6th WGNE workshop on systematic errors in weather and climate models

ECMWF | Reading | 31 October 2022 to 4 November 2022

- **Clouds and precipitation:** conv precip; sfc-fluxes and diurnal cycle; cloud microphysics; representation of low clouds, especially at high latitudes; uncertainty representation; resolved/unresolved convection; precipitation over orography; convective organisation.
- **Atmosphere-land-ocean-cryosphere interactions:** sfc fluxes and diurnal cycle; surface drag; soil/vegetation/land-use representation; stable boundary layer issues; fog-stratus simulation; impact of coupled modeling to ocean/sea-ice/waves.
- **(sub-)tropical circulations:** Tropical cyclones, MJO, QBO, double ITCZ and ENSO biases, ocean and wave coupling, role and biases over the maritime continent, tropics and mid-latitude coupling.
- **Strat-Tropo interactions:** role of strat biases on longer term predictability; strat bias correction and impact on predictability; atmos composition and long-lived tracers.
- **ML/AI and data assimilation:** novel techniques to diagnose, measure or resolve systematic errors.
- **Quantifying uncertainty:** spread-error relationships; identifying role and contribution of physical processes to uncertainty characterization; ens and hindcast strategies to identify extremes; use of multi-model ens to identify systematic errors; stochastic representations of model uncertainty.
- **Challenges and surprises in simulating the climate system:** improvements and new errors with eddy resolving / deep convection resolving simulations, errors due to vertical/horizontal resolution imbalances, shifts in statistical analyses due to resolved vs parametrised processes, systematic errors due to changes in convective organisation

Breakout Group Session Summary

High-level comments from the groups

- Common errors across models
  - Solution to these errors may be different on different models

- Difficult to rank errors even when stratified by time scale
  - Convection is near/at top

- Using a hierarchy of models and a modular approach can help isolate/understand sources of errors.

- Individual parameterisation paradigm
  - Consider unified parameterizations?

- Evaluation of models in a seamless way
  - Initialisation tests for Climate model and climate runs for NWP models

1) **What are the priority systematic errors that need to be addressed? Are priorities different for different timescales (NWP, S2S, climate)? Consider rating the systematic error in terms of importance for which timescale.**

Atmosphere: Many issues remain from the 2017 workshop, but we are making progress on some (e.g., diurnal cycle)

- Microphysics, clouds (and radiative feedbacks), and turbulence; mixed-phase clouds
- Precipitation (orographics, precip over ocean, diurnal cycle, organization, TCs, double ITCZ, precip assoc w/ African east. jet)
- Representing convection still an issue (shallow, mid-level and deep) is a problem for all timescales
- Dynamical core and dynamics-physics coupling (often overlooked, complex to diagnose)
- Stratospheric moist bias (T-S interactions)
- Modes of variability (wave propagation, blocking, MJO, teleconnections, ENSO, monsoons)
- BL representation (vertical resolution issues)
- Gray-zone (scale awareness)

Ocean: Missing variability, SST biases (tropical, western boundary currents, southern ocean)

Sea Ice: Ice melt trends, fluxes through the ice, impacts of snow cover, initialization

Land-Surface: Missing processes (dynamic vegetation, interception), sub-grid variability, soil moisture distribution (and observations)

Coupled Models

- Interface fluxes (conservation, observations)
- Uncertainty representation (under dispersion, stochastic processes, establishing bounds, conservation)
- High latitude processes poorly observed and often not prioritized (Arctic amplification, coupled processes)
- Evolution of errors in time, nonlinear cascades

2) What are recommendations for moving forward with reducing these errors in coupled systems (understood in the most general sense of analysing and/or forecasting the complex Earth system)?

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

Some Observations

- Significant trend errors in reforecasts, mostly over sea, not so much over land
- Sea-ice thickness error and leads related to low-level temperature biases in the Arctic (cold bias == thicker sea-ice), probleamtic for arctic amplification
- Many presentations on Pacific biases both in ocean and atmosphere
- Bias corrected spread of multi-model lower than SPPT, why ? SPP shows lower spread for winds in extended range (and MJO index) why ?
- Deep ocean biases not enough attention ? How to analyse, often expensive long runs
- Adding ML-based prognostic variables for hybrid ML-physical modelling
- Boundary layer Arctic, mixed phase clouds representation, clear and cloudy states , all not captured well in models , low level stability vs clear sky radiation , possibly also atmosphere-snow interactions
- Need to constrain growing spread of carbon sink projections (emergent constraints approach ?)
- Double ITCZ, and more generally larger biases of precipitation & clouds over sea than land ? E.g. cloud top height distribution very different over oceans
- Mismatch between observed and modelled Pacific SST trends
- ENSO errors similar in shorter runs and climate simulations
- Still rather typical errors for Indian Monsoon in CMIP6, (dry bias east of India, Himalaya rainfall and dry region location, wet bias Indian ocean)
- Structured analysis of biases in the stratosphere
- Wind – SST relationship probelamtic in all models
- New Techniques to reduce biases:
    - DA-model coupling technique brings substantial bias reduction
    - Nudging popular especially when lacking observations to constrain model behaviour
    - Often confronted with structural error that cannopt be “tuned” away, example of PC analysis of multi-parameter perturbed ensemble (costly though)
    - Adding ML-based prognostic variables for hybrid ML-physical modelling (stable for long runs)
    - DA trained error model for the stratosphere, applied in reanalysis for the pre-satellite era
    - Treopical cyclone sensitivity study