Risk-informed standards and guidelines

A performance-based approach

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Natural hazards and the built environment

- Buildings
- Integrated transportation systems (roads and bridges, airports, ports & harbors)
- Telecommunications facilities
- Power generation and distribution facilities
- Water/wastewater systems
- Flood protection structures (locks & dams, levees, flood walls

- Tropical cyclones, storm surge
- Sea level rise and coastal inundation
- Riverine flooding – precipitation, snow melt
- Tornadoes
- Earthquakes and tsunamis
- Extreme drought
- Wildfires
- Heatwaves
- Landslides

Uncertainty and risk
Sources of uncertainty in natural hazards

- Natural variability of climate ("chaotic"…"aleatory")
- Uncertainty in climate model response, or sensitivity, to projection of future emissions and other natural and anthropogenic climate forcings ("epistemic")
- Uncertainty in the probability distribution increases at the tail of the distribution ("epistemic").

Comment: Uncertainty leads to risk, which cannot be eliminated. It must be managed, and its management comes at a cost.

Traditional engineering approaches to infrastructure risk management

A critical appraisal

- Performance of built environment is largely determined by codes and standards
- Performance objectives differ for buildings, bridges and other civil infrastructure and are determined individually, not collectively.
- Codes and standards focus on individual hazards and facilities
- Margins of safety and functionality may not be commensurate with uncertainty
- Investments in risk mitigation and management may be misdirected

Engineering using natural infrastructure

Marshes, wetlands, mangroves, etc

- Standards and guidelines are not available
- Objectives may be unclear and competing
- Scientific basis for design uneven
- Uncertainties in performance may be large or unknown
- Costs and benefits may not become apparent for many years
- Unfamiliarity of engineering profession

Performance-based engineering
Framework

An engineering approach that is based on

- Specific goals for safety and functionality
- Probabilistic evaluation of hazards
- Evaluation of design alternatives against performance objectives

but does not prescribe a specific technical solution

Comments

- In practice, PBE is a mix of traditional and innovative methods
- Peer review is an important ingredient of PBE

Performance-based engineering
Basic premises

- Performance levels and objectives can be quantified and tailored to stakeholder needs
- Performance can be predicted with sufficient confidence
- **Uncertainties** can be modeled
- **Risk** can be managed at an acceptable level

Risk and its de-aggregation

- **Risk**
  - Hazard
  - Consequences
  - Context
- $\lambda_{Loss>c} = \Sigma_H \Sigma_{DS} P(L>c|DS)\, P(DS|H)\, \lambda_H$
  - λ_H = frequency of hazard
  - **P(DS|H)** = probability of damage, given hazard
  - **P(L>c|DS)** = probability of loss exceeding c, given damage
  - $\lambda_{Loss>c}$ = frequency of losses exceeding c

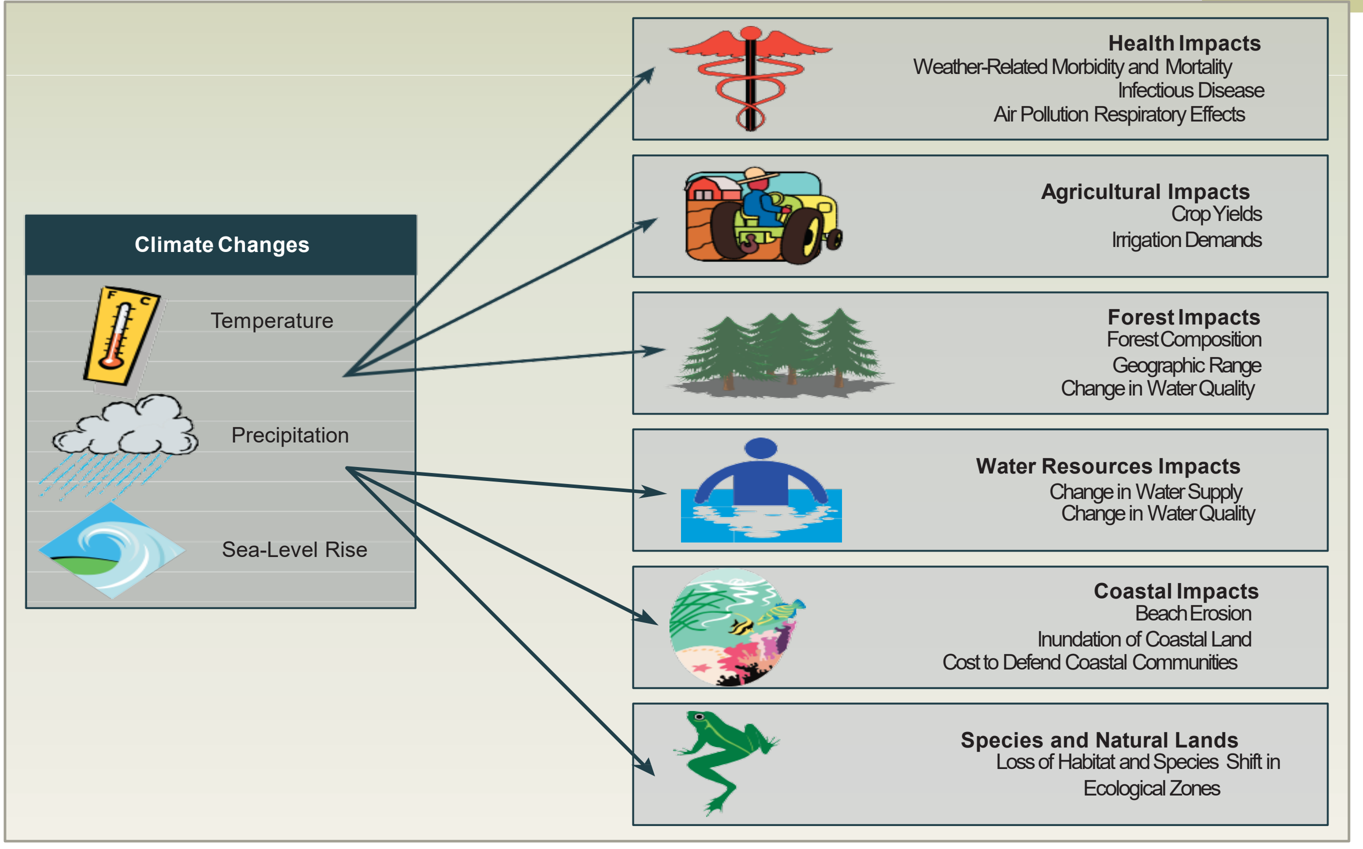
Risk analysis of the built environment

- Probabilistic risk analysis
  - Mean return period at a particular location
  - Widely used for past four decades to stipulate a site-dependent demand intensity for design, insurance underwriting, and performance evaluation of individual facility
  - Does not capture the spatial variation in demand from an event with large geographic footprint that is essential for resilience assessment at community or regional scales
- Scenario risk analysis
  - Captures the spatial variation in demand from a postulated future event
  - Easy to communicate the threat from the hazard
  - A range of scenarios must be considered to convey risk to a spectrum of events

Motivation for risk-informed life cycle engineering

- Population and economic growth in hazard-prone areas
- Aging infrastructure facilities
- Increased public expectations of infrastructure performance
- Impact of global climate change on frequency/severity of environmental events
- Current interest in resilience of communities, critical infrastructure networks and multi-hazard engineering
- Financial limits on public investments in infrastructure renewal
- Decisions for public infrastructure have very long-term (decades to centuries) and uncertain consequences

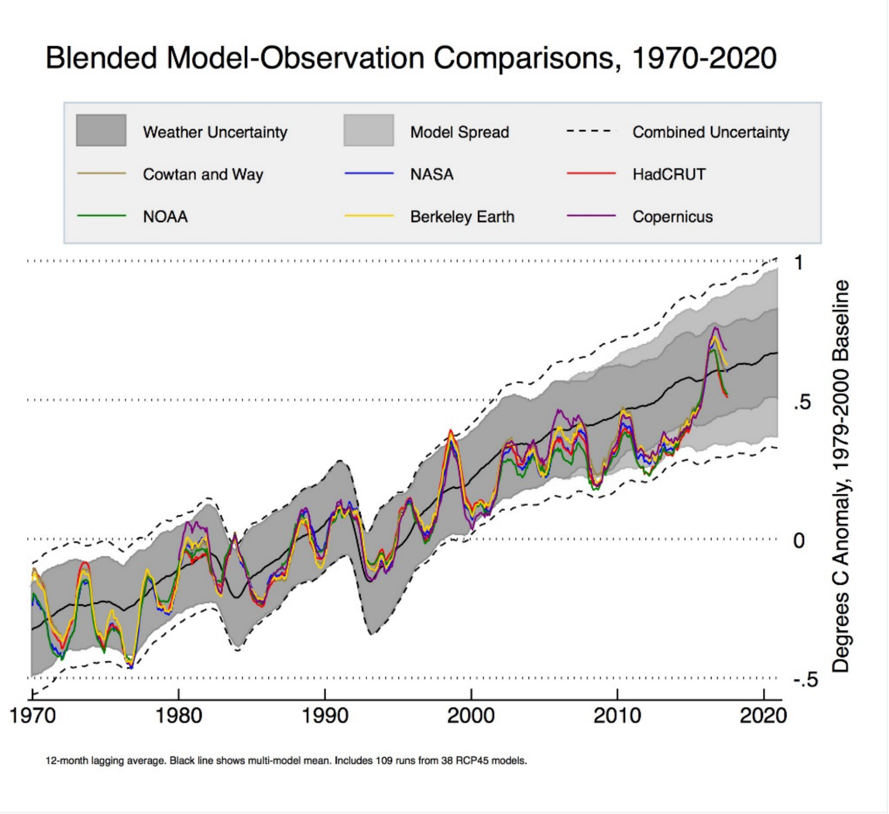
Potential climate variability and change impacts



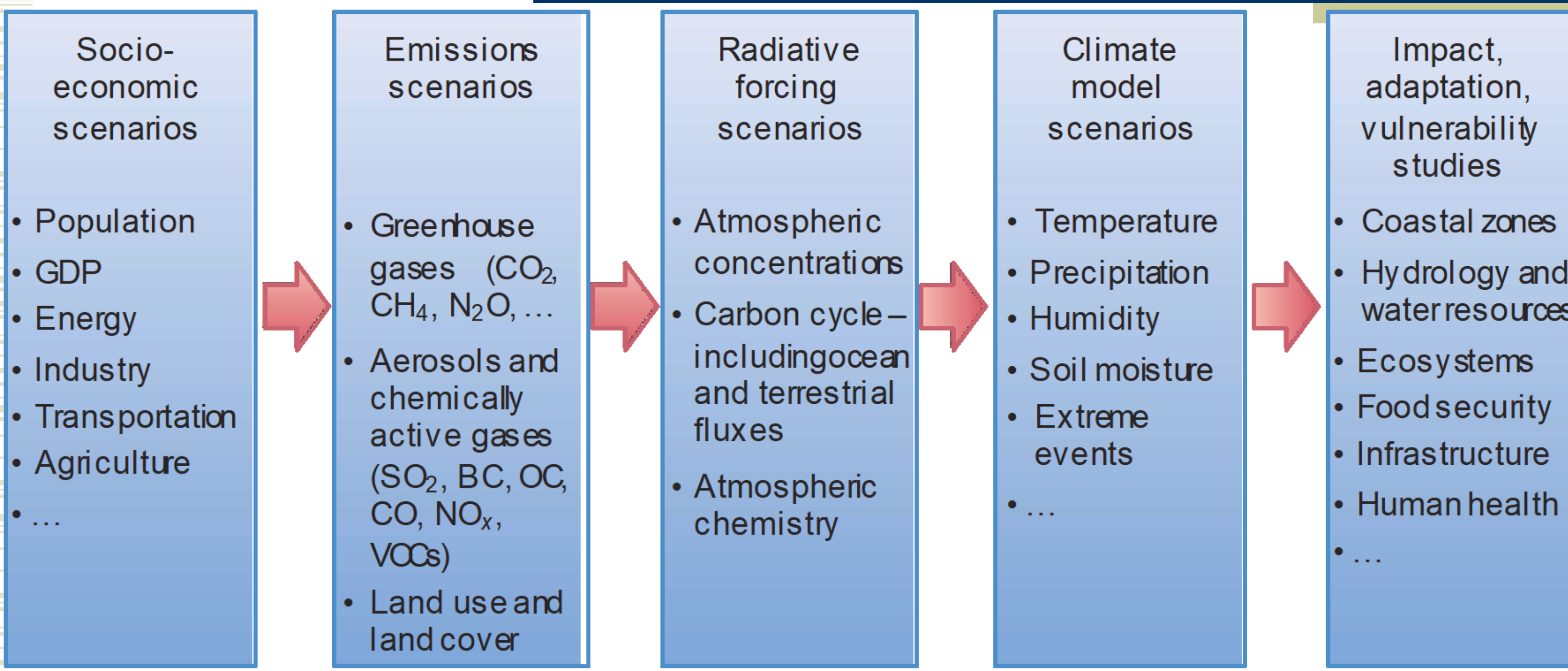
U.S. Climate Change Science Program. Strategic Plan for the Climate Change Science Program, Final Report (edited by: Subcommittee on Global Change Research)

Non-stationarity in climate parameters

Weather vs climate



Framework for addressing climate effects



Moss, R. H., J. A. Edmonds, K. A. Hibbard, et al. (2010), The next generation of scenarios for climate change research and assessment, *Nature*, *463*(7282), 747-756.

Community resilience for the built environment

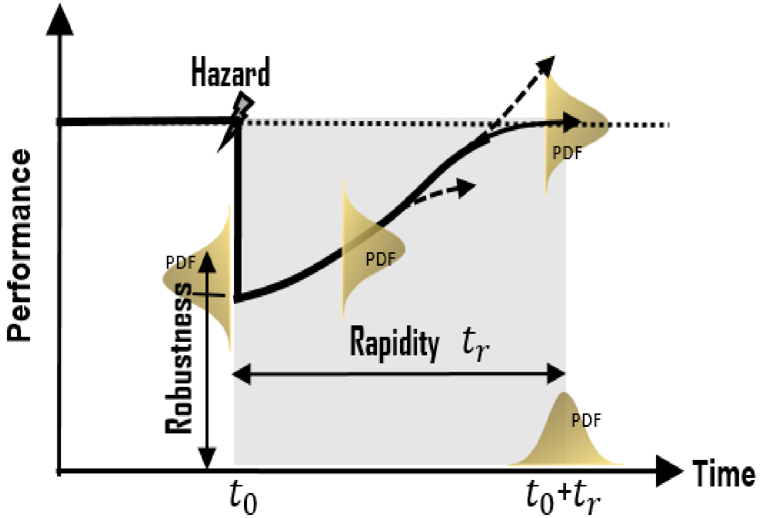
- Natural hazards
- Manmade hazards
- Degradation
- Climate change

- Performance Goals
- Mitigation
- Response
- Recovery

- **Community resilience depends on the performance of the built environment and social, economic, and public institutions.**
- **Goal: Limit disruption to a tolerable duration for an expected (design level) event and minimize detrimental effects to the community.**

What is community resilience, and how do we model it?

"The ability of a community to prepare for and adapt to changing conditions and to withstand and recover from disruptions to its physical and non-physical infrastructure."



Community resilience emphasizes both mitigating damage and implementing measures to ensure that the community recovers to near normal functionality in a reasonable timeframe.

Engineering for community resilience goals

A framework to create decision support

- Risk-informed infrastructure design should be linked directly to community performance goals developed by a broad stakeholder group in the context of the community's social, political, and economic systems.
- General frameworks should be developed to guide communities in deriving performance objectives and metrics.
- A systems-based approach should be adopted, recognizing that civil infrastructure must function as an integrated system with possibly competing objectives.
- Beyond-basis events, which may dominate risk-averse community decision-making, should be considered.
- A tiered approach is important, recognizing that in addition to life safety, various levels of functionality are important following a natural hazard event.
- Performance objectives articulated for the built environment must be expressed as requirements that are compatible with engineering and regulatory practices, wherever possible, to engender support from the professional engineering community.

Communicating risk to the public

Principles

- Be clear as to objectives
  - Use simple text and graphics, mixing verbal and visual sources
  - Engage audience by adapting the message to the local community
- State who is at risk
  - Describe potential losses
  - Discuss odds
- Give options
  - What people can do before, during and after an event to cut losses
  - Prompt individuals to question their behaviors
- Embrace uncertainty
- Build trust

Risk-informed decision-making