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EVIDENCE, REVERSIBILITY AND LONG-HORIZON DECISIONS IN COMPLEX SUBSURFACE SYSTEMS

Committee of Environmental and Geological Engineering (12EGE)

International Organization on Technical and Physical Problems of Engineering (IOTPE)

Why Long-Horizon Subsurface Decisions Are Difficult

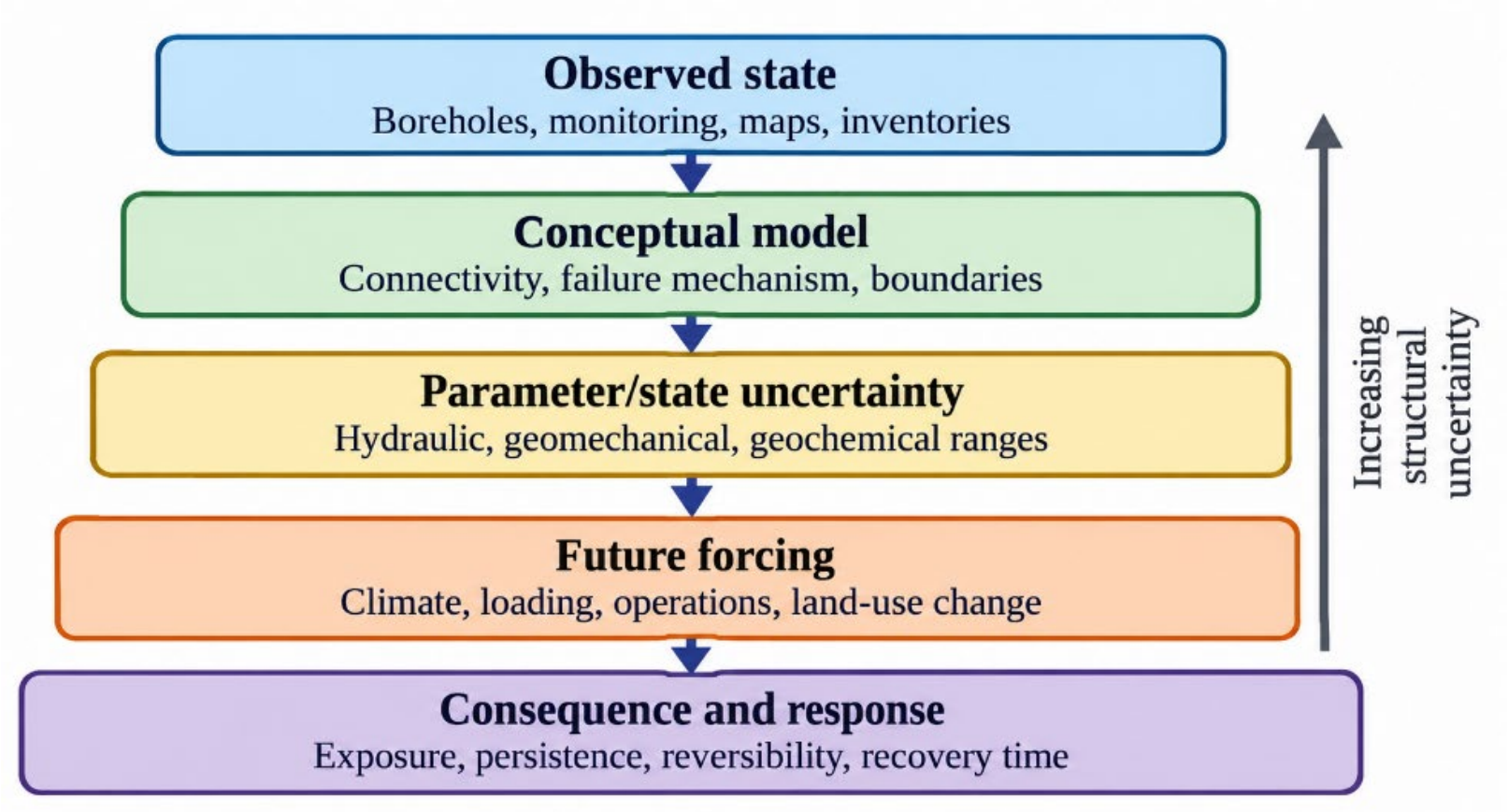
- Sparse observations cannot reveal every connection or failure mechanism.
- Competing geological interpretations can fit the same evidence.
- Future forcing and operating conditions remain uncertain.
- Some commitments persist far beyond the project lifetime.

Central question: Is the evidence adequate for the commitment proposed?

Review Objective and Contribution

- Scientific-committee synthesis—not a new numerical risk score.
- Classify decisions by the uncertainty that controls them.
- Challenge preferred explanations using plausible alternatives.
- Link evidence maturity to reversibility and staged commitment.
- Treat monitoring as a continuing scientific test.

Anatomy of Subsurface Decision Uncertainty



Original paper — Figure 1. Layers of uncertainty

Four Decision Families

OBSERVATION-LIMITED

System state is partly observed; test alternative interpretations.

THRESHOLD-LIMITED

Trigger levels and response lead times are uncertain.

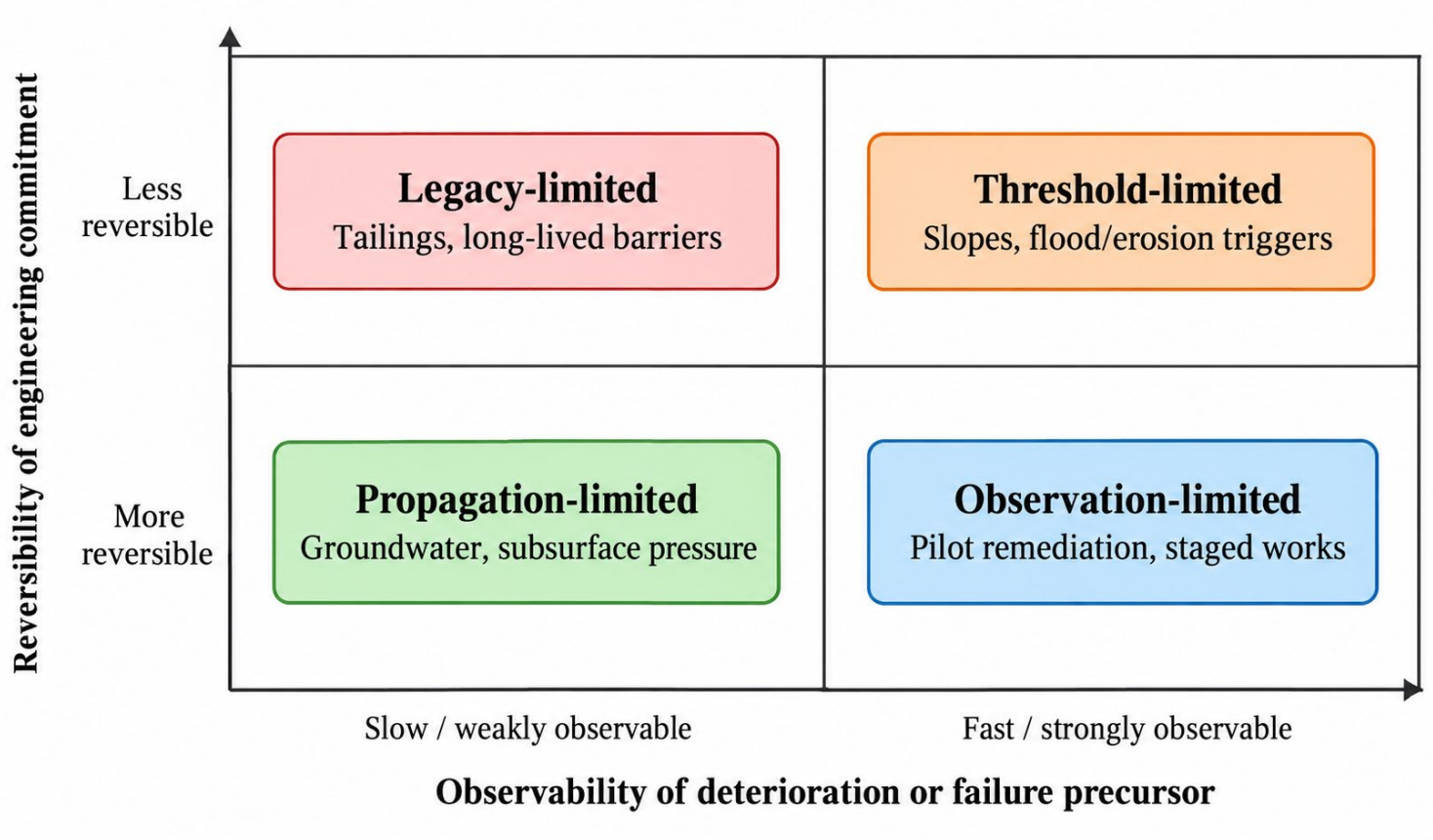
PROPAGATION-LIMITED

Migration pathways and spatial impacts are uncertain.

LEGACY-LIMITED

Persistent consequences outlast projects and institutions.

Observability Versus Reversibility



Original paper — Figure 2. Decision archetypes

Cross-Domain Scientific Questions

GROUNDWATER: Which connected pathways control transport?

SLOPES: Which mechanisms govern acceleration or failure?

INJECTION/STORAGE: Where can pressure and stress propagate?

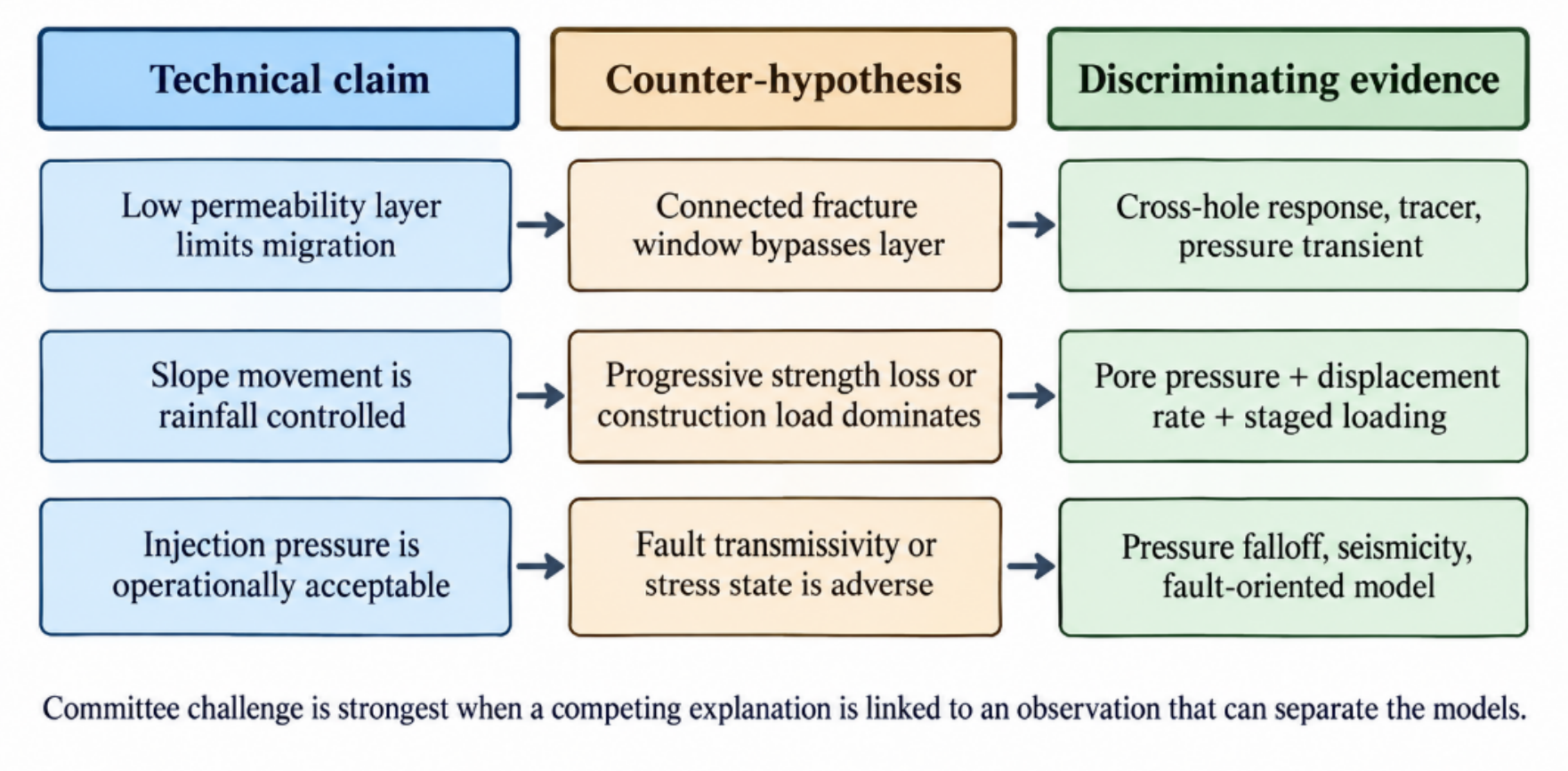
TAILINGS/BARRIERS: Can deterioration precede visible evidence?

RIVER/COAST: How will morphology respond to changed forcing?

Conceptual-Model Challenge

- A precise parameter estimate does not rescue the wrong conceptual model.
- Alternative physical explanations should remain visible.
- Require a consequential, physically plausible counter-hypothesis.
- Identify the observation that could discriminate between the two.
- Avoid averaging incompatible models into misleading certainty.

Claim → Counter-Hypothesis → Discriminating Evidence



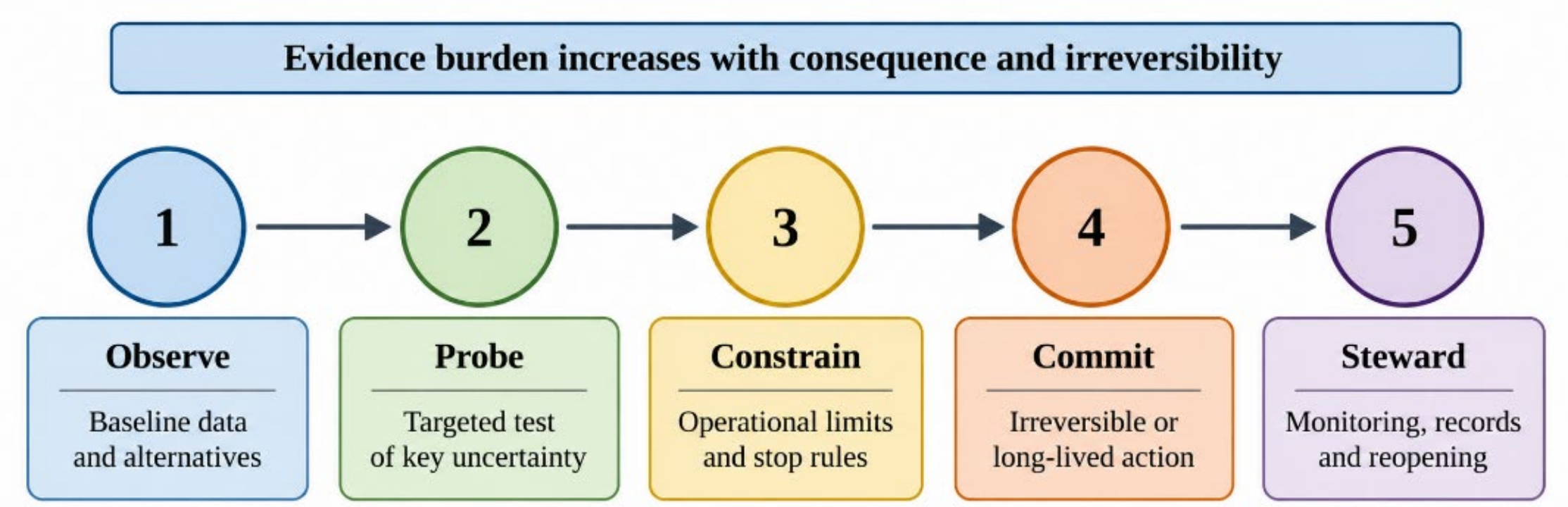
Original paper — Figure 3. Structured committee challenge

Risk Depends on Competing Models

- The manuscript outlines ensemble risk across conceptual models.
- Model weights express assumptions; they are not objective truth.
- A low-weight model may still imply a high-consequence pathway.
- Decision-critical disagreements can justify targeted observation.

Use model plurality to test the decision—not conceal disagreement.

Staged Commitment and Evidence Burden



Original paper — Figure 4. Observation through stewardship

Committee Recommendation Classes

PROCEED — mechanism and residual risk are adequately bounded.

PROCEED WITH LIMITS — use an operating envelope, trigger and response.

STAGED PILOT — learn reversibly with a short review and stop rule.

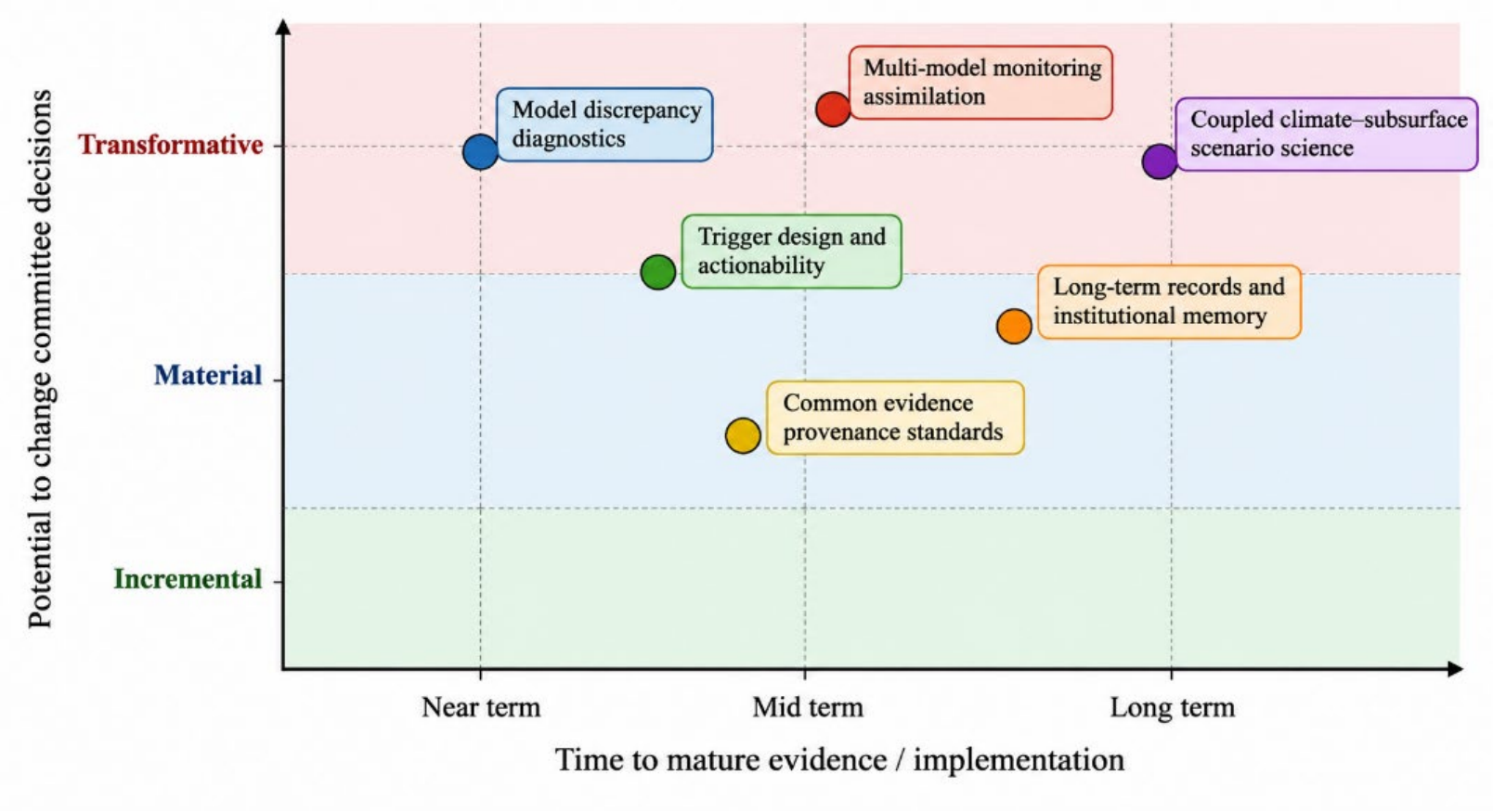
DEFER — investigate the decision-critical evidence gap.

REDESIGN / REJECT — uncontrolled credible high-consequence pathway.

Monitoring Must Lead to Action

- Detect deterioration, distinguish models or verify a control.
- Define thresholds and discrepancies before operating.
- Reopen review when a physical limit is crossed or observations leave the model envelope.
- Pair each alert with feasible lead time and a specified response.
- Preserve dissent, assumptions, model versions and trigger history.

Strategic Research Priorities



Original paper — Figure 5. Research horizon and committee value

What Future Research Must Demonstrate

- MODEL DISCREPANCY — detect structural error, not just parameter error.
- DISCRIMINATING MONITORING — prioritize measurements that change decisions.
- MULTI-MODEL ASSIMILATION — update alternatives during operation.
- ACTIONABLE TRIGGERS — validate the full detection-to-response chain.
- INFORMATION STEWARDSHIP — preserve evidence through institutional change.

Limitations of the Review

- A conceptual decision classification, not a substitute for safety codes or statutory approval.
- The four families can overlap and evolve as evidence changes.
- Ensemble-risk and reopening expressions are explanatory, not universal acceptance criteria.
- Domain-specific review and field evidence remain necessary.

Conclusions and Take-Home Message

- Numerical precision is not the same as decision adequacy.
- The evidence burden should reflect consequence, observability and reversibility together.
- Test competing mechanisms with discriminating observations.
- Increase commitment in stages when reversible learning is possible.
- Design monitoring with explicit actions and persistent records.

A defensible decision can be revised as new evidence emerges.