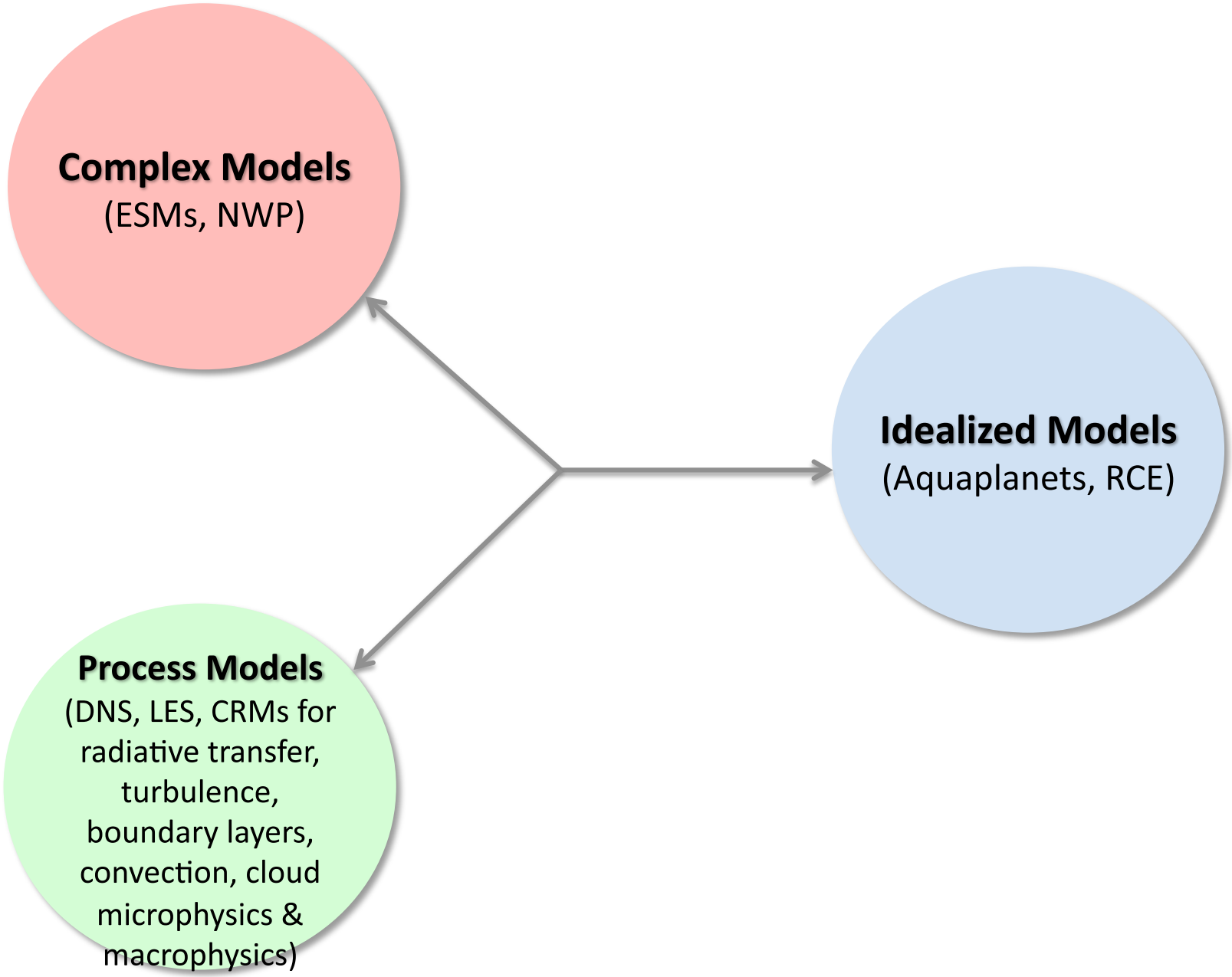
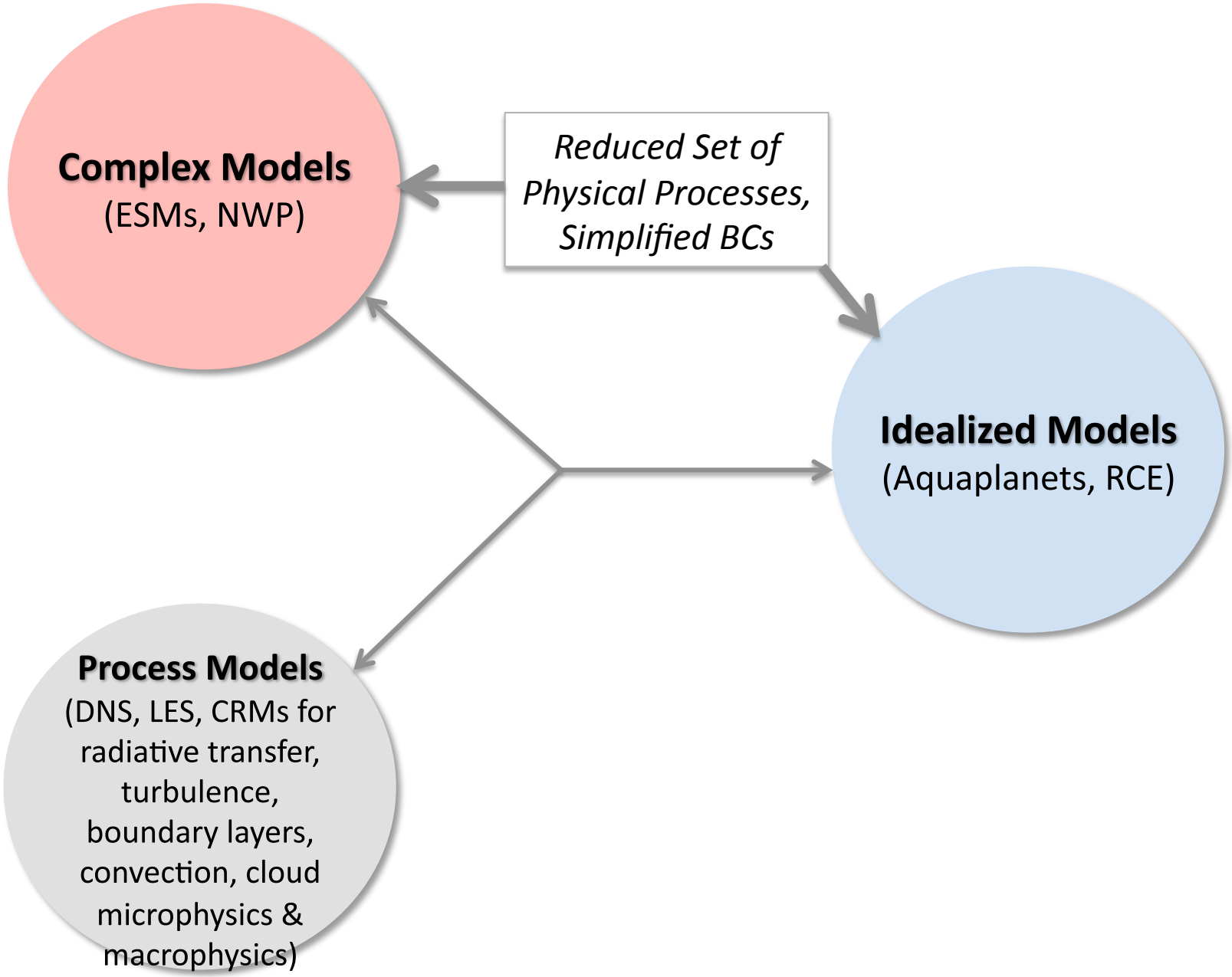
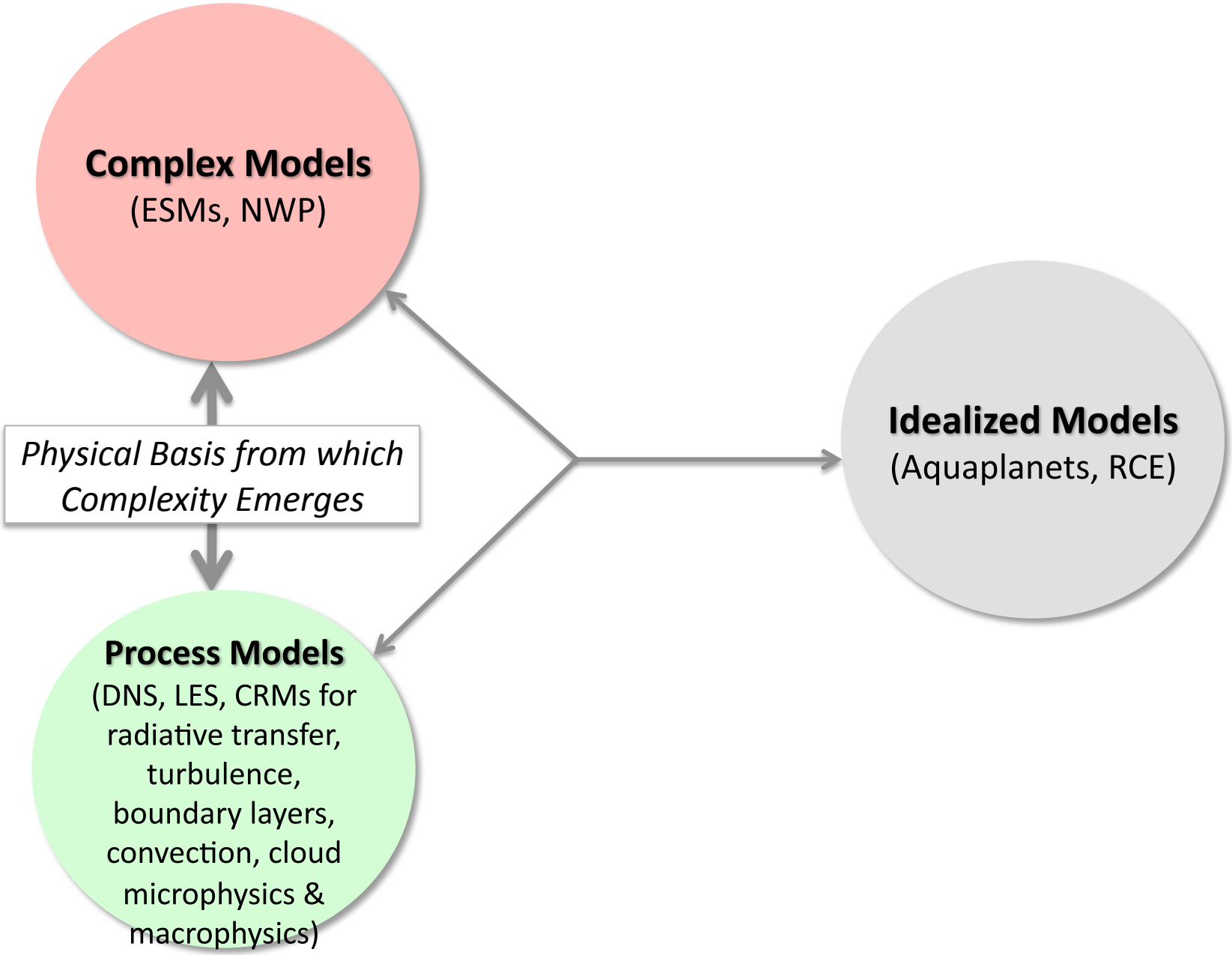
Physical Process Realism and Model Hierarchies

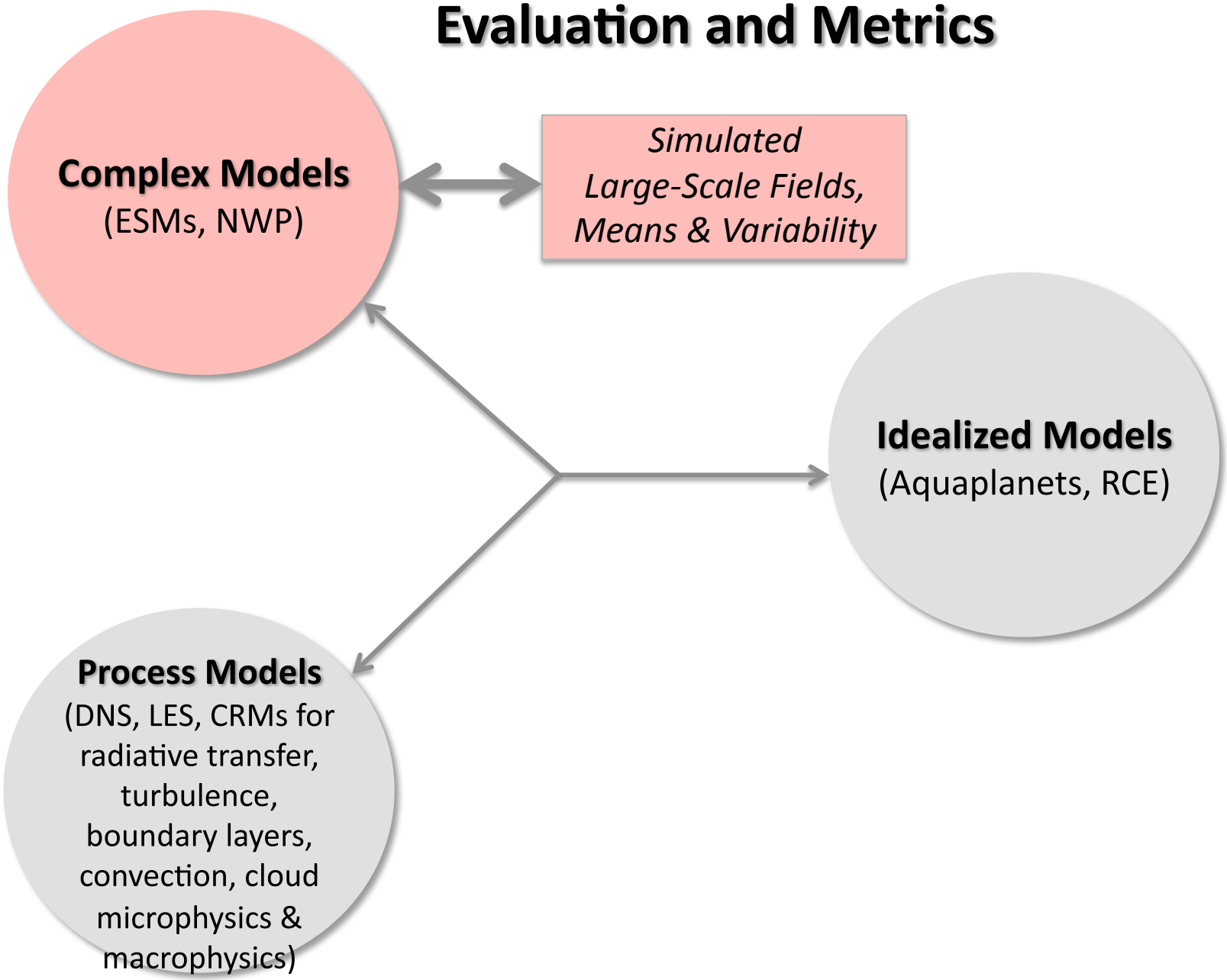
Leo Donner
GFDL/NOAA, Princeton University

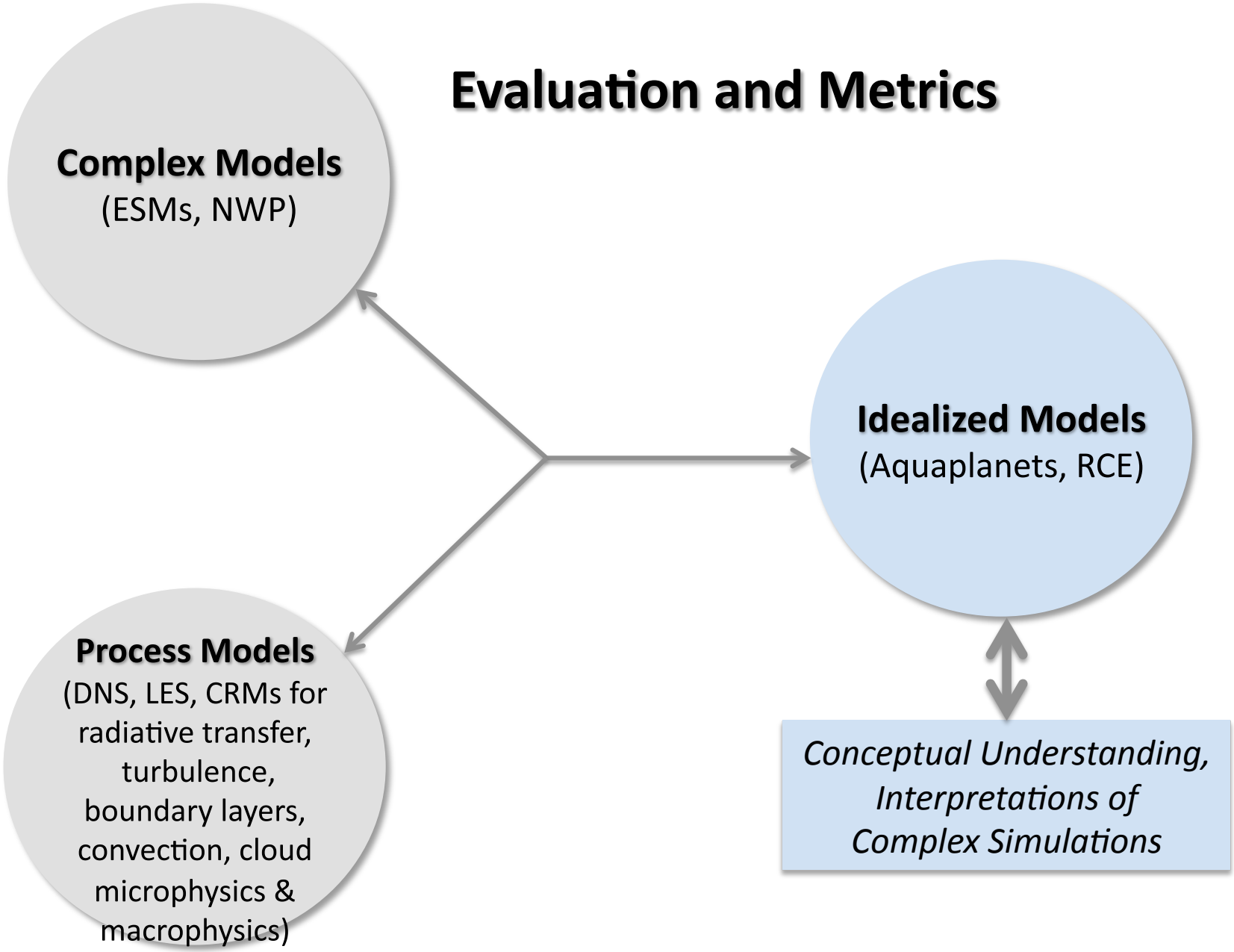
Model Hierarchies Workshop
Princeton University, 4 November 2016


Complex Models
(ESMs, NWP)
Idealized Models
(Aquaplanets, RCE)
Process Models
(DNS, LES, CRMs for radiative transfer, turbulence, boundary layers, convection, cloud microphysics & macrophysics)


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)


Complex Models
(ESMs, NWP)
Physical Basis from which Complexity Emerges
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
(ESMs, NWP)
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Process Models
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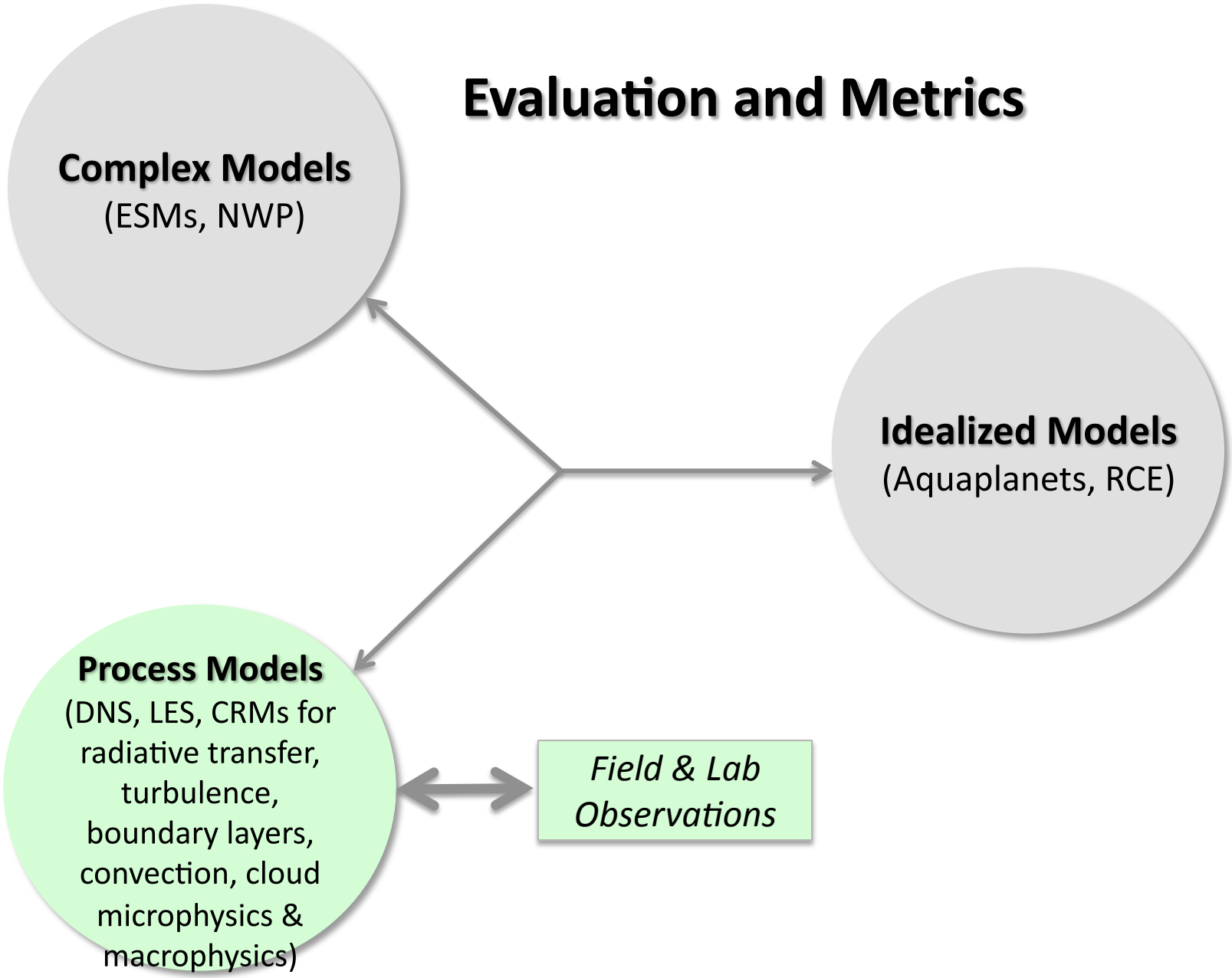
Conceptual Understanding, Interpretations of Complex Simulations


Evaluation and Metrics
Complex Models
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Idealized Models
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Process Models
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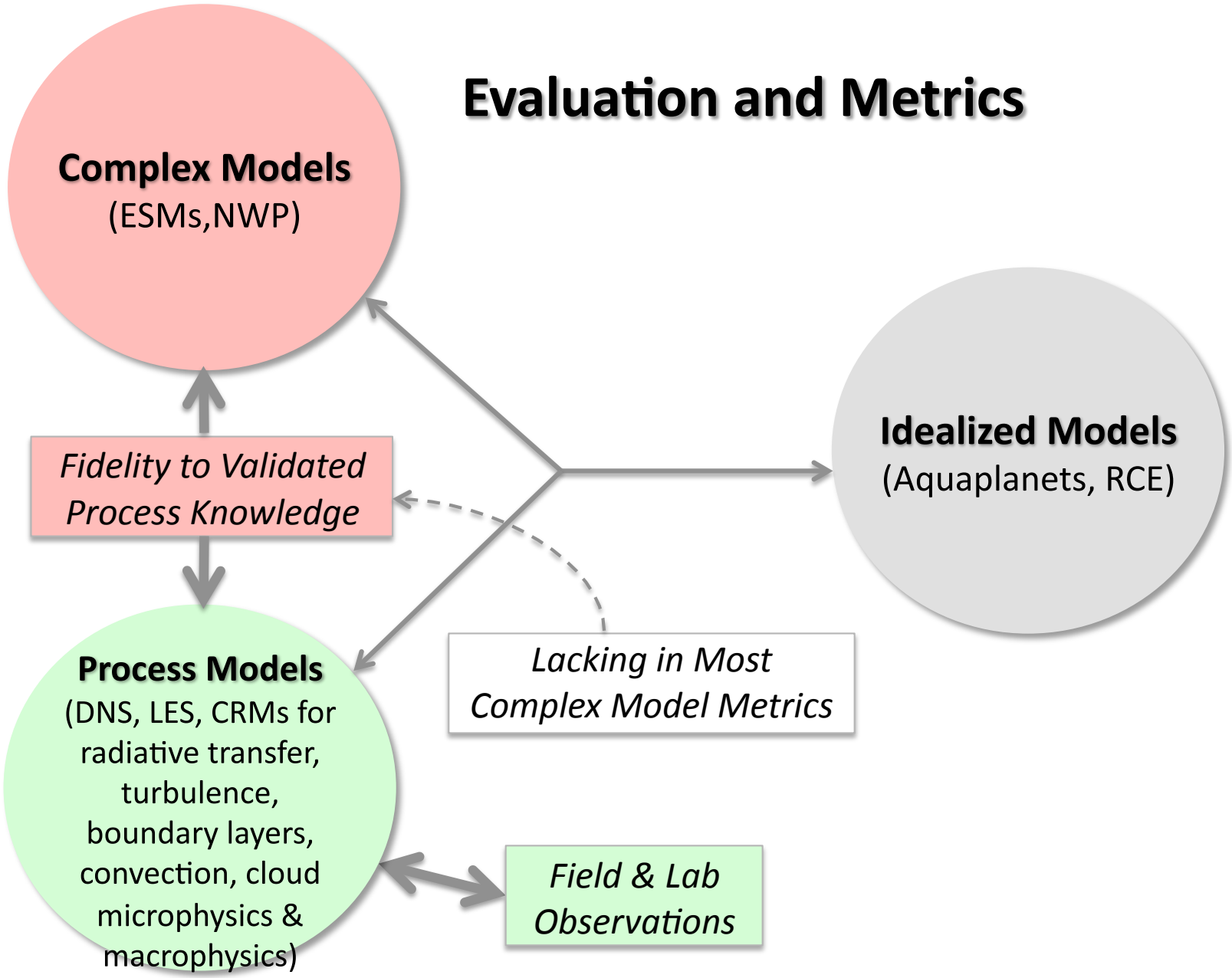
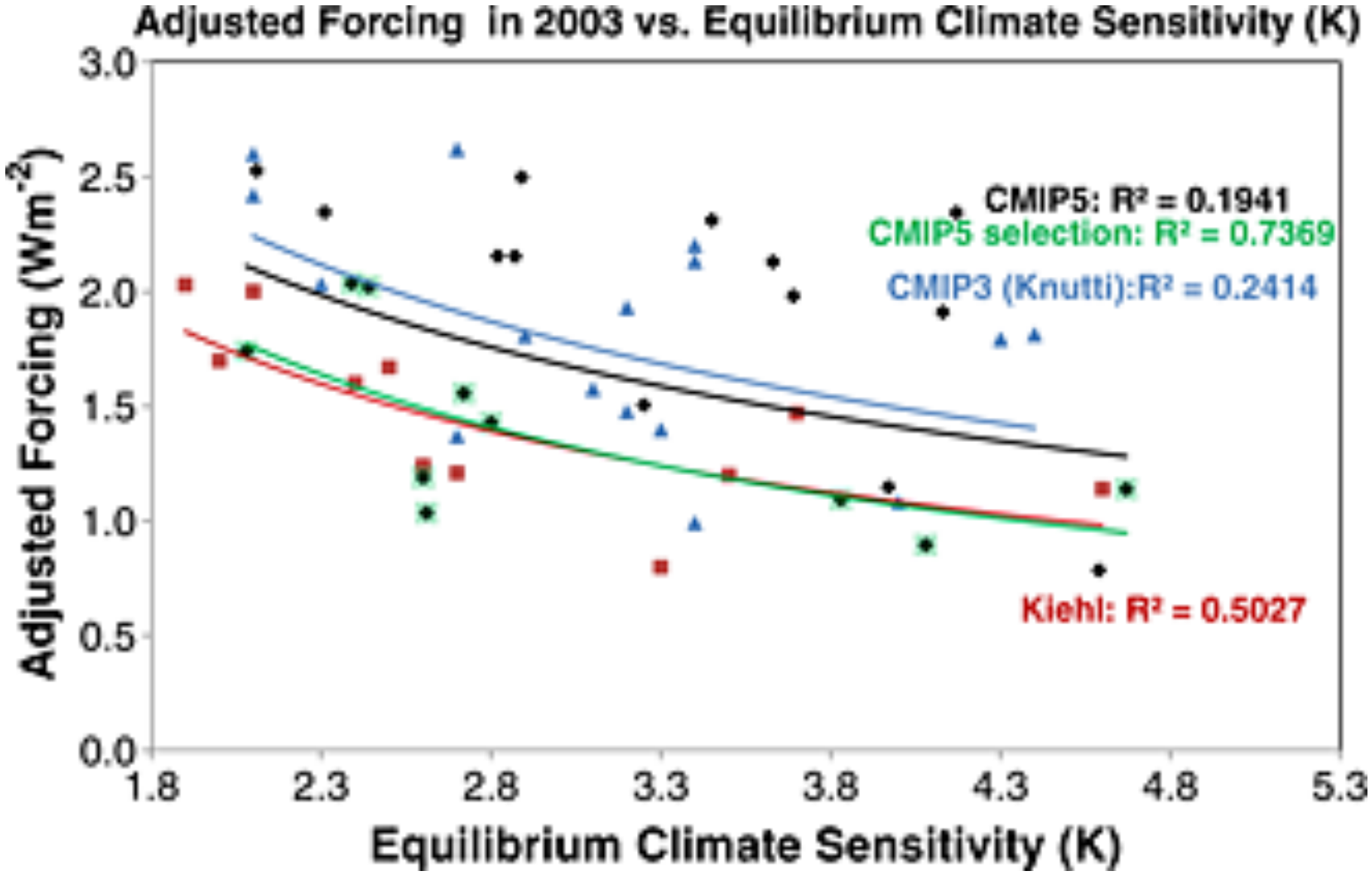
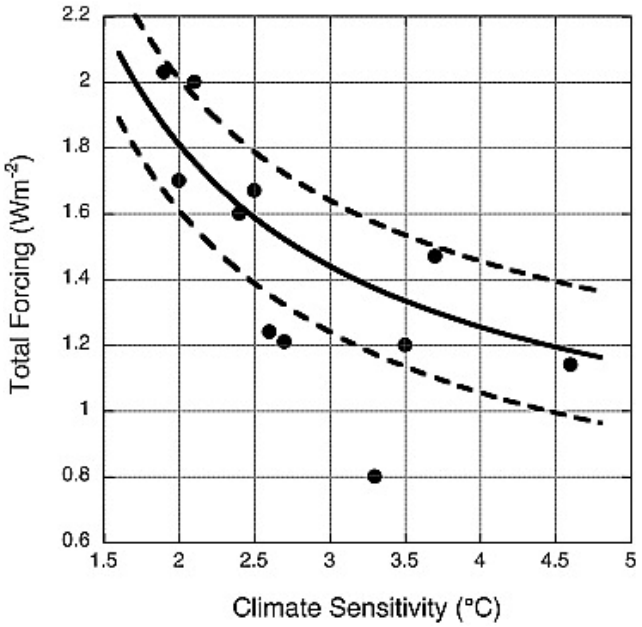
Field & Lab Observations


Evaluation and Metrics
Complex Models
(ESMs,NWP)
Idealized Models
(Aquaplanets, RCE)
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
Field & Lab
Observations

Countervailing Metrics: The Example of an Emergent System Property (Historical Global Temperature Change) versus a Fundamental Process Property (Rain Production Rate)



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
http://onlinelibrary.wiley.com/doi/10.1002/jgrd.50174/full#jgrd50174-fig-0007



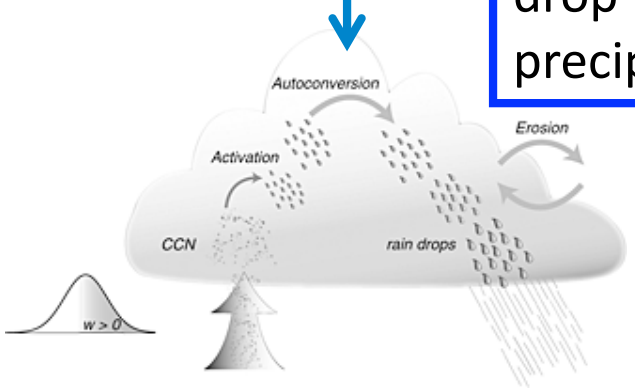
Kiehl (2007, *Geophys. Res. Lett.*)

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



Observations show volume-mean drop radius for precipitation formation around 10-12 µm (Gerber, 1996, *J. Atmos. Sci.;* Pawlowska and Brenguier, 2003, *J. Geophys. Res.;* Boers *et al.,* 2006, *QJRMS*)

Geophysical Research Letters
Volume 40, Issue 10, pages 2246-2251, 27 MAR 2013 DOI: 10.1002/grl.50232
http://onlinelibrary.wiley.com/doi/10.1002/grl.50232/full#grl50232-fig-0001

based on Golaz *et al.* (2013)

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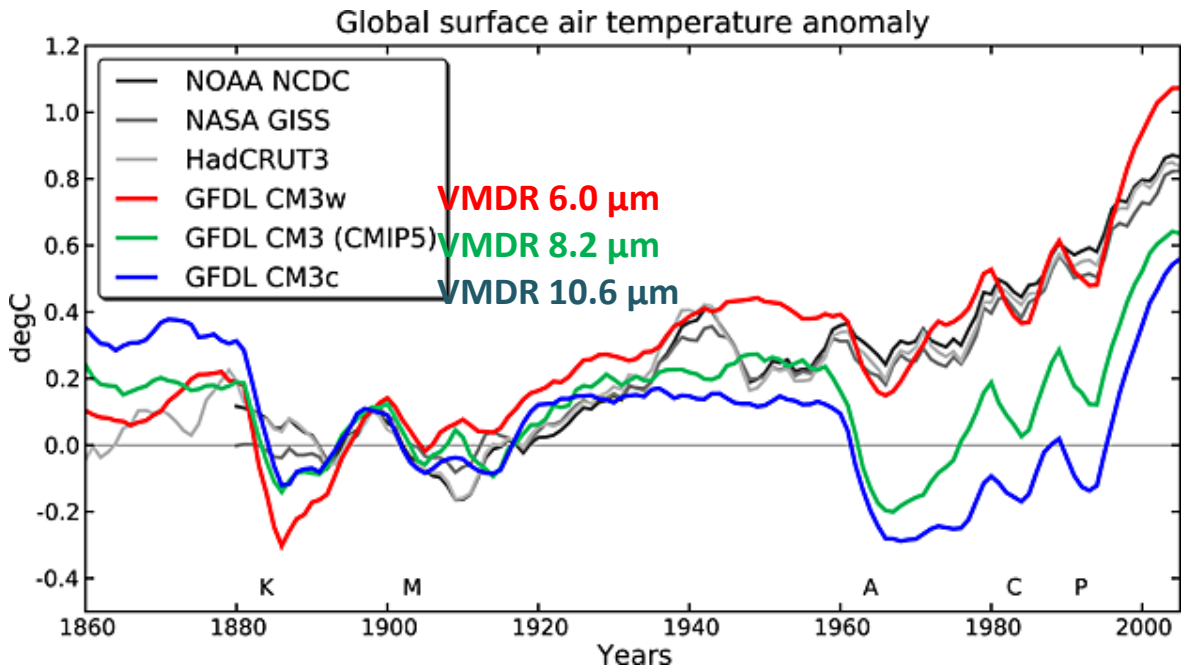

Observed volume-mean drop radius for precipitation initiation (VMDR)
10-12 µm

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Volume 40, Issue 10, pages 2246-2251, 27 MAR 2013 DOI: 10.1002/grl.50232
http://onlinelibrary.wiley.com/doi/10.1002/grl.50232/full#grl50232-fig-0003

based on Golaz *et al.* (2013)

Evaluating cloud tuning in a climate model with satellite observations

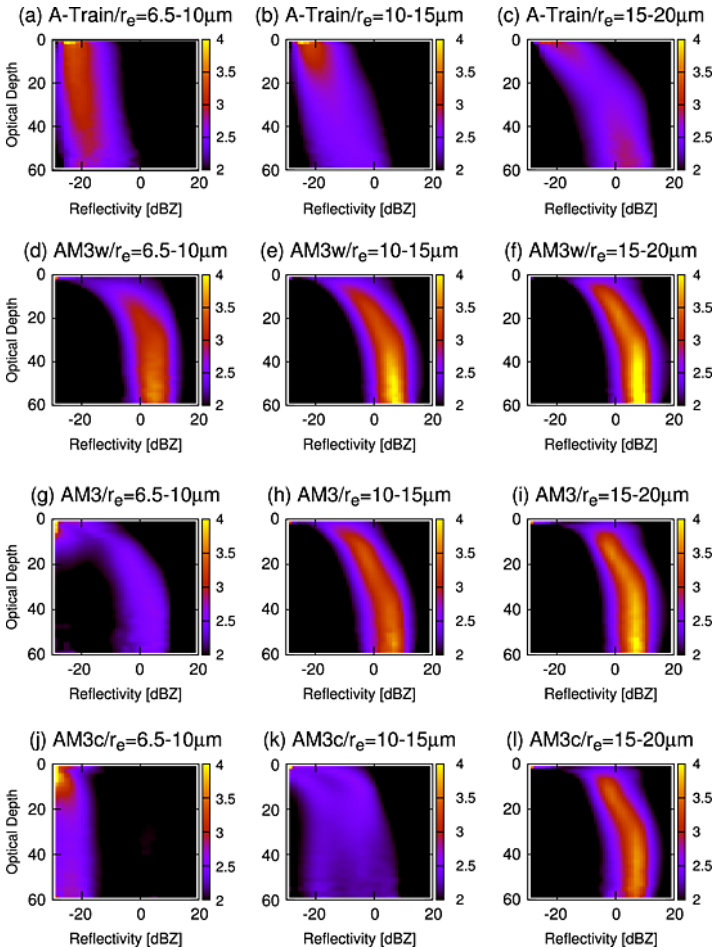
PDFs of Radar Reflectivity (%dBZ^{-1})

CloudSat/MODIS

GFDL AM3w

GFDL AM3

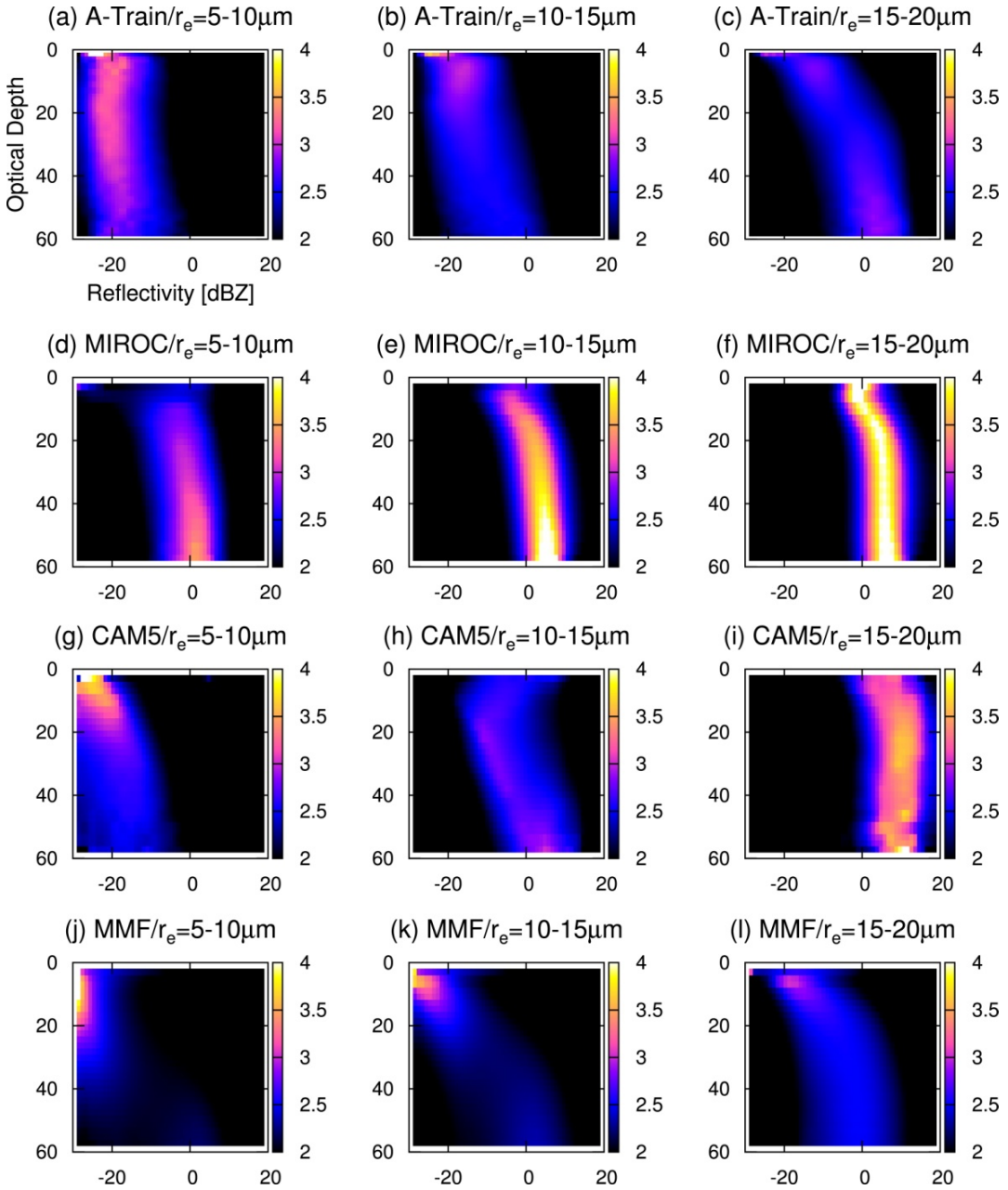
GFDL AM3c



Geophysical Research Letters
Volume 40, Issue 16, pages 4464-4468, 29 AUG 2013 DOI: 10.1002/grl.50874
http://onlinelibrary.wiley.com/doi/10.1002/grl.50874/full#grl50874-fig-0002

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.

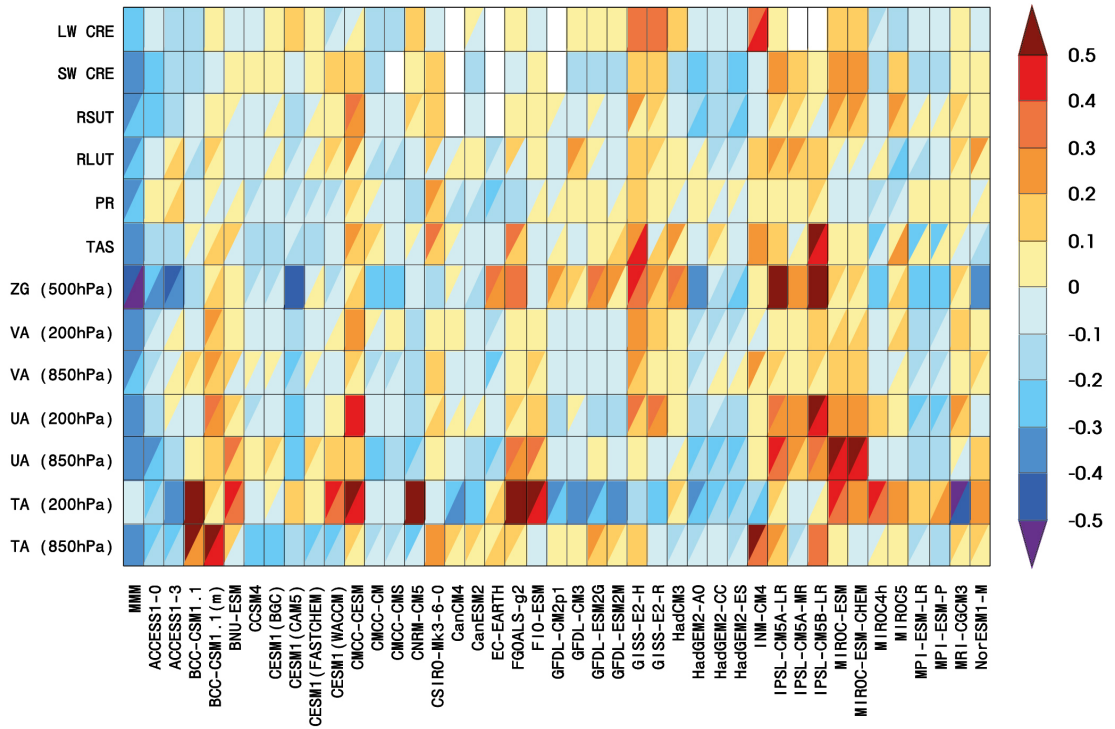


PDFs of Radar Reflectivity (%dBZ^{-1})

Figure 3 from Suzuki et al 2015: Evaluation of the Warm Rain Formation Process in Global Models with Satellite Observations. J. Atmos. Sci., 72, 3996–4014, doi: 10.1175/JAS-D-14-0265.1.

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

CMIP5 Normalized RMS Errors for Large-Scale Fields



IPCC AR5 Fig. 9-7 (2013, Cambridge University Press)

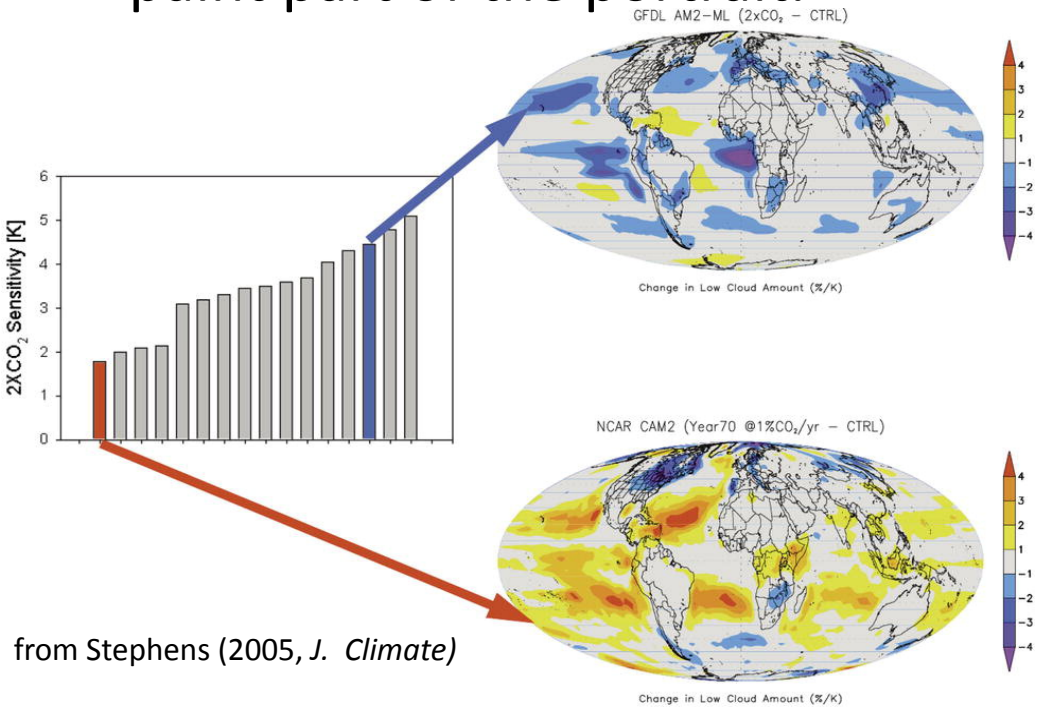
A New Portrait Diagram Based on Process Evaluation?

Example:

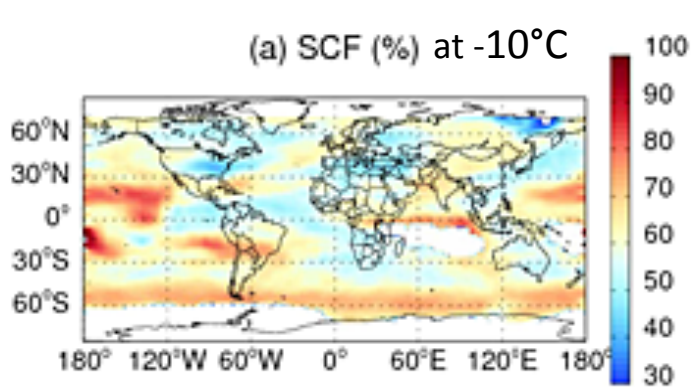
RMS Errors, Bias, Correlation Coefficients for A-Train vs. Models' Reflectivity/Optical Depth PDFs

Building a Portrait for Evaluating Physical Processes in Climate Models

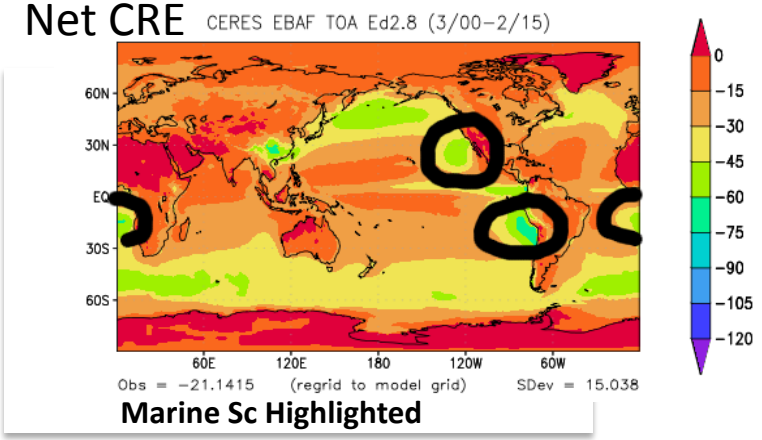
Uncertainties in climate sensitivity related to cloud feedbacks are apparent in distinct cloud systems that can be evaluated with LES and CRMs, in turn evaluated against observations. GCM/SCM comparison with process-based skill scores can paint part of the portrait.



from Stephens (2005, *J. Climate)*



from Tan *et al.* (2014, *JGR*)



Marine Sc Highlighted

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.