Physical Process Realism and Model Hierarchies

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Complex Models (ESMs, NWP)

Process Models (DNS, LES, CRMs for radiative transfer, turbulence, boundary layers, convection, cloud microphysics & macrophysics)

Idealized Models (Aquaplanets, RCE)
Complex Models (ESMs, NWP)

Reduced Set of Physical Processes, Simplified BCs

Idealized Models (Aquaplanets, RCE)

Process Models (DNS, LES, CRMs for radiative transfer, turbulence, boundary layers, convection, cloud microphysics & macrophysics)
Physical Basis from which Complexity Emerges

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(ESMs, NWP)

Process Models
(DNS, LES, CRMs for radiative transfer, turbulence, boundary layers, convection, cloud microphysics & macrophysics)

Idealized Models
(Aquaplanets, RCE)
Evaluation and Metrics

Complex Models (ESMs, NWP)

Simulated Large-Scale Fields, Means & Variability

Idealized Models (Aquaplanets, RCE)

Process Models (DNS, LES, CRMs for radiative transfer, turbulence, boundary layers, convection, cloud microphysics & macrophysics)
Evaluation and Metrics

**Complex Models**
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**Idealized Models**
(Aquaplanets, RCE)

**Process Models**
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Conceptual Understanding, Interpretations of Complex Simulations
Evaluation and Metrics

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Field & Lab Observations
**Evaluation and Metrics**

- **Complex Models** (ESMs, NWP)
  - Fidelity to Validated Process Knowledge

- **Process Models** (DNS, LES, CRMs for radiative transfer, turbulence, boundary layers, convection, cloud microphysics & macrophysics)
  - Lacking in Most Complex Model Metrics

- **Idealized Models** (Aquaplanets, RCE)
  - Field & Lab Observations
Countervailing Metrics: The Example of an Emergent System Property (Historical Global Temperature Change) versus a Fundamental Process Property (Rain Production Rate)
Adjusted Forcing in 2003 vs. Equilibrium Climate Sensitivity (K)

- CMIP5: $R^2 = 0.1941$
- CMIP5 selection: $R^2 = 0.7369$
- CMIP3 (Knutti): $R^2 = 0.2414$
- Kiehl: $R^2 = 0.5027$

From Forster et al. in *Journal of Geophysical Research: Atmospheres*
*Volume 118, Issue 3*, pages 1139-1150, 6 FEB 2013 DOI: 10.1002/jgrd.50174
How did the 20th Century warm? High forcing/low sensitivity or low forcing/high sensitivity? Why is it important?

Future climate change will be driven more by greenhouse gases than aerosols, as aerosols have shorter lifetime than dominant anthropogenic greenhouse gases and aerosols likely to be regulated by air-pollution policy. “Masking” by aerosols will be less. Projecting warming requires knowledge of sensitivity.

Cloud tuning in a coupled climate model: Impact on 20th century warming

In GFDL CM3, aerosol indirect effect (cooling by cloud-aerosol interactions) depends strongly on volume-mean drop radius at which precipitation forms.


*Geophysical Research Letters*


Based on Golaz *et al.* (2013)
Cloud tuning in a coupled climate model: Impact on 20th century warming

Observed volume-mean drop radius for precipitation initiation (VMDR)
10-12 µm

based on Golaz et al. (2013)
Evaluating cloud tuning in a climate model with satellite observations

PDFs of Radar Reflectivity (%dBZ$^{-1}$)

CloudSat/MODIS

GFDL AM3w

GFDL AM3

GFDL AM3c

Geophysical Research Letters
Volume 40, Issue 16, pages 4464-4468, 29 AUG 2013 DOI: 10.1002/grl.50874

based on Suzuki et al. (2013)
This diagnostic can be used with many formulations for cloud microphysics. Summary statistics (bias, RMSE, correlation coefficients) against A-Train provide process metrics for climate models.

Portrait Diagrams for Large-Scale Fields and Process-Level Metrics

CMIP5 Normalized RMS Errors for Large-Scale Fields

A New Portrait Diagram Based on Process Evaluation?

Example:

RMS Errors, Bias, Correlation Coefficients for A-Train vs. Models’ Reflectivity/Optical Depth PDFs

IPCC AR5 Fig. 9-7 (2013, Cambridge University Press)
Building a Portrait for Evaluating Physical Processes in Climate Models

Uncertainties in climate sensitivity related to cloud feedbacks are apparent in distinct cloud systems that can be evaluated with LES and CRMs, in turn evaluated against observations. GCM/SCM comparison with process-based skill scores can paint part of the portrait.

from Stephens (2005, J. Climate)

from Tan et al. (2014, JGR)
Conclusions

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• Controls on critical and still poorly understood aspects of the climate system (forcing, sensitivity) should be identified in complex models.
• Idealized models can be guides to doing so and generate hypotheses.
• Once identified, these controls should be evaluated against process models and observations.
• Process realism should join means and variability among the evaluation metrics for complex models.