WCRP
World Climate Research Programme

ESMO
Earth System Modelling and Observations

Working Group on Numerical Experimentation - WGNE

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40th Session
3-7 November 2025
Beijing, China

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

WGNE goals

To foster collaborative development of Earth system models

- Design
- Implementation
- Error diagnosis and model revision

→ Across the full range of temporal and spatial scales

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

Emerging technologies & HPC & R2O

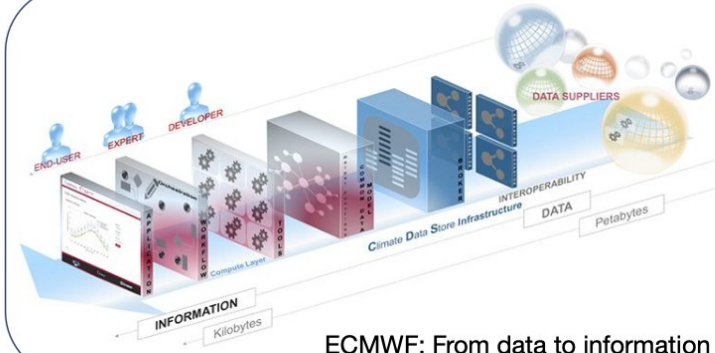
Modernization of modeling software

Co-design between scientists and computer scientists

Data Science, new workflows, AI/ML, data management

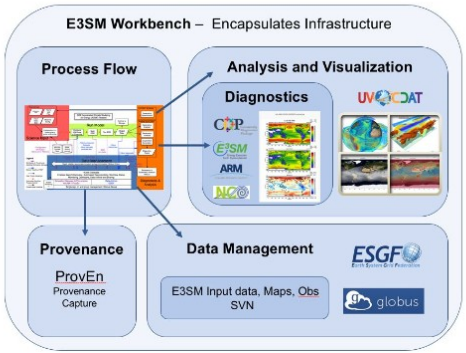
Investment in software engineering, scientific design

Adapted from UK Met Office & EPSRC: Harnessing Exascale Computing

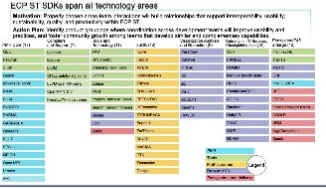


ECMWF: From data to information

DOE E3SM



DOE Exascale project



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

NCAR | UCAR

Hauser et al., 2023

WGNE before 1985

Background

1967 - GARP (Global Atmospheric Research Programme) established by WMO (World Meteorological Organization)

1967 - JOC (Joint Organizing Committee) established by WMO and ICSU (International Council for Scientific Unions) to implement GARP

1967 - WGNE (Working Group on Numerical Experimentation) established by JOC for GARP

1968 - Working Group on Numerical Experimentation meeting, Oslo

1969 - WMO Working Group on Numerical Weather Prediction reference regarding the utilization of standardized datasets for model verification

1970 - Conference on numerical experimentation, Oslo

1970 - GARP Publication Nº. 1: “An introduction to GARP” published by WMO/ICSU JOC (B. R.Döös)

WGNE before 1985

Background

Numerical experimentation plans for the First Global Atmospheric Research Program (GARP) Global Experiment (FGGE)
Leadership: WMO and ICSU

Goas

- Improve weather forecasting: gather compreensive data to improve NWP models for short-to-medium range forecasting
- Understanding atmospheric processes: study physics of the troposphere and stratosphere
- Assess predictability: determine the limits of weather predictability
- New observation systems: design and test global observing systems for weather prediction

WGNE before 1985

Background

GARP Scope and participation

- Global coverage: included land and ocean observations
- International collaboration: over 140 countries participated
- Diverse observing systems
- Specialized data: atmospheric data and more

Legacy

- Breakthrough in data collection
- Fundation of future research: understanding of weather and climate
- Predecessor to modern weather systems: precursor to modern global weather obs systems

WGNE before 1985

Background

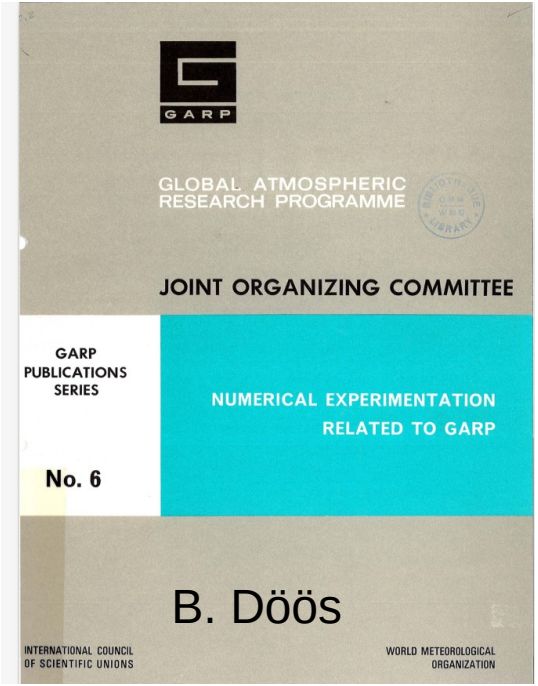
The Working Group on Numerical Experimentation was established in 1968: Professor J. Smagorinsky as chair

B. Döös and other 30 scientists met in Oslo (1970) to discuss numerical experimentation for GARP – international collaboration

Task: to arrive at conclusions concerning the specification of observational requirements for the atmospheric variables needed

Minimum requirements established on the basis of results of numerical experiments

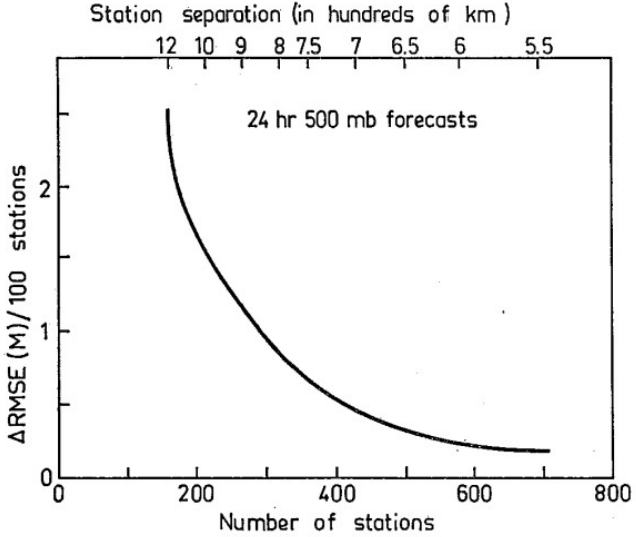
Results presented to observational technitians who would indicate the feasibility of observing systems which would satisfy the numerical experiments



WGNE before 1985

Background

Data requirement



Relative performance of a multi-layer model with networks of varying densities. The scale on the ordinate shows the change in rms error resulting from an increment of 100 stations. Source: Döös, 1970

Analysis problem

"...realistic trial of the method on these lines is not possible on the present computer"

The forecast problem

"*The programme for numerical experimentation need to be planned in such a way that it is possible to determine the relative importance of the individual error sources.*"

Adoption of stantardized met data to verify aspects of modeling system as: resolution, parametrizations, initialization etc

Verification benchmark stablished

WGNE before 1985

Background

1970-1974 - Conduct of GARP Regional Experiments:
– GATE: GARP Atlantic Tropical Experiment
– MONEX: Monsoon Experiment
– ALPEX: Alpine Experiment
– AMEX: Air Mass Transformation Experiment

1974 - Study Conference on Climate Models, organized by JOC in Stockholm

1975 - Publication of "The Physical Basis of Climate and Climate Modelling“, GARP Publication No. 16

1978 - Study Conference on Climate Models, Geneva, organized by GARP WGNE JOC

WGNE before 1985

Background

1979 - First World Climate Conference, Geneva

1979 – 8th WMO Congress – approved the establishment of WCRP (World Climate Research Programme)

1980 - WCRP formally established by WMO/ICSU

1980 - JSC (Joint Scientific Committee) established for WCRP

1983 – 9th WMO Congress established the Comission for Atmospheric Sciences (CAS) Co-ordinating Group for Experimentation on Numerical Weather Prediction

1984 – 1st session of CGE (CAS Group for Experimentation)

WGNE after 1985

1985 – 7th Session of WGNE for WMO/ICSU JSC in Florida (chair L. Bengtsson)

CAS CGE - Group for Experimentation on Numerical Weather Prediction

Goals

- Promote weather prediction research on all time scales based on numerical techniques and to co-ordinate numerical experimentation projects for this purpose
- Responsible for overseeing further studies based on the analysis

of GARP data

WMO/ICSU JSC WGNE - Working Group on Numerical Experimentation

Focused on the numerical climate prediction

There was an ongoing need for the co-ordination of numerical experimentation related to NWP using GARP data sets

WGNE after 1985

1985 – 7th Session of WGNE for WMO/ICSU JSC in Florida

"*The objectives of numerical experimentation for weather prediction and climate research are different, but the underlying scientific problems are the same, or at least intimately related, to the point that specific research projects normally help both*."

GARP data sets continued to be used in WCRP studies
- Validation purposes
- Assessment of data requirements
- Input data for weather prediction experiments

WGNE task: continuous assessment of quality and usefulness of operational NWP products to be used as basic data sets for the WCRP

WGNE after 1985

CAS CGE was recommended to orient its activity towards medium- to long-range weather prediction → strongest overlap with WGNE

Benefits of model improvement were considered important for both communities
two-way feedback → WCRP studies benefited numerical climate simulations and NWP; improvements in NWP models benefited climate models

Joint JSC/CAS Working Group on Numerical Experimentation

WGNE after 1985

Coupled ocean-atmosphere models development: WGNE worked in the comparison of surface flux quantities derived from analyses produced by the data assimilation systems in use at ECMWF and UKMet Office

- Momentum
- Heat
- Water vapour fluxes

There were substantial systematic differences between them, especially in the Tropics

→ ***1996 - WGNE/JSC and CLIVAR/SSG established the WGCM to coordinate couple modeling scientific activities and CMIP***

→ **Reanalysis:** In the mid-80's the Swedish Meteorological and Hydrological Institute and ECMWF had undertaken reprocessing of GARP datasets

AMIP – a relevant project

1990 - **AMIP (Atmospheric Model Intercomparison Project)**

Led by Program for Climate Model Diagnosis and Intercomparison (PCMDI) in collaboration with WGNE

- First global coordinated evaluation of atmospheric GCMs
- Common protocol with prescribed observed SST & sea ice
- Standardized outputs → comparable diagnostics across centers
- Revealed shared systematic model errors
- Created the first global multimodel climate archive
- Foundation for CMIP and all modern MIPs

AMIP Timeline

| 1990 | Concept developed (PCMDI + WGNE) |

| 1992 | AMIP-I launched |

| 1995 | First AMIP results in IPCC |

| 1997 | AMIP-II |

| Late 1990s | Evolves into CMIP framework

| 2008 | Basis to Transpose AMIP II framework

WGNE in a new Era

Research Board – established by WMO Congress in 2019 (Res. 8, Cg. 18)

- Act as coordination body → WMO strategic aims/decisions into research priorities

WMO recognized the need for stronger linkage between research (weather, climate, water, environment) and operational services ⟹ R2O

- Ensures coordination across WCRP, WWRP and GAW programmes

WGNE supports the goals the RB sets → WGNE's strategic role as a connector between scientific disciplines and operational communities

WGNE evolved to foster collaborative development of atmospheric models to Earth system models (design, implementation, error diagnosis and model revision) across the full range of temporal and spatial scales

Bridging Research and Operations

WGNE contributed to the creation of interlinked projects:

- MJO Model Intercomparison Project (MSMIP)
- Model Uncertainty MIP (MUMIP)
- Drag Project
- DIMOSIC (Different Models, Same Initial Conditions)

→ each tackling specific process-level biases identified through Systematic Error Workshops

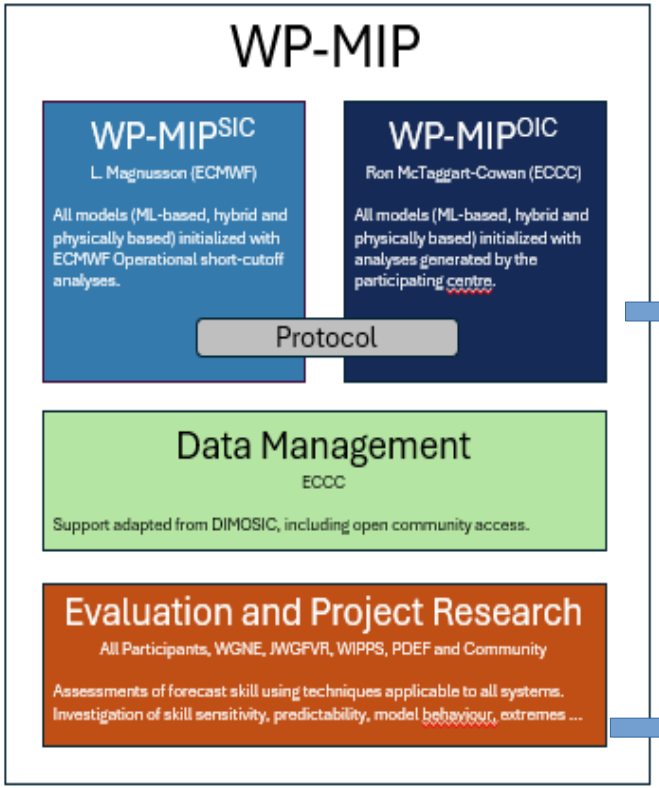
Alignment with WMO's Early Warnings for All initiative

- South American Regional Model Verification Pilot Projec
- WP-MIP

→ **WGNE's scientific insights translate directly into improved forecasting capabilities**

Bridging Research and Operations

Alignment with WMO's Early Warnings for All initiative: WP-MIP



AI-based systems are cheaper to run compared to traditional NWP models

A MIP with broad international engagement can bring opportunities to WMO members through WIPPS

DIMOSIC 2nd phase: WP-MIP SIC & WM-MIP OIC
smoothing of predicted fields;
Better understanding of:

- stability of AIWP models;
- physical consistency, dynamical balance and conservation properties in AIWP system;
- quality of precipitation forecasts;
- Prediction of extremes or out-of-sample events (inclding trop. cycl. track and intensity)

Guidance for assessments of prediction quality → strong collaboration with the JWGFVR

Systematic Errors in Weather and Climate Models

WCRP World Climate Research Programme

ESMO Earth System Modelling and Observations

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

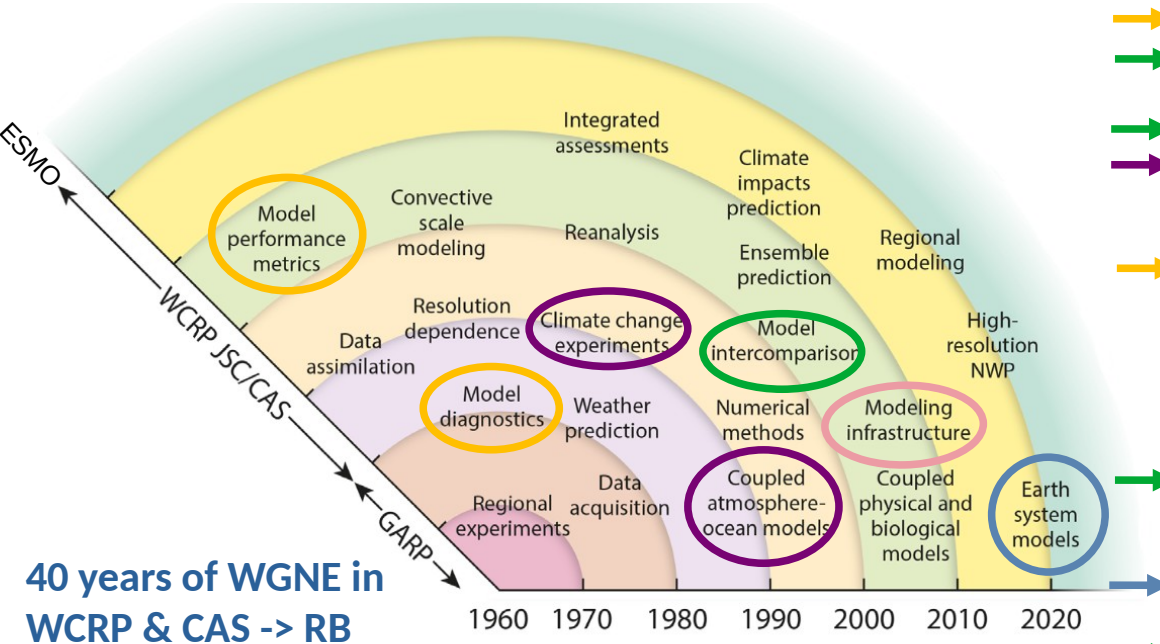
BAMS, 2023

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 evolution

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



WGNE OVERVIEW

Adapted from Gates, 2015

40 years of WGNE in WCRP & CAS -> RB

- 1980 - WCRP established by WMO/ICSU / JSC (Joint Scientific Committee) established for WCRP
- 1985 – WGNE re-establishment for WCRP JSC and CAS
- 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
- 2022 - DIMOSIC
- 2024 – WP-MIP

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.

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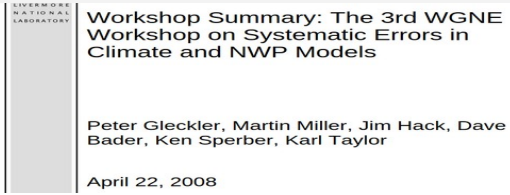
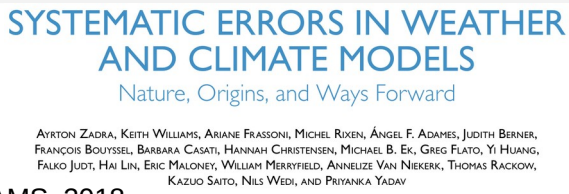
Extra slides

Workshop on Systematic Errors in Weather and Climate Models





BAMS, 2018

BAMS, 2023

Errors in low-level clouds over the sub-tropical oceans responsible for SE	Improved treatments of cloud microphysics and boundary layer processes -> to reduce uncertainties in low-cloud radiative feedbacks; may have a coupled component/feedback	The southeast Pacific Ocean stratus cloud deck is still misrepresented in kilometer-scale simulations despite improvements in parameterized and explicit shallow convection
Diurnal cycle of near sfc temperature poorly simulated	Outstanding errors in the modeling of surface fluxes; errors in the representation of the diurnal cycle of surface temperature	New techniques (DA/ML) has been used to optimize near-surface parameters (e.g., 2-m temperature) by adjusting uncertain parameters in land surface schemes
Manpower limitation - inability of the field to attract and keep young talent	Foster developments toward kilometer-scale global weather and climate simulations Promote optimal use of future high-performance computing platforms	Promote ECS career development; provide opportunities to improve scientific and technical skills; actively involve ECS in shaping the future of ES modeling

WGNE projects

Active projects

- 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
- The Surface Flux Intercomparison project
- Global model comparison: DIMOSIC Different models – same initial conditions
- South American Regional Model Verification Pilot project: Enhancing the assessment of regional forecasts to contribute to the EW4All initiative – jointly with JWGFVR

Previous projects

- The Drag Project
- The Grey Zone project
- Intercomparison of precipitation forecasts by operational global models
- To cite a few …