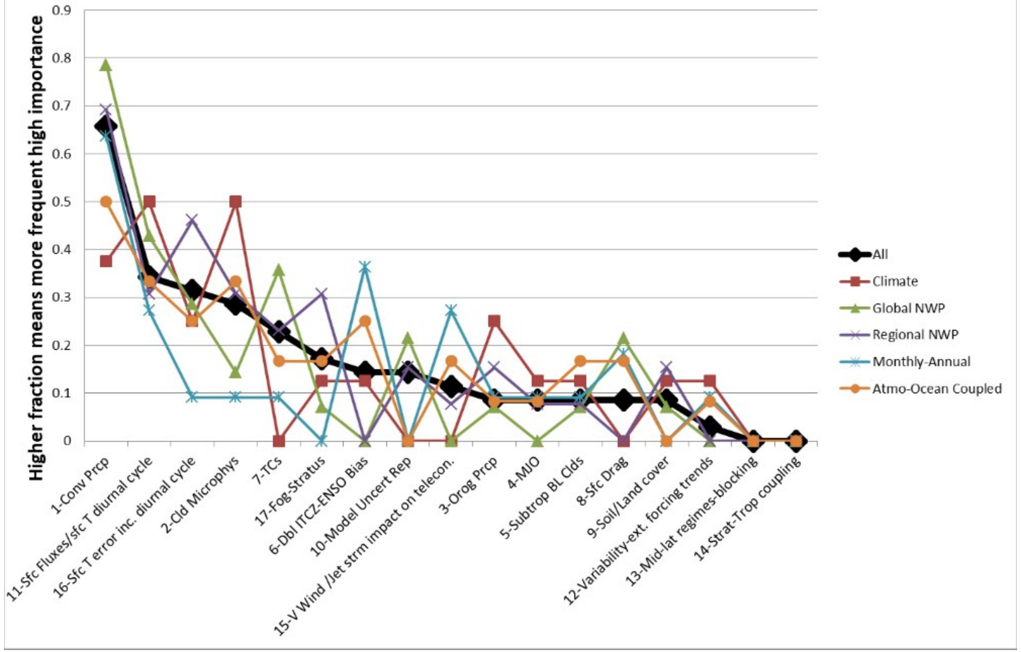
Share knowledge on the development & trends in R2O processes, operational NWP and climate services with ESMO and the Research Board.

Thank you!

Extra slides

Systematic Errors in Weather and Climate Models Survey

Frequency of higher importance given to an issue by modeling centres/groups



The results are sorted by the fraction for all entries, from most frequent (most often ranked as important) to least frequent (least often ranked as important)

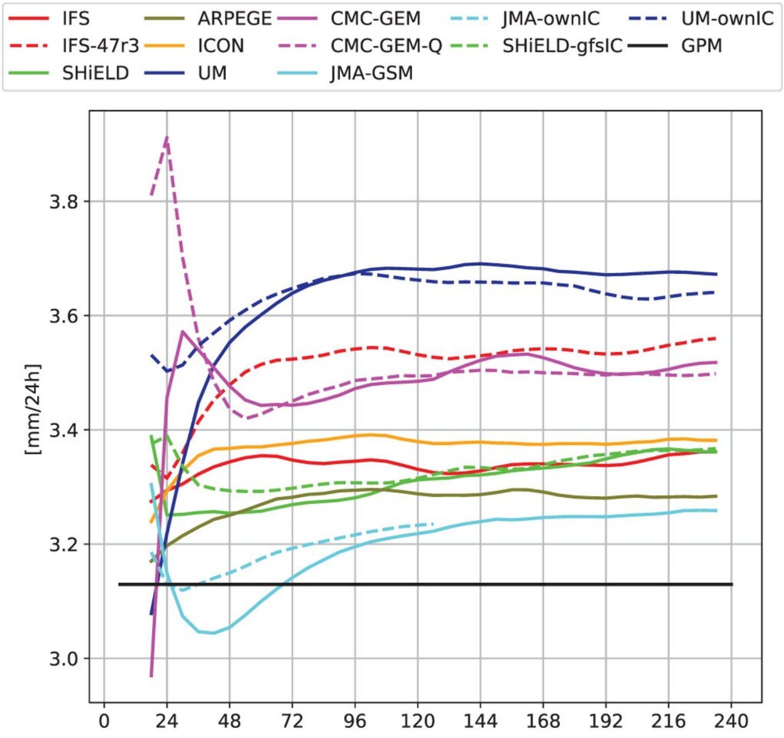
For all entries (black line)
1st - Convection/precipitation
2nd - Sfc fluxes/sfc temp diurnal cycle
3rd – Sfc temp errors including diurnal cycle
4th – Cloud microphysics
5th – Tropical cyclones

https://wgne.net/wp-content/uploads/2019/02/WGNE_Systematic_Error_Survey_Results_20190211.pdf

WGNE projects

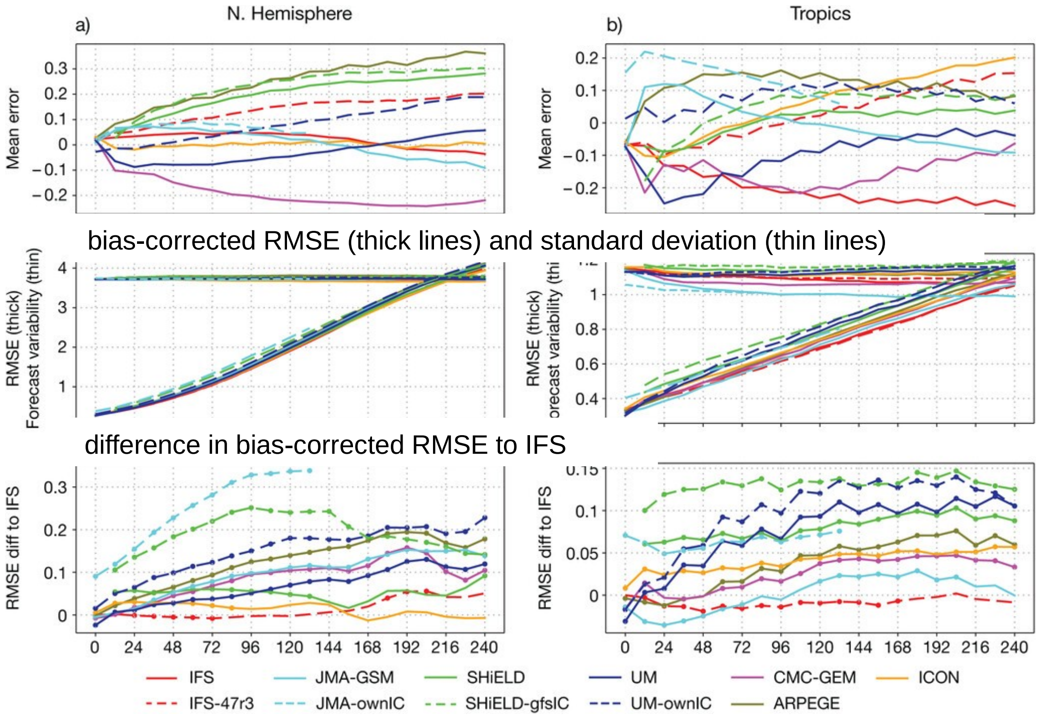
Active projects Global model comparison: DIMOSIC Different models – same initial conditions

24-h mean precipitation for running-mean windows
for 40°N–40°S, as a function of lead time (h).



Magnusson et al., 2022

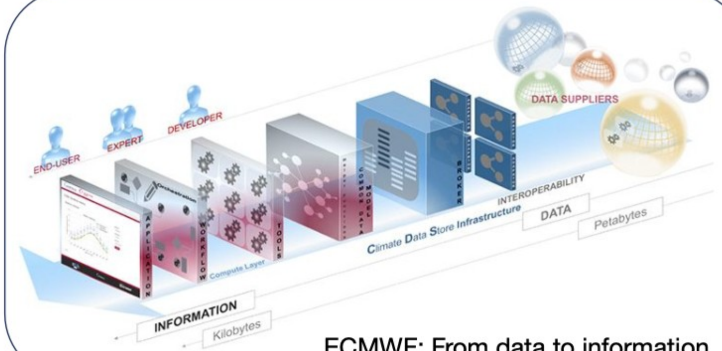
T500 mean error



Emerging technologies & HPC & R2O

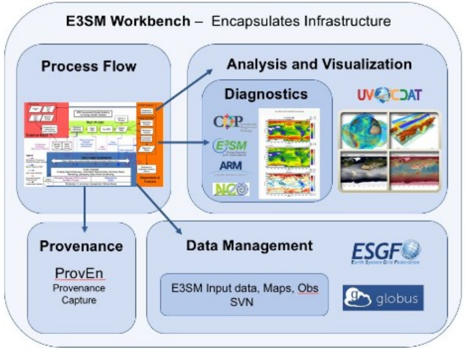
- Modernization of modeling software
- Co-design between scientists and computer scientists
- Data Science, new workflows, AI/ML, data management
- Investment in software engineering, scientific design

Adapted from UK Met Office & EPSRC: Harnessing Exascale Computing



ECMWF: From data to information

DOE E3SM



DOE Exascale project

Many opportunities for cross-agency and international partnership on tools and methods

Hauser et al., 2023

ECMWF

Forecast Errors in Weather and Climate Models 2013 → 2023

High Impact weather error reduction

Thomas Haiden

Feature	Current error or score (2023)	Error or score 10 years ago (2013)	Approximate improvement in 10 years	Comments
Tropical cyclone position	MAE (D+3) = 160 km MAE (D+5) = 250 km	MAE (D+3) = 180 km MAE (D+5) = 350 km	11% 29%	
Tropical cyclone intensity (central pressure)	MAE (D+3) = 11 hPa	MAE (D+3) = 15 hPa	27%	
Strong wind	ROCS (D+5) = 0.77	ROCS (D+5) = 0.72	6%	EFI (95th percentile) ROC skill in Europe
Significant wave height	SI (D+3) = 20% SI (D+5) = 30%	SI (D+3) = 23% SI (D+5) = 33%	13% 9%	SI = Scatter Index (error standard deviation divided by obs) in %
High temperatures	ROCS (D+5) = 0.92	ROCS (D+5) = 0.88	5%	EFI (95th percentile) ROC skill in Europe
Heavy rainfall	ROCS (D+5) = 0.68	ROCS (D+5) = 0.63	8%	EFI (95th percentile) ROC skill in Europe
Heavy rainfall	ETS (D+3) = 0.155 ETS (D+5) = 0.100	ETS (D+3) = 0.125 ETS (D+5) = 0.075	24% 30%	Equitable Threat Score (ETS) for >50mm/24h in N. Extratropics

Selected qualitative conclusions for the 2024-2027 time-scale (EW4All Initiative):

- Constraining errors on troposphere-stratosphere coupling and improved predictability
- Amplitude of diurnal cycle of precipitation over land remains a challenge
- Reduction in systematic errors of upper ocean (SST, salinity, Gulf stream separation) and of some deep ocean properties
- Substantial errors in high-latitudes remain
- Substantial MJO simulation errors (and convective boundary layers in coupled models) remain
- Substantially improved tropical cyclone track and intensity forecasts, in part through improved air-sea coupling
- Improved hydrological and flood prediction and improved representation of vegetation and soil, and
- snow, in part based on more up-to-date mapping information
- Increased complexity of very-high resolution simulations within coupled ocean-atmosphere-land
- systems give also rise to new systematic errors...
- Bias correction of systematic errors through ML/AI advances
- Recommendations to advance on systematic error reduction including data assimilation, machine
- learning, and a hierarchy of models supported by standardised and widely available observational data

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Systematic Errors in Weather and Climate Models
6th WGNE WSE recommendations

ESMO
Earth System Modelling and Observations

Models

High-res/digital twins: Useful for some problems - process studies, coarse graining (e.g., GWs, momentum budgets)

Model evaluation using high res obs, subsurface obs (ocean) and process-relevant obs (TEAM-X, INCUS ...)

Employ hierarchies of models, including single column models, constrained components, relaxation, nudging)

Carefully consider coupling (physics-dynamics, physics-physics, cross component)

List of physical properties that must hold (e.g., mass conservation)

Drive software quality

Modular model developments

Techniques

Diagnostics from DA can effectively identify systematic errors and constrain parameters, inline bias correction

ML/AI: Improve model behavior, identify flow-dependent systematic errors, detect causal connections

In-line bias correction: consider risks/benefits of inline bias correction vs. model improvement

Weather - Climate communication (verification, AMIP and Transpose AMIP)

Km-scale global coupled models should engage and learn from mesoscale modeling community

Ensemble sensitivity, parameter exploration, perturbation experiments, adjoint sensitivity, relaxation-nudging

Data sets

Central repository and inventory of field campaign data (ease of use)

Error estimates for reanalysis and observation

Modeler input for field campaigns

Observations of data-poor regions (ocean, land, sea-ice) and coupled observations

Data available for different levels of granularity

- Review the WGNE systematic error survey
- Overview paper of biases across timescales
- Virtual discussions by subgroups

https://journals.ametsoc.org/view/journals/bams/104/9/BAMS-D-23-0102.1.xml