THE LOGIC AND ETHICS OF ACTIONABLE SCIENCE:
Recommendations for Responsible Use of Earth System Models for Applied Purposes

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NCAR
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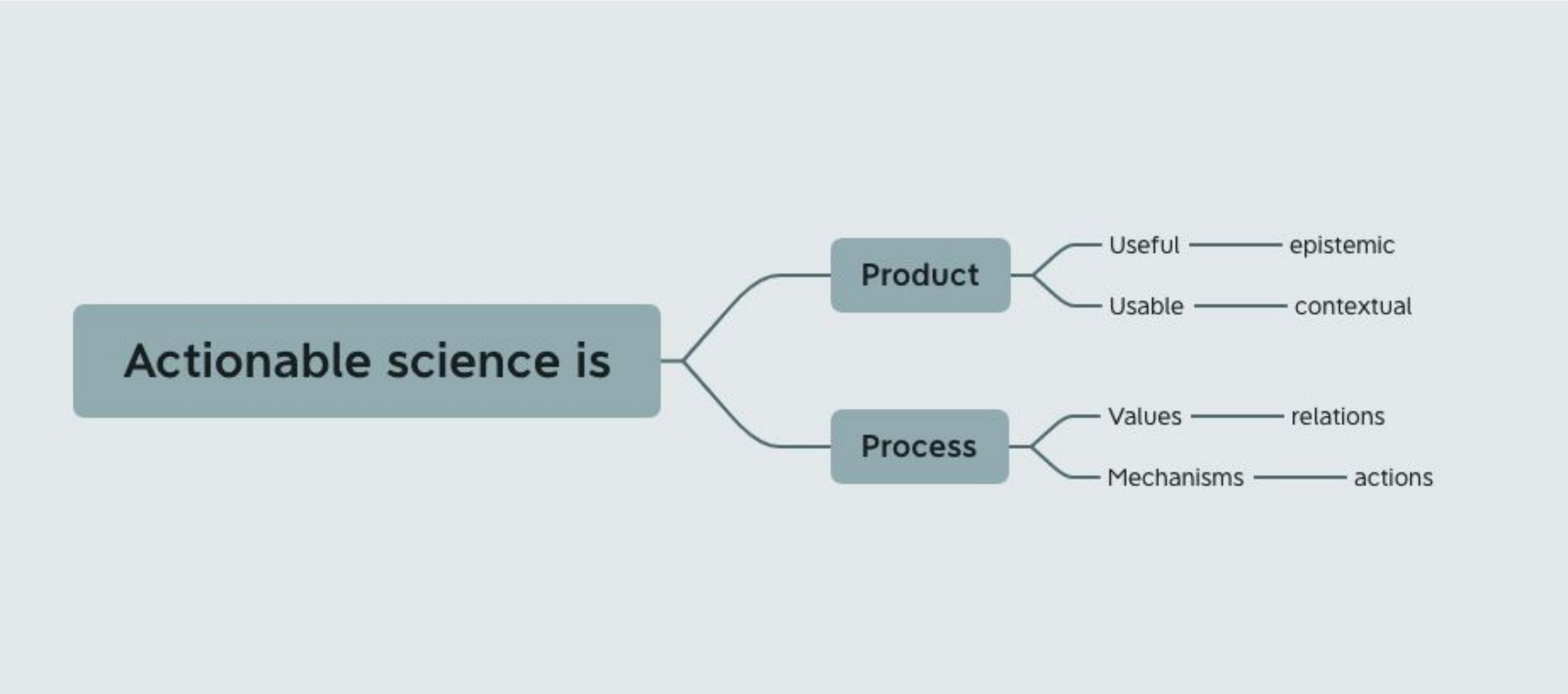
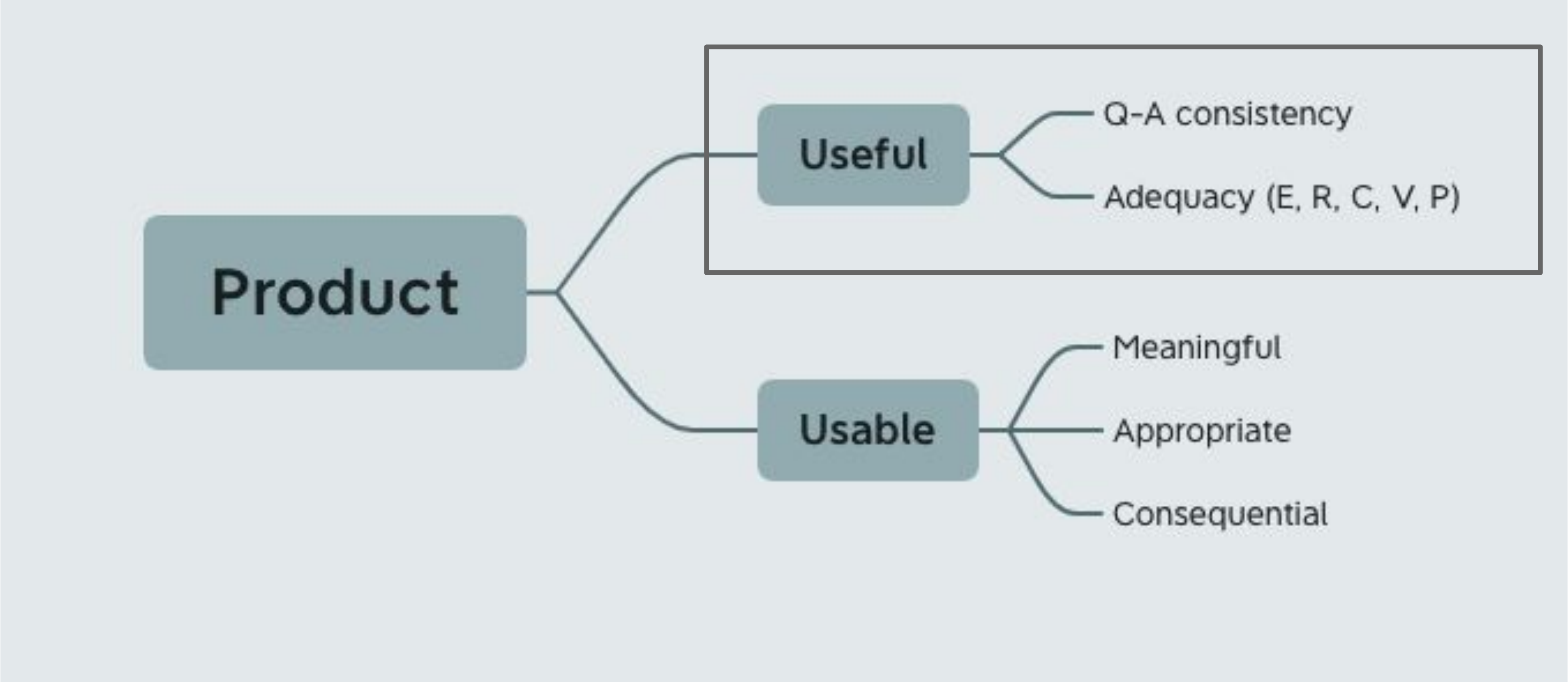
Epistemic risk and hazard management—in terms of greater transparency, translation, and explicit and systematic communication about adequacy-for-purpose—is how the modeling community can contribute to actionable science and climate justice.

Morrison, forthcoming, 2023b

What is Actionable Science?



Actionable Information Products



Philosophy of Scientific Representation

Models are perspectives on a targets system, are adequate-for-purpose, and built to be such.

A model will represent certain features of the complex causal system at the expense of oversimplifying, obscuring, or omitting other features of the causal space.

This representational perspective a model occupies is a function of the interests, aims, and priorities of the research and development communities.

Parker, 2020 (see also Giere and van Fraassen)

Purposes of GCMs/ESMs

1. Historical reconstructions of past climates

2. Future projections of global climate changes under scenarios of human activities

3. Understanding large-scale energy fluxes between ocean, land, and atmosphere

4. Episodic forcings and equilibrium response on global climate, e.g. volcanic eruptions

5. Large-scale atmospheric and oceanic dynamics; carbon cycle

Repurposing of GCMs/ESMs

1. Rates of sea level rise in coastal regions

2. Changes in wildfire regimes under possible future climates

3. Feasibility of ocean-based carbon dioxide removal approaches

4. Assessments of future water security related to changes in precipitation, evapotranspiration and runoff

5. Impacts to agricultural lands under future climate

Epistemic Risk

Scientific inquiry involves making decisions.

With each decision there is a possibility of mistake.

Decisions about what assumptions to involve, what approaches to use, how to evaluate results, carry this risk.

This “risk of getting it wrong” is epistemic risk—as is the risk of the decision being “inadequate” for a purpose.

Risk in Model Development Choices

Representational risk is a specific kind of epistemic risk in model-based science.

It results when a representational decision is inadequate for a purpose, as a hazard can be introduced and result in a downstream harm depending on the information use context.

Risk in Model Application Choices

Phronetic risks are those that arise during activities and decisions that serve as preconditions for empirical reasoning.

The choice of which models to use to collect statistical information to inform reasoning about a result involves this risk.

The presence of risk, and the introduction of hazards, is amplified, and becomes especially salient when models are repurposed, or applied to answer questions for which they were not originally constructed—inconsistent with development purposes.

Morrison, forthcoming, 2023a

The Ethical Dimensions of Scientific Modeling

If our model is inadequate in terms of its representational features for answering certain questions…

There are associated hazards with using the model to answer those questions…

And in actionable contexts this can lead to harms such as maladaptation, mal-intervention…high degrees of inaccuracy, irrelevance, misleading or largely incomplete results.

Morrison, forthcoming, 2023a

The Problem of the Great Lakes

"We found that most CMIP5 models do not simulate the Great Lakes in a way that captures their impact on the regional climate, which is a credibility issue for their projections."

Briley et al. 2021

These models simulate large lake dynamics (i.e., lake-atmosphere feedbacks), but in a few models it is not clear whether the Great Lakes are simulated. Further evaluation is required to know if the simulated lake dynamics are realistic.

BCC-CSM1-1m	1.12°x1.13°	y
CCSM4	0.94°x1.25°	y
CESM1-BGC	0.94°x1.25°	y
CESM1-CAM5	0.94°x1.25°	y
CESM1(WAC-CM)	1.88°x2.5°	y
CESM1(fast- chem)	0.94°x1.25°	y
CSIRO-Mk3.6.0	1.87°x1.88°	y
FGOALS-g2	2.79°x2.81°	y
GFDL-CM3	2.00°x2.50°	y
GFDL-ESM2G	2.02°x2.50°	y
GFDL-ESM2M	2.02°x2.5°	y
GISS-E2-H	2.00°x2.50°	unknown
GISS-E2-H-CC	2°x2.5°	unknown
GISS-E2-R	2.00°x2.50°	unknown
MIROC5	1.40°x1.41°	unknown
MRI-CGCM3	1.12°x1.13°	unknown
NorESM1-M	1.89°x2.50°	y
NorESM1-ME	1.89°x2.50°	y

The MIROC4h model simulates the Great Lakes as oceans. Further evaluation is required to know if the simulated lake dynamics are realistic.

MIROC4h	0.56°x0.56°	y

These models treat lakes as a water surface, but the absence of interactive (i.e., dynamic) lakes is a limiting factor for accurately representing lake temperature and lake ice cover feedbacks. For this reason, use of these models is not recommended.

ACCESS 1.0	1.25°x1.88°	unknown
BNU-ESM	2.79°x2.81°	unknown
HadGEM2 family	1.875°×1.25°	unknown

Part of the Great Lakes are crudely (with limited spatial coverage and resolution) simulated as oceans in these models. These models may be able to offer useful information and simulate lake-atmosphere feedbacks at the regional scale, but site-specific or local analysis is not advised.

HadCM3	2.5°x3.75°	n
IPSL-CM5A-LR	1.89°x3.75°	n
IPSL-CM5A-MR	1.27°x2.50°	n
IPSL- CM5B-LR	1.89°x3.75°	n

From the found documentation, it is not apparent that there is any form of lake representation in these models. These models are not recommended for the Great Lakes region.

ACCESS 1.3	1.25°x1.88°	n
BCC-CSM1.1	2.79°x2.81°	n
GFDL-CM2.1	2.79°x2.81°	n
MIROC-ESM	2.79°x2.81°	n

In these models, there are conflicts over how the Great Lakes are geographically defined in the land and ocean components. Inspection of the land and ocean components revealed the case where 1) both components claim 100% responsibility for simulating surface states/fluxes over at least one Great Lake and/ or 2) neither component is responsible for simulations over at least one Great Lake. These conflicts indicate uncertainty in how fluxes between the land, ocean, and atmosphere components are coupled. These models are not recommended for the Great Lakes region.

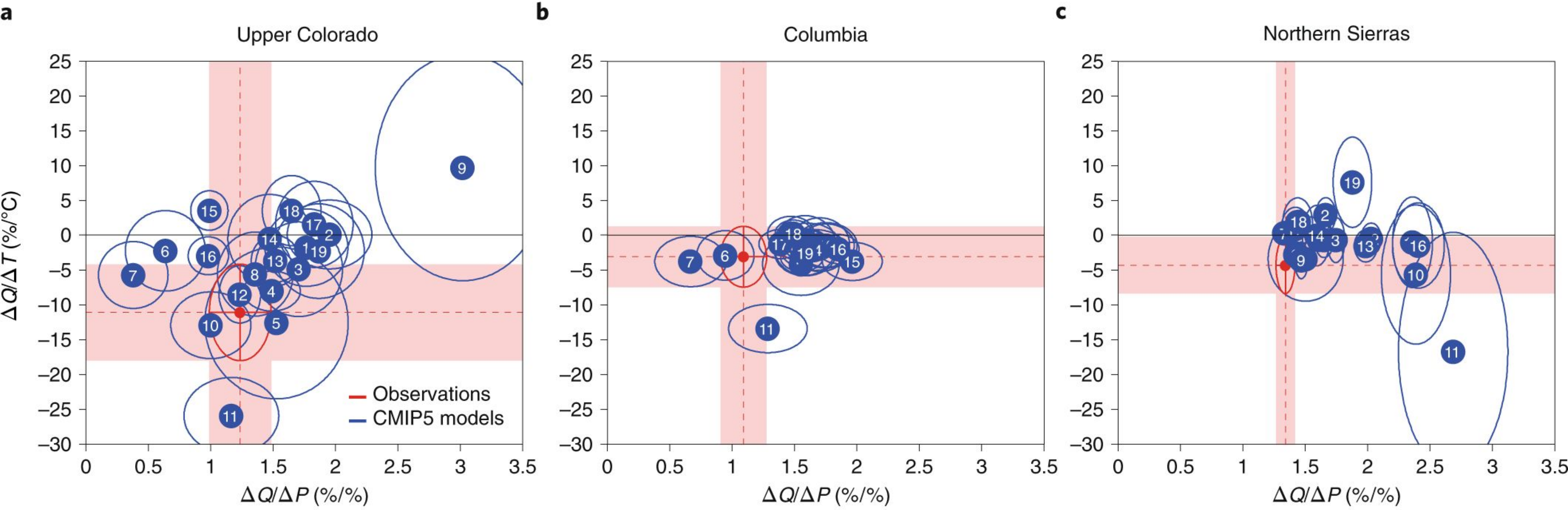
CMCC-CESM	3.44°x3.75°	n
CMCC-CM	0.75°x0.75°	n
CMCC-CMS	1.86°x1.88°	n
INM-CM4	1.50°x2.00°	n
CanESM2	2.79°x2.81°	n
NCEP-CFSv2	1°x1°	n
CNRM-CM5	1.40°x1.41°	n
EC-Earth	1.12°x1.13°	n
MPI-ESM-LR	1.86°x1.88°	n

Bulletin of the American Meteorological Society 101, 10; 10.1175/BAMS-D-19-0099.1

Problems with Runoff Sensitivities

“To the best of our knowledge, no systematic effort has been made to assess the credibility of the regional runoff sensitivity in coupled ESM simulations.”

“We urge caution in the direct use of climate model runoff for applications…”



1 CCSM4
2 CESM1-BGC
3 CESM1-CAM5
4 CNRM-CM5
5 CanESM2
6 GFDL-ESM2G
7 GFDL-ESM2M
8 GISS-E2-H
9 IPSL-CM5A-MR
10 MIROC-ESM
11 MIROC5
12 MPI-ESM-LR
13 MPI-ESM-MR
14 MRI-CGCM3
15 NorESM1-M
16 NorESM1-ME
17 bcc-csm1-1
18 bcc-csm1-1-m
19 inmcm4

At the Very Least…

…explicit guidance must be provided about the representational limitations of the models—their simulations and data—for certain purposes, and more communication about what models, their simulations and related output, have been purposed for, and not purposed for…

Morrison, forthcoming, 2023b

Criterion for Representational Adequacy of Models

Representational adequacy—representational content (what is represented, and how)

Configuration adequacy—experimental set up

Process and dynamical adequacy—simulated behavior of key causal determinants/drivers

Data adequacy-for-purpose

Morrison, forthcoming, 2023c

What Does this Mean for our Practices?

Less

Boundary Management (reduce harm)

- Guidance documents—standardization
- Decision and purpose transparency
- Translations/translators

Collaboration (promote justice)

- Minimal-adequacy studies—model culling
- Co-design—tailored-assessments
- Co-development/production—configurations, experiments, (and ideally, models)

More

Morrison, forthcoming, 2023b

Minimal representational adequacy:

Are the key features of the system of interest adequately represented in the model—are the physical characteristics that are causal determinants of the phenomenon of interest included in the model, and are these parameterizations designed to simulate the processes associated with the phenomenon of interest in the science question?

Think—are there 3-D lakes or not for adequate representation of lake-atmosphere interactions in model?

Yes—minimally adequate; no-inadequate

Example: process, pattern, and dynamic adequacy tests

System simulated behavior adequacy-for-purpose: Assessment of characteristic and identifiable structures, and representations of key climate features and behavior under change, which function as determinants of the phenomena central to the model application purpose (ability to simulate the causal and dynamical dependencies for key processes that govern the variable/phenomena of interest)…

Example: process, pattern, and dynamic adequacy tests

1. What information do we want to take from the model—what is the phenomenon of interest?
    1. Precipitation regimes in Great Plains.
2. What are the climatic drivers (systematic or regional) that are the causal determinants of the phenomenon of interest?
    1. Upper-level jet; Great Plains lower-level jet; land surface feedbacks; monsoon anticyclone
3. What can we say about how those driver will change under future climate conditions?
    1. (Upper-level jet): northward shift—increase in speed of winds in north, and decrease speed of winds in south
4. What are the underlying processes that interact to determine the emergent behavior of the drivers?
    1. Specific humidity; perpendicular air flow; parallel air flow.
5. Are ways in which the processes simulated going to produce the behaviors for the driver hypothesized in (3)?

Bukovsky et al. 2017, see Kawamleh 2022 (analysis)

Questions?