Vulnerability: Methods and Models for Science and Sustainability

New England Chapter of the Society for Risk Analysis and the Boston Risk Assessment Group

May 14, 2003

Vulnerability:

Methods and Models for Science and Sustainability

Explore Four Thoughts:

- **The Concepts for Sustainability**
- **The S&T Issues that Evolve from the Sustainability Framework**
- **Vulnerability, Resilience, and Sensitivity: Risk Concepts?**
- **Methods and Models for Research, Analysis, and Assessments**

First:
Concepts of Sustainability and Sustainable Development

Members of the Initiative's Steering Group have been involved or influenced by many discussions, particularly Brundland Commission report, Our Common Future was published. Recent discussion of note include work from institutions of the South:

The 3rd World network of scientific organizations (TWNSO);

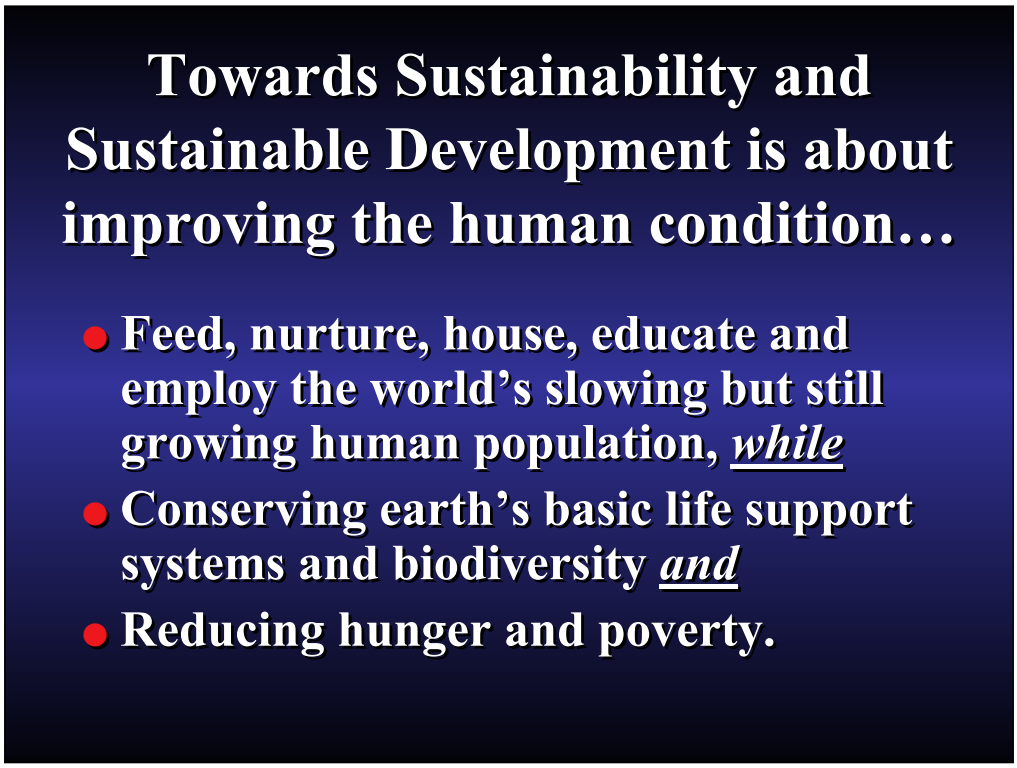
The Commission on S&T for Sustainable Development in the South (COMSATS); and

The South Center

•1999 US NAS report on *"Our common journey: A transition toward sustainability"*

•In May 2000, the World Academies of Science hosted in Tokyo a conference on the role of S&T in a transition toward sustainability, with substantial contributions from the Third World Academy of Sciences (TWAS), the Latin Academy of Sciences, the African Academy of Sciences, and the National Academies of Brazil, Bolivia, the UK, the USA, and many others.

•In Fall 2000, Bob Kates, Akin Mabogunje, Bill Clark, and Bob Corell convened a meeting in Friibergh, Sweden to discuss sustainability science.



This expanding global discourse also reveals a growing consensus that science and technology for sustainability should be driven by a commitment to directly address *socially* defined goals for improving the human condition. In particular, the goals that have emerged at the top of priority setting negotiations of recent international conferences and summits are to:

•Feed, nurture, house, educate and employ the world's slowing but still growing human population, *while*

•Conserving earth's basic life support systems and biodiversity *and*

•Reducing hunger and poverty.

These are the goals of sustainability science.

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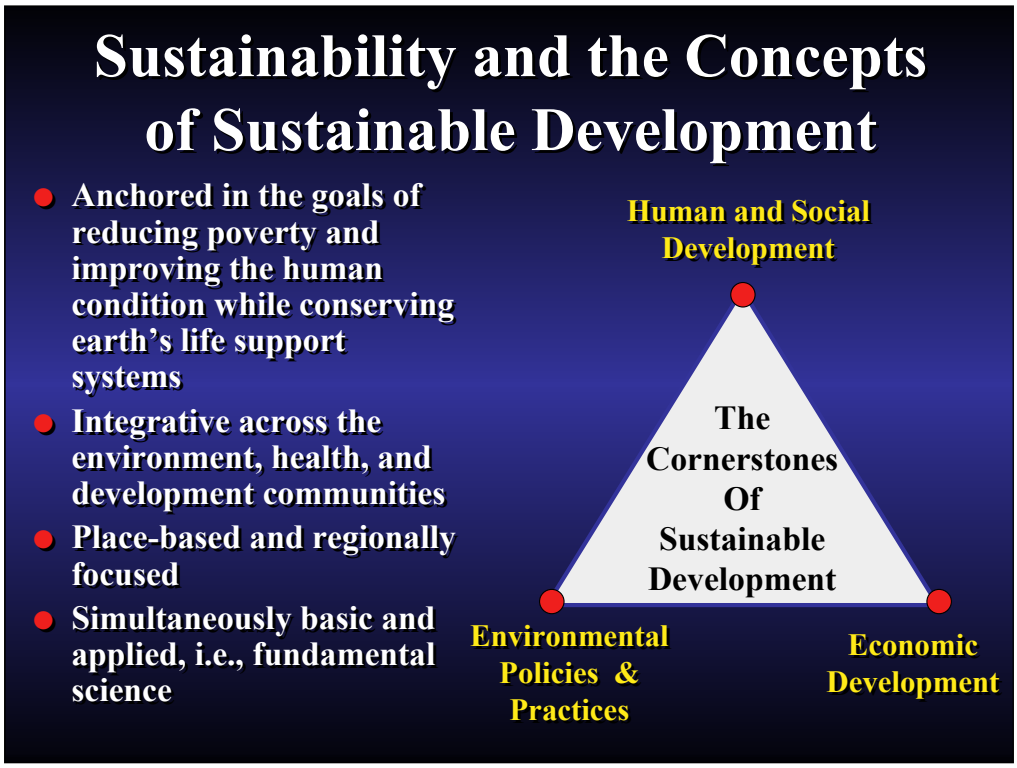


*Anchored in the goals of reducing poverty and improving the human condition while conserving earth's life support systems

*Integrative across the environment, health and development communities;

Includes natural sciences, social sciences and engineering;

* Place-based and regionally focused.This is the scale where:

multiple stresses intersect; complexity is comprehensible;integration is possible, innovation and management happen.

* Work to connect science and policy by fostering collaboratives between scientists and managers in areas where not only discovery of new knowledge but experimental *application* of existing knowledge, is the limiting factor:

[E.g., - What long-term, large-scale T&T are most important in shaping the prospects for S?

- Which modeling methods best capture the complexity and nonlinearlity of N-S systems?

-How can we accommodate the next 50 years' expected 2-3X of urban pop in ways healthy for people & nature

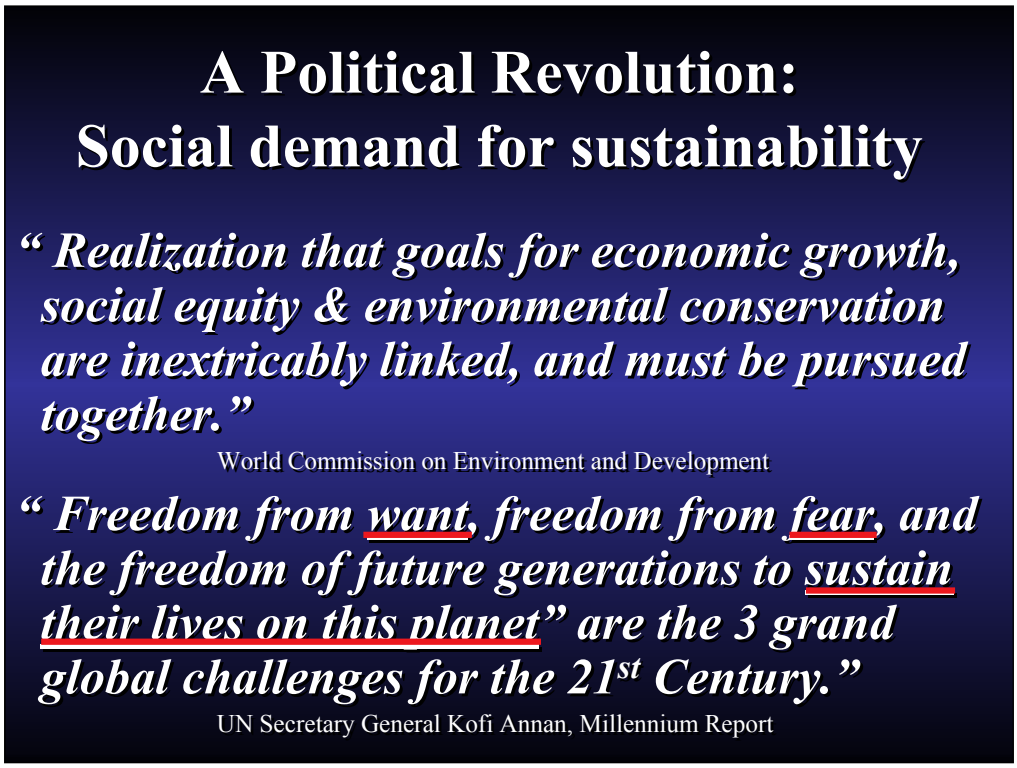
- to reverse declining trends in African ag prod while conserving biodiversity;

The "World Summit" Focused on Five Key Sectors, the so-called WEHAB Approach. Increasingly the central agenda for sustainable development is being addressed around these challenges:

- **Water,**
- **Energy,**
- **Health,**
- **Agriculture, and**
- **Biodiversity.**

Second:

The S&T Issues that Evolve from the Sustainability Framework



The second environmental revolution has been political.

Already in the late 1980s, the World Commission on Environment and Development had captured a growing social conviction that goals for economic growth, social equity & environmental conservation are inextricably linked, and must be pursued together.

But the magnitude of this political revolution in the environment is perhaps best illustrated by UN Secretary General Kofi Annan who, in conveying his recent Millennium Report to the General Assembly wrote that the grand challenge facing humanity in the 21st century was to secure for all its people

"Freedom from want, freedom from fear, and the freedom of future generations to sustain their lives on this planet".

The first two of these goals, of course, are familiar ones enshrined in the original 1945 Charter of the United Nations. The third goal, however, is new. As Annan put it, the "founders of the UN could not imagine that we would be capable of threatening the very foundations for our existence."

Today, the environmental threat to our health, prosperity, and "very foundations of our existence" have become a political reality of the highest order, with a place at the "high tables" of international, national, and local affairs.

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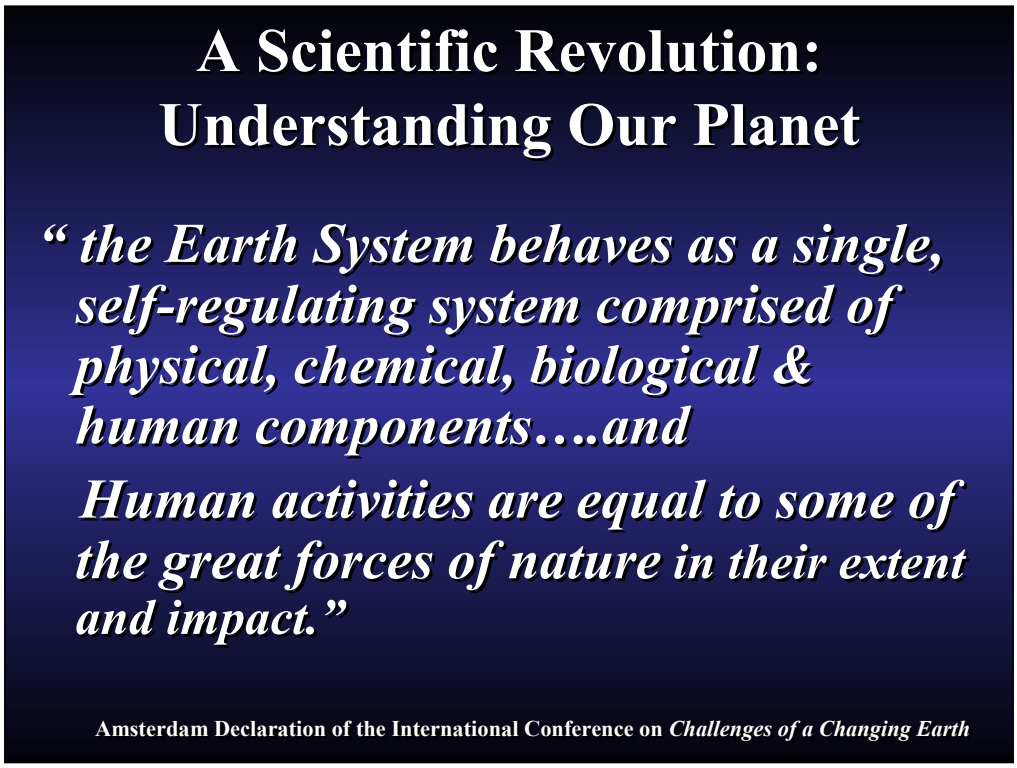

As we seek to rise to the challenges before us, it is important to recognize that we stand today at the intersection of *two* environmental revolutions that have taken shape over the last 20 years.

The first revolution has been scientific. With the emergence of *Earth Systems Science* we have seen the integration of ideas rooted in such diverse fields as Russian geochemistry, Swedish meteorology, German ecology and Anglo-American geography.

The result, as characterized by this past summer's Amsterdam conference on "Challenges of a Changing Earth," has been an increasing recognition that "the Earth System behaves as a single, self-regulating system comprised of physical, chemical, biological and human components… [the latter] equal to some of the great forces of nature in their extent and impact."

Slide #3 please.

The task of Sustainability Science is to integrate the two revolutions, harnessing our emerging *scientific* understanding of the Earth System to the social *quest* for sustainability.

The opportunity to bring about that integration has never been greater.

•*Political* and *private sector acceptance* of the sustainable development concept is growing, with cities, companies and even nations embracing it as a goal.

•*Democratization* and *decentralization* are spreading throughout the world, empowering a growing number of voices calling urgently for sustainability.

•*Population growth* is slowing, with a real prospect of steady state by the end of the century. For the first time this lets concerns for limits to the human use of the earth move beyond the demographic transition to think about a broader transition toward sustainability – a transition that addresses not only the number of people on the planet, but their consumption patterns and institutional ability to discipline their impacts on the biosphere.

•The potential contributions of appropriately targeted technological innovation to a sustainability transition are increasingly recognized, as documented in the most recent UNDP *Human Development Report.*

•Last summer's Global Change conference in Amsterdam has highlighted the ways in which revolutionary changes in our understanding of earth system science can be used to promote sustainability goals.

•Finally, the World Summit on Sustainable Development, scheduled for Johannesburg next year, will provide an opportunity to bring the full spectrum of our knowledge and know-how to bear on broad issues of sustainable human development.

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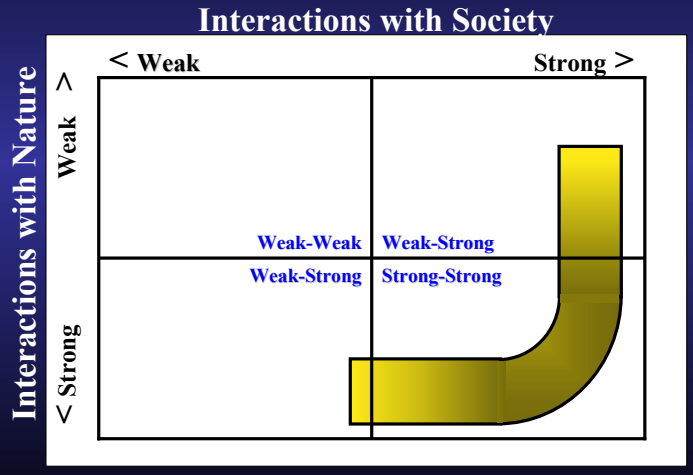
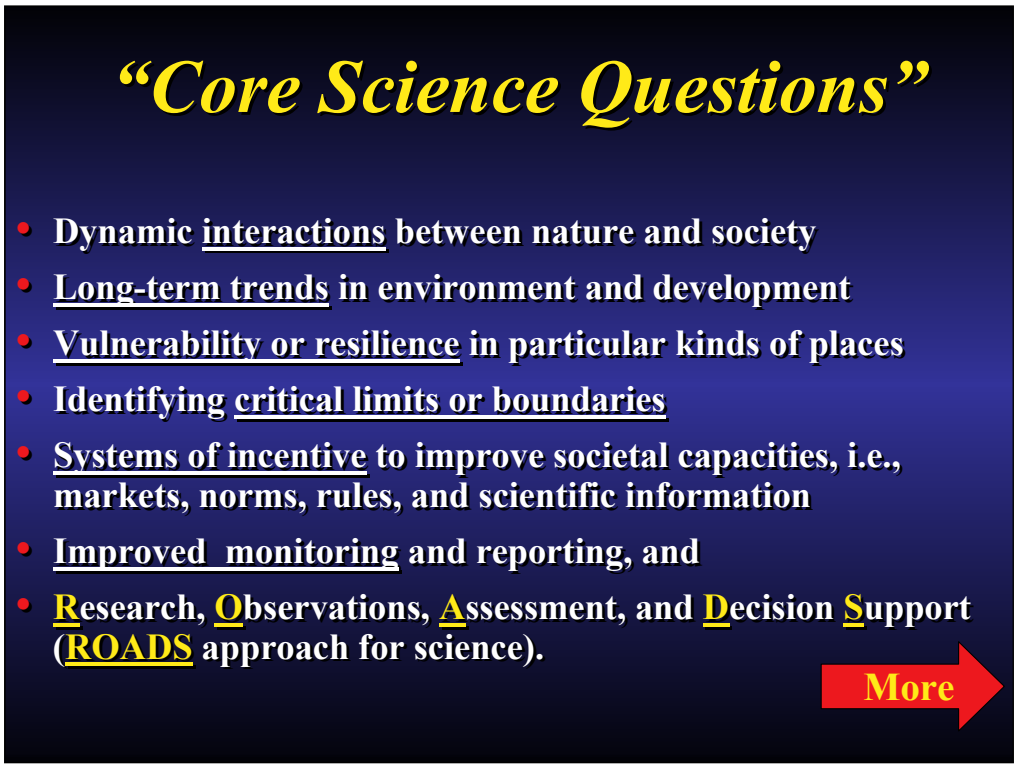
Science and Technology for Sustainability

Strong Interactions between Nature and Society



An Informal Group of Scientist Around the World Joined together in an Initiative for Science and Technology for Sustainable Development (ISTS)

ISTS held numerous workshops around the world to expand and deepen our understanding of the central issues for S&T and sustainable development



The initial set of core questions for sustainability science from Friibergh address the following topics. These are meant to complement the core questions of existing global change programs.

Corell will elaborate on these

1-4 deal with understanding the interactions between nature and society

5-6 deal with expanding social capacity to encourage a transition towards sustainability

7 deals with learning to do better

Full text of Qs in Science article

[* Methods and models that integrate the earth system and human development

* Long-term trends in envt and dev

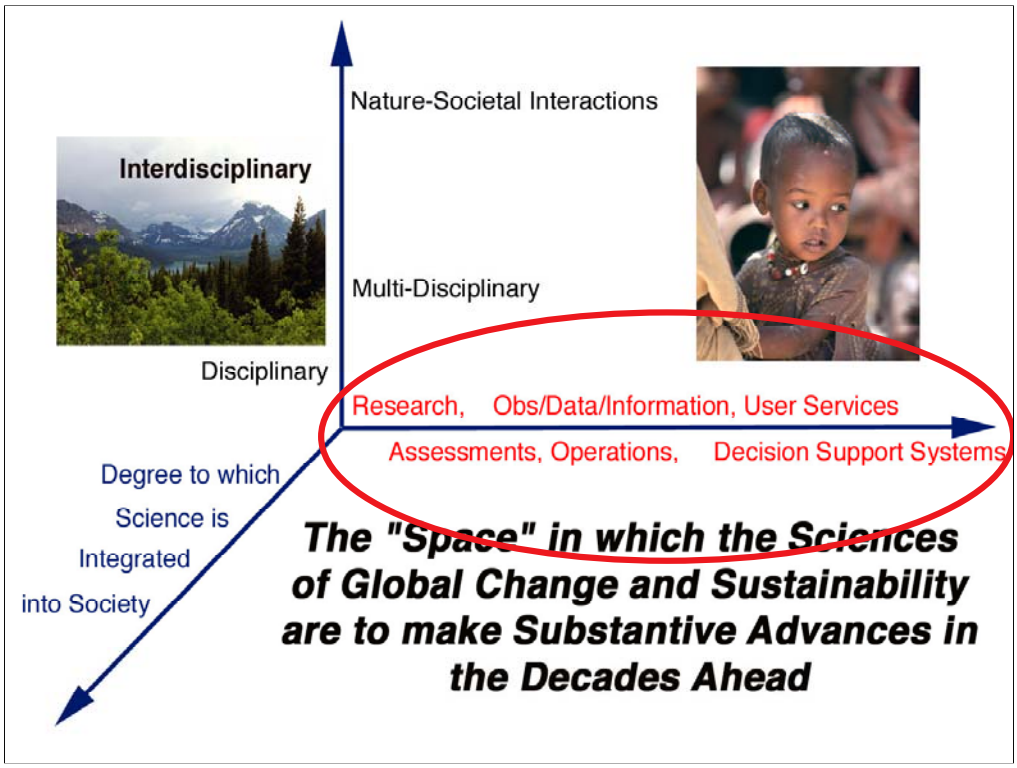
*Vulnerability of a system in particular kinds of places, ecosystems or livelihoods

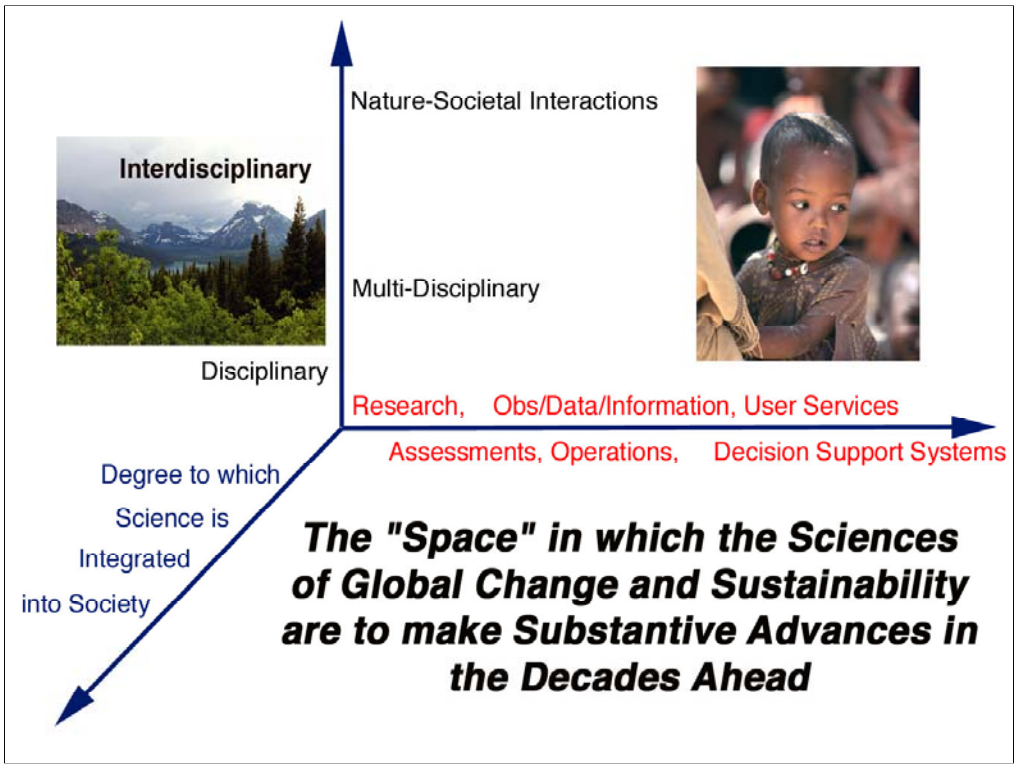
*Can limits or boundaries be defined to provide effective warning systems

*What incentive structures - markets, rules, norms, information are most effective

*Monitoring and reporting to provide useful guidance

*Research, observation, assessment, and decision support systems be used for adaptive management and societal learning]


Nature-Societal Interactions
Interdisciplinary
Multi-Disciplinary
Disciplinary
Research, Obs/Data/Information, User Services
Assessments, Operations, Decision Support Systems
Degree to which
Science is
Integrated
into Society
The "Space" in which the Sciences
of Global Change and Sustainability
are to make Substantive Advances in
the Decades Ahead


Nature-Societal Interactions
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The "Space" in which the Sciences of Global Change and Sustainability are to make Substantive Advances in the Decades Ahead

Thoughts for the S&T community as we approach the challenges of S.D.

- S&T for SD is about achieving social goals, solving problems, empowering people, and promoting social learning.
- The social goals vary for different groups in different places (what is to be developed, what is to be sustained, in what relation, for how long?).
- Basic goal: to advance fundamental human and social needs while protecting the earth‘s life support systems and biological diversity.

This may suggest a new societal contract with the Science Community , i.e.,

- To harness S&T to support transitions to sustainability will require much more than a continuation of present practices.
- A large gap remains between what the S&T community thinks it has to offer S.D. and what society has been willing to pay for those services.
- The New Contract probably needs a change (i.e., address) in both the *demand* and *supply* side (to move beyond the present).

Towards a New Contract

- **Understand of the nature and urgency of the SD problem,**
- **Demonstrate that the S&T community can deliver solutions as well as problem identification, and**
- **Institute substantive changes in the world`s S&T institutions and systems will be required.**

What does this mean for S&T?

- ***Strengthening the core disciplines*** **of the natural, social sciences + expertise in analyzing complex systems,**
- ***Establish enhanced Research Programs*** **focused on fundamental questions of sustainable development, e.g., vulnerabilities of nature/society systems,**
- ***Solution-Oriented*** **programs focused on where we know enough to begin "learning-by-doing", e.g., sustainable cities, biodiversity, carbon management, and**
- ***Enhanced Institutions and Infrastructure*** **for science and practitioner partnerships and the co-production of knowledge and knowledge-to-action collaboration,**
- ***Enhanced Regional/Local Capacity for S&T*** **and enhanced abilities for integration throughout the R&D communities, but particularly in the developing world,**
- ***Broaden the International Community*** **committed to conducting R&D for sustainability, and**
- ***Build a Stronger Network*** ***Interconnecting the Science, Technology, and Public and Private Sector Communities***

Third:

Vulnerability, Resilience, and Sensitivity: Risk Concepts?

Elements Central to Vulnerability Analysis:

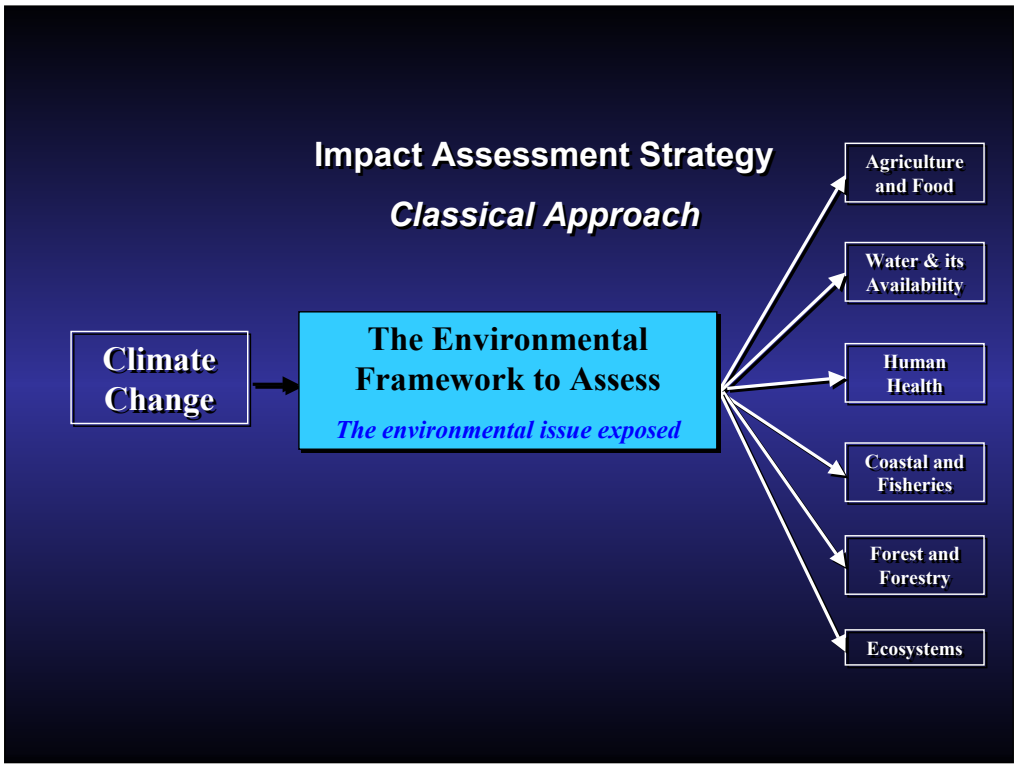
- Multiple, interacting perturbations and stressors/stresses and the sequencing of them;
- Exposure beyond the presence of a perturbation and stressor/stress, including the manner in which the hazards are experienced;
- Sensitivity of the coupled system to the exposure;
- System's capacities to cope or respond (resilience), including the consequences and attendant risks of slow (or poor) recovery;
- System's restructuring following the responses taken (i.e., adjustments or adaptations); and
- Nested scales and scalar dynamics of hazards, coupled systems, and their responses.

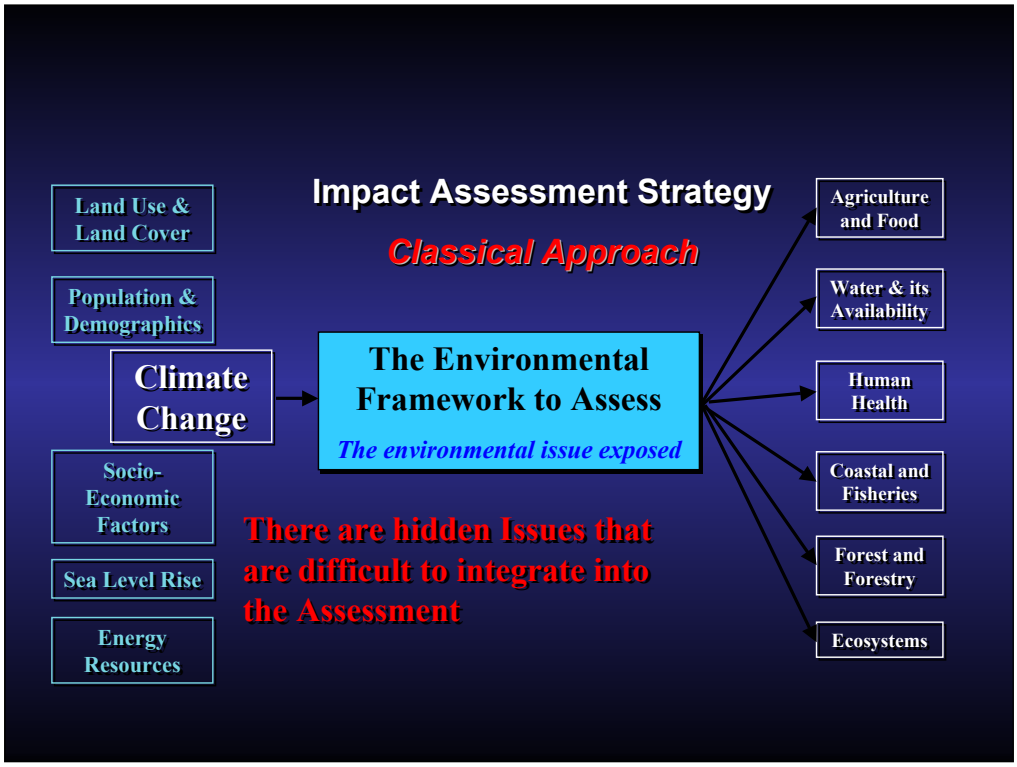
A comprehensive vulnerability analysis should consider:

- Plausible scenarios for interacting multiple perturbation regimes as generated by Global Change. A fundamental distinction between regular (smooth) and singular (discontinuous or extreme) disturbances has to be made.
- Plausible scenarios for development trends affecting systems sensitivity and adaptive capacity, like population growth, urbanization or industrial transformation.
- Sensitivity analysis for pertinent natural and socio-economic inventories including, i. a., ecosystems, economic sectors, social groups, cultural hot spots, valued landscapes, etc. Responses to both regular and singular stresses (or combination of stresses) have to be considered.
- Inspection of critical response potentials in relevant exposure units due to intrinsic thresholds or positive feedbacks.

A comprehensive vulnerability analysis should consider, i. a., the following items (continued):

- Analysis of adaptive capacity as a function of major entity characteristics like diversity, connectivity, affluence, technological development, institutional endowment, etc.
- Valuation schemes for quantifying the natural and socio-economic elements at stake as well as the generalized costs of adaptive measures.
- Ensemble and averaging schemes in order to generate robust probabilistic results independent of particular uncertainties.


Impact Assessment Strategy
Classical Approach
Climate Change
The Environmental Framework to Assess
The environmental issue exposed
Agriculture and Food
Water & its Availability
Human Health
Coastal and Fisheries
Forest and Forestry
Ecosystems


Impact Assessment Strategy
Classical Approach
Land Use & Land Cover
Population & Demographics
Climate Change
Socio-Economic Factors
Sea Level Rise
Energy Resources
The Environmental Framework to Assess
The environmental issue exposed
There are hidden Issues that are difficult to integrate into the Assessment
Agriculture and Food
Water & its Availability
Human Health
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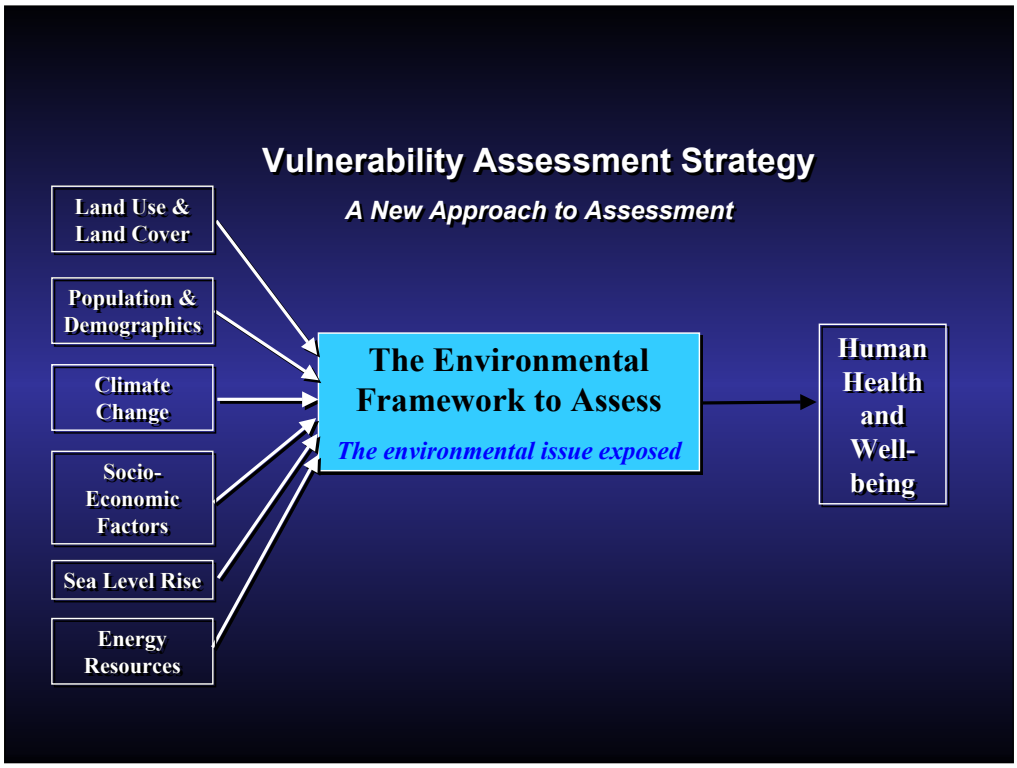
Vulnerability Assessment Strategy
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Socio-Economic Factors
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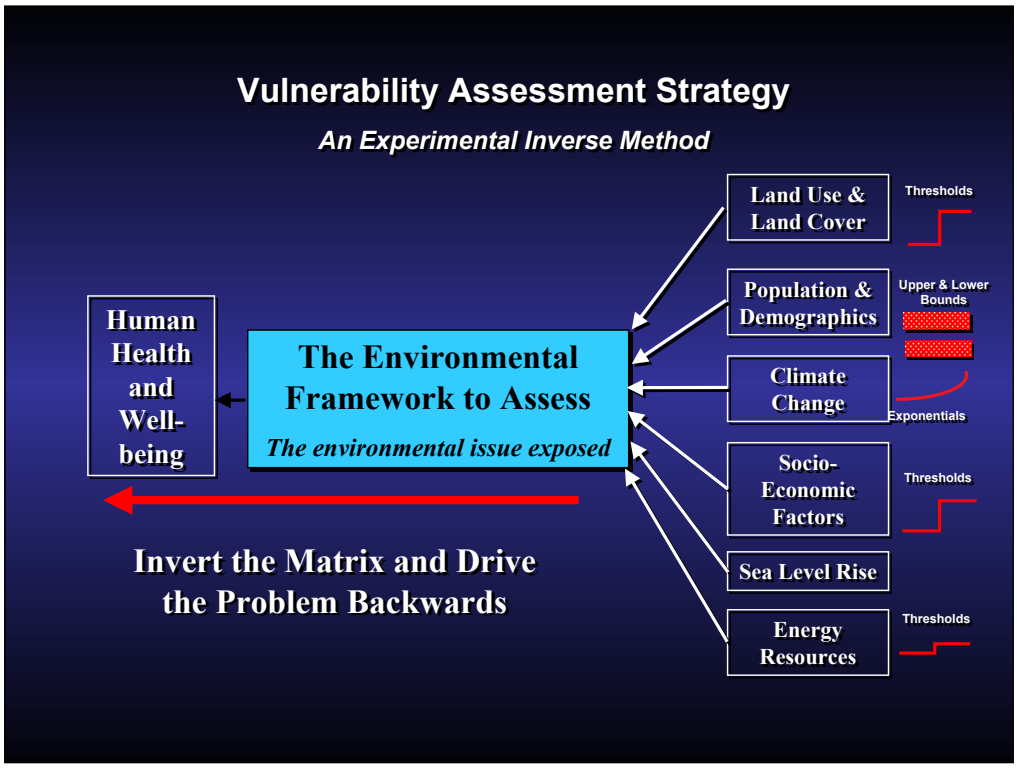
Energy Resources
The Environmental Framework to Assess
The environmental issue exposed
Human Health and Well-being


Vulnerability Assessment Strategy
An Experimental Inverse Method
Land Use & Land Cover
Thresholds
Population & Demographics
Upper & Lower Bounds
Climate Change
Exponentials
Socio-Economic Factors
Thresholds
Sea Level Rise
Energy Resources
Thresholds
Human Health and Well-being
The Environmental Framework to Assess
The environmental issue exposed
Invert the Matrix and Drive the Problem Backwards

A Perspective on Vulnerability

Vulnerability (V) = Can be seen as the difference between the Cumulative Impacts (I) from multiples stessors and), modulated by mitigation (M), and differenced by the Adaptive Capacity (AC) or:

$$V = I(\text{function of } M) - AC$$

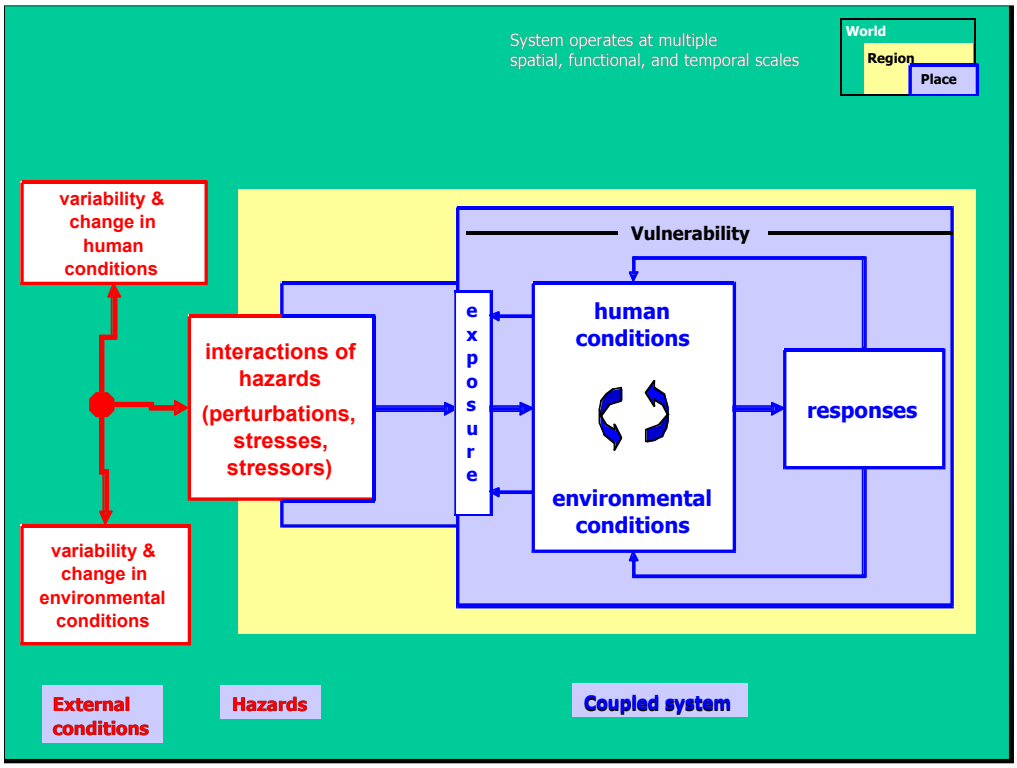
First, these do vary with time and spatial scales, and second, this can be written in this simple arithmetic form or in more complex multi-dimensional matrix or vector calculus form.

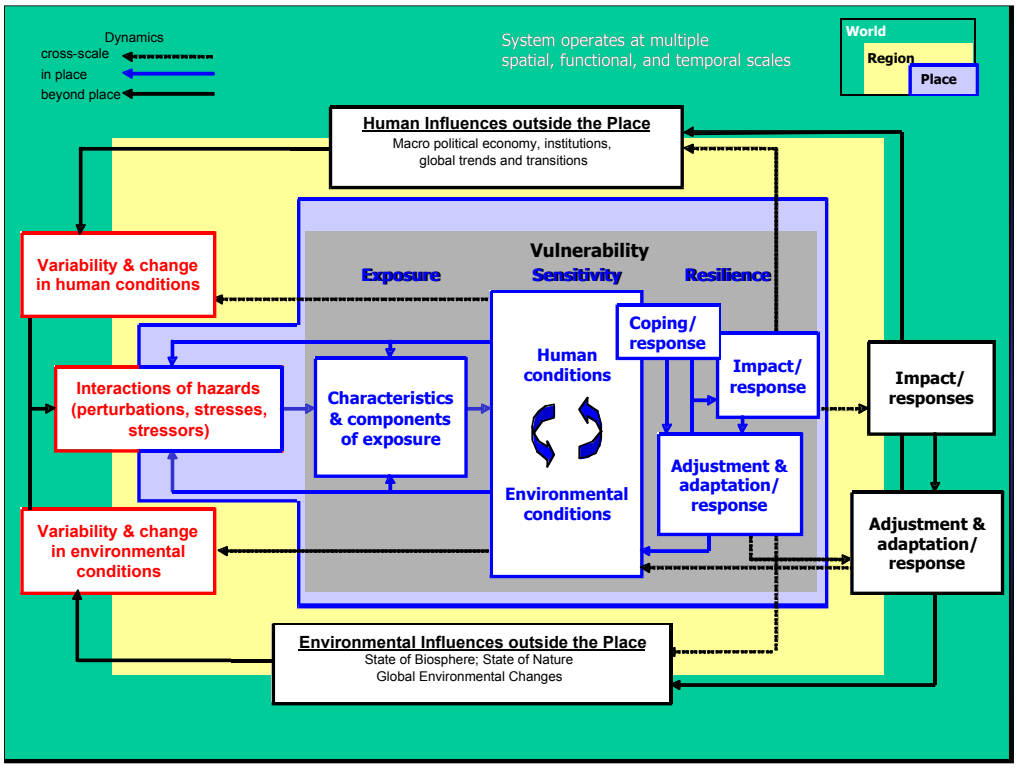
Finally

Methods and Models for Research, Analysis, and Assessments

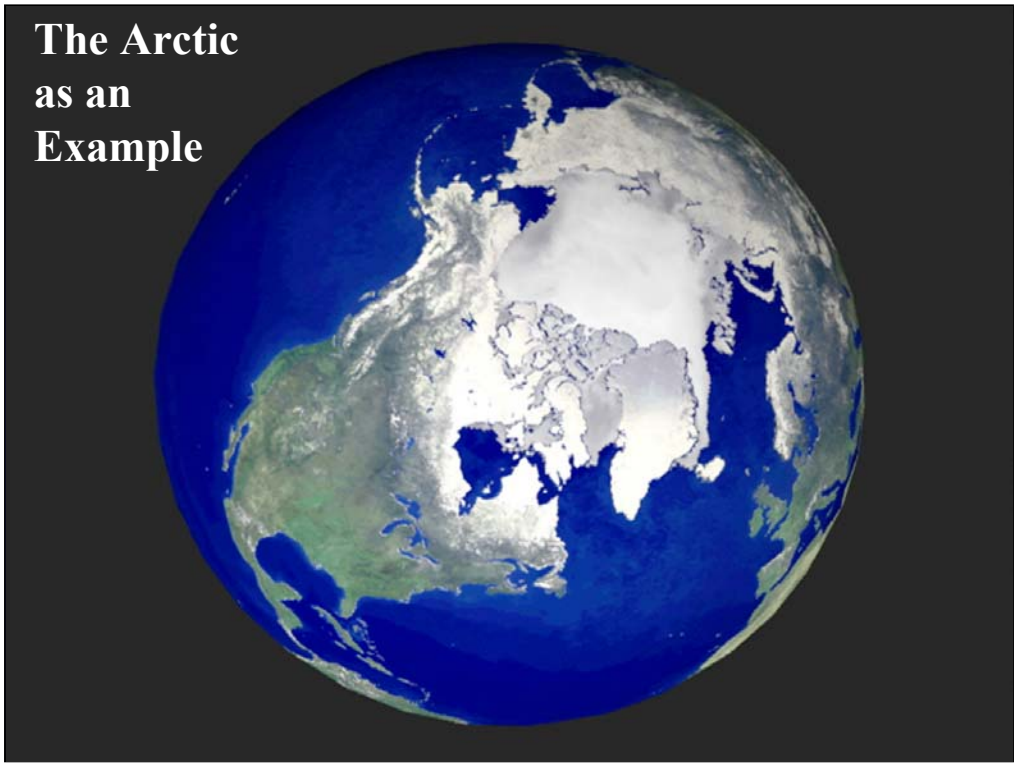
Research Strategies, A short-list might contain the following:

- **Integrated Modelling & Simulation (Emphasizing Multi-Agent Approaches and Decision Theatres)**
- **Semi-Quantitative Typology (Degradation Syndromes, etc.)**
- **Case Studies**
- **Complex Indicator Approaches**
- **Stochastic Economic Valuation Schemes**
- **Systems Analysis and Criticality Theory**
- **Advanced Versions of Game Theory**
- **Re-Analysis of Historical Records**
- **Risk & Disaster Assessment**
- **Extreme-Value Statistics and Non-Linear Dynamics.**


System operates at multiple
spatial, functional, and temporal scales
World
Region
Place
variability & change in human conditions
interactions of hazards
(perturbations, stresses, stressors)
variability & change in environmental conditions
exposure
Vulnerability
human conditions
environmental conditions
responses
External conditions
Hazards
Coupled system


Dynamics
cross-scale
in place
beyond place
System operates at multiple
spatial, functional, and temporal scales
World
Region
Place
Human Influences outside the Place
Macro political economy, institutions,
global trends and transitions
Vulnerability
Exposure
Sensitivity
Resilience
Variability & change
in human conditions
Interactions of hazards
(perturbations, stresses,
stressors)
Characteristics
& components
of exposure
Human
conditions
Environmental
conditions
Coping/
response
Impact/
response
Adjustment &
adaptation/
response
Impact/
responses
Adjustment &
adaptation/
response
Variability & change
in environmental
conditions
Environmental Influences outside the Place
State of Biosphere; State of Nature
Global Environmental Changes

The Arctic as an Example



Research Prospectus
Arctic Vulnerability Study (AVS)

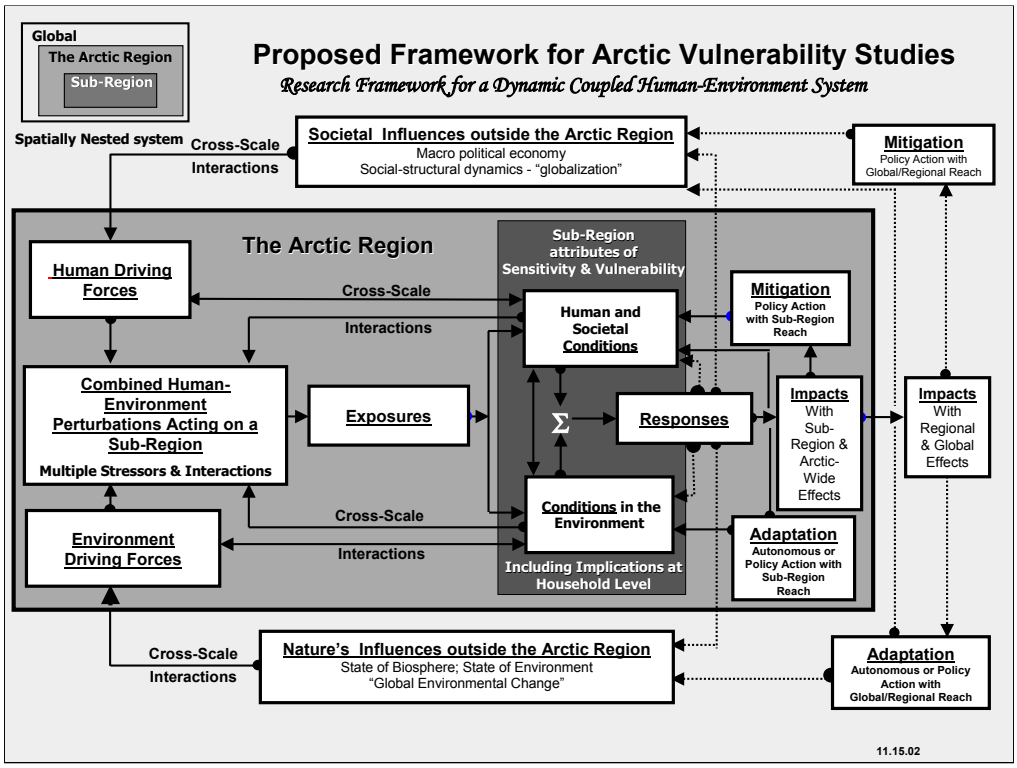
A Collaborative Study of the Application of a Vulnerability Approach to Understanding the Consequences of Societal and Environmental Changes in the Arctic particularly in Indigenous Communities

Arctic Vulnerability Study Goals

- **First**, the research will seek to identify particular sensitivities in Arctic at community levels, the factors that are likely to result in adverse impacts, and strategies for avoiding or coping with such impacts, and
- **Second**, the study will seek to serve as a vehicle for developing, testing, and refining cutting-edge methods of vulnerability analysis. Vulnerability is an increasingly important concept in global environmental assessment and vulnerability information can have important policy implications for at-risk populations. Currently, methods for evaluating and measuring vulnerability remain underdeveloped.

Arctic Vulnerability Study Approach

- ***Climate Variability and Change and Solar Radiation:*** **(increases in UV-B radiation, as well as changes in temperature, precipitation, snow cover, permafrost, sea ice, sea level, and extreme weather events.**
- ***Environmental pollution:*** **(persistent organic pollutants (POPs), heavy metals, radionuclides, and hydrocarbons.**
- ***Trends in Human and Societal Development:*** **(changes in consumption, access to information and data, exposure to external cultures, expansion of markets and trade, literacy and education, and decision-making and sovereignty issues.**


Global
The Arctic Region
Sub-Region
Proposed Framework for Arctic Vulnerability Studies
Research Framework for a Dynamic Coupled Human-Environment System
Spatially Nested system
Cross-Scale Interactions
Societal Influences outside the Arctic Region
Macro political economy
Social-structural dynamics - "globalization"
Mitigation
Policy Action with Global/Regional Reach
The Arctic Region
Sub-Region attributes of Sensitivity & Vulnerability
Human Driving Forces
Cross-Scale Interactions
Human and Societal Conditions
Mitigation
Policy Action with Sub-Region Reach
Combined Human-Environment Perturbations Acting on a Sub-Region
Multiple Stressors & Interactions
Exposures
Σ
Responses
Impacts With Sub-Region & Arctic-Wide Effects
Impacts With Regional & Global Effects
Conditions in the Environment
Cross-Scale Interactions
Environment Driving Forces
Adaptation
Autonomous or Policy Action with Sub-Region Reach
Including Implications at Household Level
Cross-Scale Interactions
Nature's Influences outside the Arctic Region
State of Biosphere; State of Environment
"Global Environmental Change"
Adaptation
Autonomous or Policy Action with Global/Regional Reach
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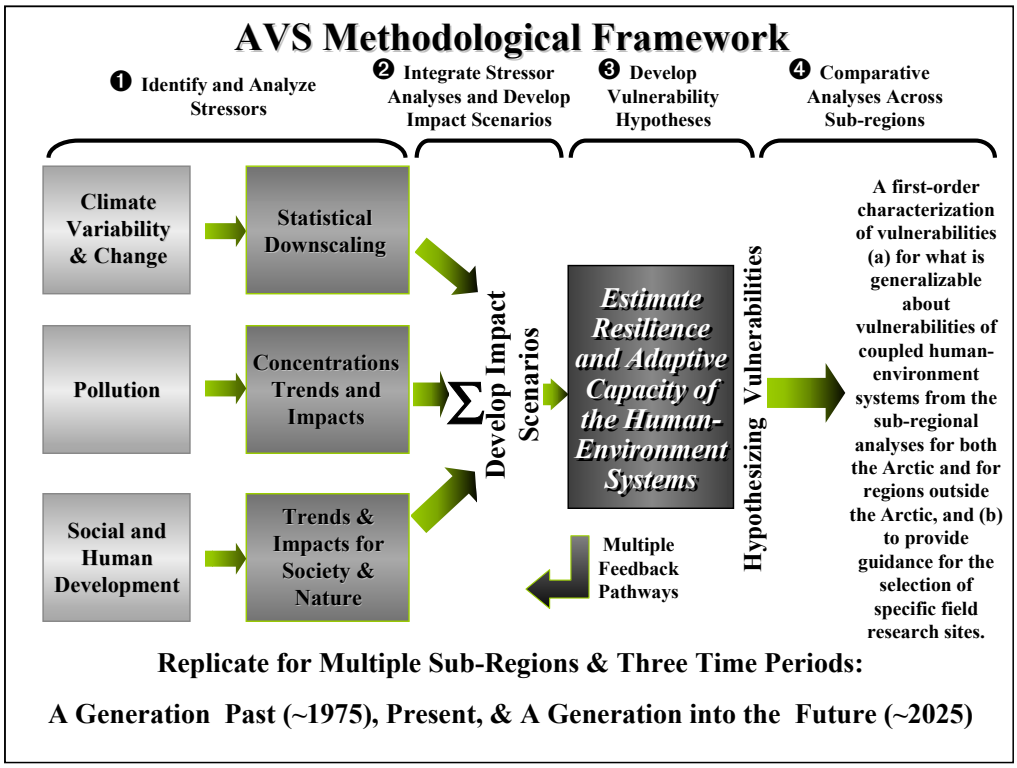
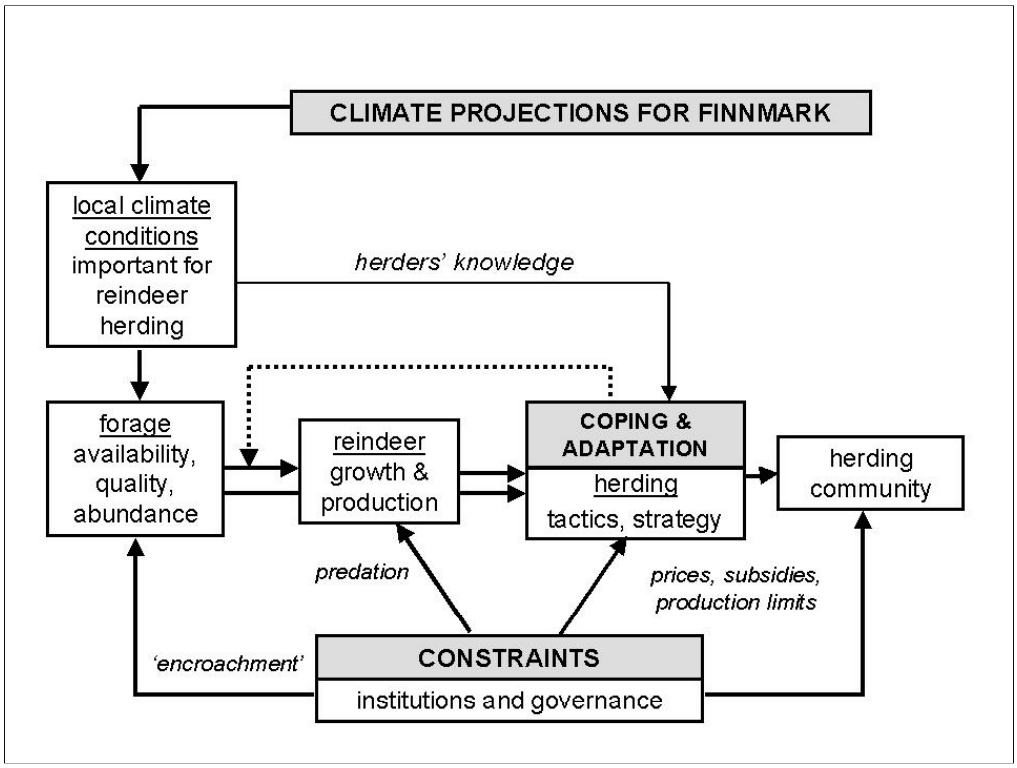
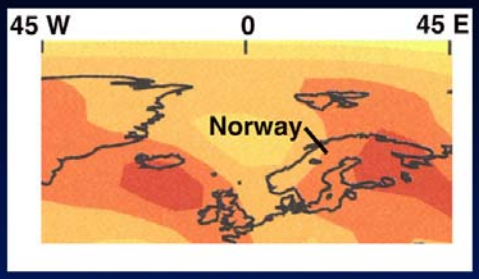

AVS Methodological Framework
❶ Identify and Analyze Stressors
❷ Integrate Stressor Analyses and Develop Impact Scenarios
❸ Develop Vulnerability Hypotheses
❹ Comparative Analyses Across Sub-regions
Climate Variability & Change
Statistical Downscaling
Pollution
Concentrations Trends and Impacts
Social and Human Development
Trends & Impacts for Society & Nature
Σ Develop Impact Scenarios
Estimate Resilience and Adaptive Capacity of the Human-Environment Systems
Multiple Feedback Pathways
Hypothesizing Vulnerabilities
A first-order characterization of vulnerabilities (a) for what is generalizable about vulnerabilities of coupled human-environment systems from the sub-regional analyses for both the Arctic and for regions outside the Arctic, and (b) to provide guidance for the selection of specific field research sites.
Replicate for Multiple Sub-Regions & Three Time Periods:
A Generation Past (~1975), Present, & A Generation into the Future (~2025)


CLIMATE PROJECTIONS FOR FINNMARK
local climate conditions important for reindeer herding
herders' knowledge
forage availability, quality, abundance
reindeer growth & production
COPING & ADAPTATION
herding tactics, strategy
herding community
predation
prices, subsidies, production limits
'encroachment'
CONSTRAINTS
institutions and governance

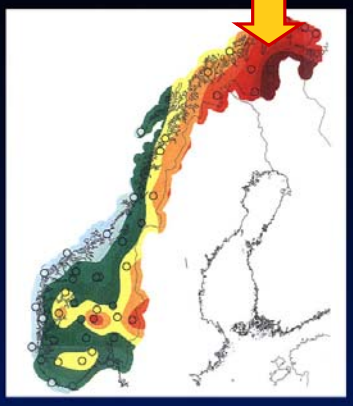
Spacial Scale Matters

Projected Warming

0.7° C/Decade



Low resolution global estimate of temperature change in Norway



High resolution global estimate of temperature change in Norway

Methods and Models of Vulnerability Research, Analysis and Assessment

The General Questions :

- **Which methods and models are currently available for vulnerability research, analysis, and assessment?**
- **What are the benefits and drawbacks associated with current methods and models?**
- **What are the opportunities for developing better methods and models?**