

Systematic Biases: Key Scientific Advances

CMIP3 to CMIP5 improvement primarily, but only anecdotal since CMIP5

- El Nino *
 - AMOC *
 - Low clouds ~*
 - Eastern boundary ocean areas *
 - Sea Ice – Arctic * / Antarctic
 - Ocean currents and sub-grid scale *
 - More comprehensive inclusion of BGC Ocean & Land*
 - Large model spread in Land BGC, but not ocean *
 - Atmospheric Blocking *
 - QBO*
 - Polar Vortex in HiTOP models*
 - IPO/PDO*
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- Monsoons, Double ITCZ, Cold tongue, Diurnal cycle, Dry bias over Amazon, Westerlies, SO warm bias

Systematic Biases: Shortcomings, Gaps & Opportunities

- Terrestrial nitrogen cycle
- Frozen soil impacts on heat and carbon
- Ice sheets beginning to be incorporated in ESMs
- Permafrost
- Aerosol forcing
- Decadal climate variability
- Assessment of ocean mixing for heat & carbon
- Argo, BGC Argo & Deep Argo
- OSSE, state estimation and reanalysis for the ocean
- Transpose CMIP – NWP: Use climate prediction systems
- Agricultural representation in land surface/dyn veg models
- Manipulated experiments for land bgc
- Large ensembles – initial condition & perturbed physics
- Groundwater & aquifers

Systematic Biases: Future and Vision

- Evaluating impact of higher resolution on systematic biases
- More systematic availability of observations (and multiple observational datasets) for ESM evaluation and improvement
- Observing system design based on systematic bias in projection uncertainty
- More Climate Process Teams (modelers + observationalists)
- Carbon reanalysis based on earth system model assimilation of observations
- Improve decadal prediction by reducing systematic bias
- Learning to live with systematic bias
- Extracting useful information from imperfect models
- Broaden interaction with a diversity of impacts and observational communities